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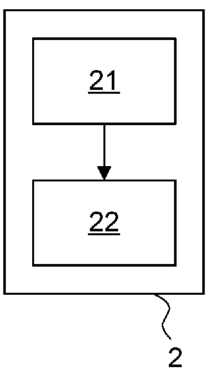


Fig 2

**(57) Abstract:** A method of forming an energy carrier, comprises providing (2) silicon having a level of purity corresponding at least to metallurgical grade silicon, formatting (31) the silicon into a silicon powder having a predetermined particle size, and pressing (32) an amount of said silicon powder into a silicon powder body (1001).

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# ENERGY CARRIERS, THEIR USE AND METHODS OF FORMING ENERGY CARRIERS

## Technical field

The present disclosure relates to an energy carrier concept, including a method of forming energy carriers, energy carriers having a format which is suitable for being transported and to methods of using such energy carriers.

## Background

US2016046486A and US2016046487A disclose the general idea of using silicon as an energy carrier, instead of e.g. hydrocarbon based energy carriers. In particular, these documents disclose a system and method for employing silicon as a supplement or replacement for current hydrogen storage techniques., The method may include generating or using energy from an energy source, using this energy to purify and refine silicon to an acceptable level of purity, transporting the purified and refined silicon to a place of use, reacting the purified and refined silicon with water in a particular environment or in a particular system in order to produce hydrogen gas and other products, and storing or directly using the generated hydrogen while optionally recycling the other products.

However, one problem with using silicon as an energy carrier resides in its transportation and storage.

Hence, there is a need for solutions that provide for efficient storage and transport of a silicon based energy carrier.

## Summary

It is an objective of the present disclosure to provide solutions that provide for efficient storage and transport of a silicon based energy carrier.

The invention is defined by the appended independent claims, with embodiments being set forth in the appended dependent claims, in the following description and in the attached drawings.

According to a first aspect, there is provided a method of forming an energy carrier, comprising providing silicon having a level of purity corresponding at least to metallurgical grade silicon, formatting the silicon into a silicon powder having a predetermined particle size, and pressing an amount of said silicon powder into a silicon powder body.

The term “particle size” is to be understood as a nominal particle size in the sense commonly used for the relevant type of product. As a particular example, the particle size may be determined as the maximum dimension of each particle. In such case, the particle size may be defined as an average maximum dimension of the measured particles.

By pressing the silicon powder into a silicon powder body, there is provided a simple, yet effective, way of handling, storing and transporting a product which is in a powder form. The silicon powder bodies can easily be converted back into powder at the site where energy is to be extracted.

Such pressing can, but need not, be performed without the addition of binder material.

The silicon may comprise at least about 95 wt.-% silicon, preferably at least about 98 wt.-% silicon.

In the method the formatting may comprise grinding the silicon into silicon powder.

The silicon powder may have a particle size of less than about 5 mm.

In particular, the silicon powder may have a particle size of about 0.5 µm to about 5 mm.

In some applications, the silicon powder may have a particle size of about 0.1-0.2 mm, about 0.2-0.5 mm, about 0.5-0.7 mm, about 0.7-1 mm, about 1-3 mm, about 3-4 mm or about 4-5 mm.

In some applications, the silicon powder may have a particle size of about 1-100 µm, about 100-200 µm, about 200-300 µm, about 300-400 µm or about 400-500 µm.

In other applications, the silicon powder may have a particle size of about 1-100 nm, about 100-200 nm, about 200-300 nm, about 300-400 nm, about 400-500 nm, about 500-600 nm, about 600-700 nm, about 700-800 nm, about 800-900 nm, about 900-1000 nm.

The pressing may comprise supplying thermal energy, such that the silicon powder is pressed at an elevated temperature.

The pressing may be performed at a pressure of less than about 300 kN/cm$^2$, preferably of about 100-300 kN/cm$^2$or about 150-250 kN/cm$^2$.

The method may further comprise coating an outwardly exposed surface of the silicon powder body.

The method may further comprise transforming the silicon powder body into silicon powder.

The method may further comprise extracting energy directly or indirectly from the silicon powder by oxidizing the silicon powder.

The method may further comprise collecting a residual product from said oxidization, said residual product consisting essentially of silicon dioxide.

The method may further comprise converting said silicon dioxide to reprocessed silicon having a level of purity corresponding at least to metallurgical grade silicon.

In the method the step of providing silicon may comprise providing said reprocessed silicon.

The method may further comprise transporting the silicon powder body to a extraction site where energy is to be extracted from the silicon powder body.

The method may further comprise providing the silicon powder body in a fuel receptacle of a vehicle, in which energy is to be extracted from the silicon powder body.

According to a second aspect, there is provided an energy carrier, comprising a silicon powder body which is formed of a silicon powder, said silicon powder having a level of purity corresponding at least to metallurgical grade silicon and a particle size which is less than about 0.5 mm.

The energy carrier may further comprise a coating on an outwardly exposed surface of the silicon powder body.

The silicon powder body may have a density near room temperature of less than 2329 kg/m$^3$.

The energy carrier may comprise at least one reaction helper, such as magnesium, in an amount of about 0-01-0.1 wt-%, said reaction helper preferably having a particle size which is 50-150 % of that of the silicon powder.

Such magnesium particles may advantageously have an MgO coating, so as to counteract unintended ignition.

According to a third aspect, there is provided an energy carrier device, comprising a web, and a plurality of energy carriers as described above, wherein said energy carriers are attached to the web.

The web may be a flexible web, which may be formed of a relatively thin woven or non-woven material, a polymer film, or a combination thereof.

Alternatively, the web may be formed of a relatively thin rigid material, such as a sheet, in particular a polymer sheet.

The energy carriers may be attached to the web by an adhesive or a glue.

The web may be formed from at least two laminated or folded layers of material, in which the energy carriers may be encased in one or more pockets formed between the layers. The layers may be interconnected by means of e.g. welding, stitching, adhesive or glue.

In the energy carrier device the web may be essentially planar and define a web plane, and the energy carriers may be spaced from each other in at least one direction in said web plane.

According to a fourth aspect, there is provided use of an energy carrier as described above for transferring an amount of energy between two geographically spaced apart locations.

The geographically spaced apart locations may be situated in different sites, cities, counties, states, countries or continents.

According to a fifth aspect, there is provided use of an energy carrier as described above for extracting energy directly or indirectly from the silicon powder by oxidizing the silicon powder.

Hence, the energy may be directly extracted, for example, the energy may be thermal energy that is extracted by combustion of the silicon powder.

Alternatively, the energy may be indirectly extracted by contacting the silicon powder with water, such that hydrogen gas is generated, which, in turn, can be combusted.

According to a sixth aspect, there is provided a method of forming an energy carrier, comprising providing silicon having a level of purity corresponding at least to metallurgical grade silicon and a particle size of at least about 1 µm, preferably about 1-250 mm, about 5-100 mm, about 10-100 mm, about 20-80 mm or about 10-80 mm, and pressing an amount of said silicon into a silicon block.

The method may further comprise coating an outwardly exposed surface of the block.

The method may further comprise charging said silicon block with an amount of thermal energy.

According to a seventh aspect, there is provided an energy carrier, comprising a body which is formed of silicon particles having a level of purity corresponding at least to metallurgical grade silicon and a particle size of at least about 1 µm, preferably about 1-250 mm, about 5-100 mm, about 10-100 mm, about 20-80 mm or about 10-80 mm.

The body may have a mass of at least about 50 kg, preferably about 50-3000 kg.

The body may have a density near room temperature of less than about 2329 $kg/m^3$.

According to an eighth aspect, there is provided use of an energy carrier as described above for accumulating thermal energy, said thermal energy having a temperature greater than about 120 degC, preferably greater than 200 degC, greater than 300 degC, greater than 400 degC or greater than 500 degC, and less than about 3265 degC, preferably less than about 2500 degC or less than 1414 degC.

In particular, such thermal energy may have a temperature or 120-3265 degC, such as about 120-200 degC, about 200-300 degC, about 300-400 degC, about 400-500 degC, about 500-600 degC, about 600-700 degC, about 700-800 degC, about 800-900 degC, about 900-1000 degC, about 1000-1100 degC, about 1100-1200 degC, about 1200-1300 degC, about 1300-1400 degC, about 1400-1500 degC, about 1500-1600 degC, about 1600-1700 degC, about 1700-1800 degC, about 1800-1900 degC, about 1900-2000 degC, about 2000-2500 degC, about 2500 degC-3000 degC or about 3000-3265 degC.

<u>Drawings</u>

Fig. 1 is a schematic block diagram illustrating the silicon based energy carrier system.

Fig. 2 is a schematic block diagram illustrating an embodiment of the silicon production step 2.

Fig. 3 is a schematic block diagram illustrating an embodiment of the silicon pellet production step 3.

Fig. 4 is a schematic block diagram illustrating an embodiment of the silicon energy extraction step 5.

Fig. 5 is a schematic block diagram illustrating another use of silicon as an energy carrier and/or as an energy accumulator.

Figs 6a-6b schematically illustrate a first version of a silicon based energy carrier.

Fig. 7 schematically illustrates a second version of a silicon based energy carrier.

Detailed description

Referring to fig. 1, an overview of the silicon based energy carrier concept will be provided.

Silicon, which is one of the most common elements in the earth's crust, can be supplied 1 as silicon dioxide in the form of e.g. sand, quartz, rock crystal flint, or in other forms.

As will also be appreciated from the following description, recirculated silicon dioxide may also be used as a silicon supply.

Production 2 of pure silicon can be achieved by heating silicon dioxide in the presence of carbon and with input of energy, in a process which is known per se.

Another known Silicon production method, using sand and magnesium is called the magnesiothermic reduction (MTR) process, and is a promising way to produce silicon and has big advantages as low cost and is also a simple and convenient process.

Magnesium can be used in refining the $SiO_2$ into Si. If the extraction of Mg is done from seawater, the process of refining Si can be done without production of $CO_2$.

The energy input can be provided from a sustainable energy source, such as a renewable energy source, which may be solar power, hydroelectric power, wind power or the like.

During this process, silicon having a purity level of at least about 95 wt.-% (percent by weight), preferably at least about 96 wt.-%, at least about 97 wt.-%, at least about 98 wt.-% or at least about 99 wt.-% may be produced.

The resulting silicon may, but need not, be provided in the form of polycrystalline silicon, which may take the form of small rocks or pebbles, having a particle size of about 5-100 mm. In order to enable efficient energy extraction from the silicon, it may need to be prepared to have a suitable particle size. Hence, the pure silicon produced 2 may be ground or crushed into a powder having a powder particle size that is less than about 0.5 mm.

In particular, the resulting silicon powder may be provided as porous silicon, i.e. silicon having nanopores. Such silicon can provide a surface to volume ration on the order of 500 $m^2/cm^3$.

The powder particles may be spherical or non-spherical.

For some applications, the powder particle size may be about 0.1-0.2 mm, about 0.2-0.5 mm, about 0.5-0.7 mm, about 0.7-1 mm, about 1-3 mm, about 3-4 mm or about 4-5 mm.

For some applications, the powder particle size may be about 1-100 µm, about 100-200 µm, about 200-300 µm, about 300-400 µm or about 400-500 µm.

For other applications, the powder particle size may be about 1-100 nm, about 100-200 nm, about 200-300 nm, about 300-400 nm, about 400-500 nm, about 500-600 nm, about 600-700 nm, about 700-800 nm, about 800-900 nm or about 900-1000 nm.

The thus produced powder is pressed 3 into pellets or briquettes. The pressing may be performed at a pressure of less than about 300 kN/cm2, preferably of about 100-300 kN/cm2 or about 150-250 kN/cm2

Alternatively, pellets or briquettes may be produced from larger silicon particles, in order to be crushed or ground at or in connection with the energy extraction.

The pellets or briquettes may be transported to the site where energy is to be extracted from them.

The pellets or briquettes may be shipped in a bulk form, or in a transport packaging, which may serve to protect the pellets or briquettes, and which may assist in dosing of the pellets or briquettes.

The silicon may be transported 4 as a bulk material or in transport packaging.

The silicon may optionally be stored at a site where energy is to be extracted, or in a vehicle where the energy is to be extracted.

Energy may be extracted 5 from the silicon through an oxidation reaction, which can be an exothermal reaction in the presence of oxygen or a chemical reaction in the presence of water, both of which resulting in a residual product in the form of silicon dioxide.

The residual silicon dioxide can be collected and recycled 6 such that it can be restored 2 into pure silicon.

Such recycling may involve storage and transportation of the silicon dioxide.

Referring to fig. 2, the silicon production step 2 will now be briefly described.

Silicon dioxide is received 21 for use as starting material for this process.

Extraction of silicon dioxide from raw material in the form of sand, rock, etc. is a process which is known per se.

The silicon dioxide is then processed 22 into pure silicon.

Processing of silicon from silicon dioxide is a per se well known process. Referring to fig. 3, the transport preparation step 3 will now be described in further detail.

Preparation of the silicon resulting from the silicon production 2 for transport may involve grinding 31 the silicon thus produced to the desired particle size as set forth above with reference to fig. 1.

Methods of grinding are known per se, as are methods of testing to verify that the desired particle size has been attained and methods of sorting particles so as to provide an amount of silicon particles of the relevant particle size or interval of particle sizes.

The thus formed silicon powder is dosed and pressed 32 into pellets or briquettes 1001 having a desired size.

Methods of pressing silicon powder into silicon pellets or briquettes 1001, including selection of temperature and pressure for the pressing, are known per se. Such pressing can be achieved without the addition of any binder.

The pellets or briquettes 1001 thus formed can be coated 33 so as to prevent chemical interaction between the pellets or briquettes 1001 and the surrounding environment.

Such coatings can be formed of a polymer material and applied to the pellets or briquettes in connection with the pressing or immediately thereafter.

Coatings and coating methods are known per se.

While the pellets or briquettes 1001, coated or uncoated, can be transported as a bulk material, e.g. in crates or bags, it is possible to attach 34 them to a transport web 2000, which may be used as transport protection for the pellets or briquettes and which may be used to feed the pellets or briquettes 1001 between storage and transport devices and to an energy extraction device.

The thus formed webs 2000 may be packaged 35, e.g. by being folded or rolled up, to provide a compact transport format, from which the web 2000 can be easily extracted and fed to a storage device or to an energy extraction device.

Referring to fig. 4, the energy extraction step 5 will now be described in further detail.

The pellets or briquettes 1001, where not packaged on a web 2000, may be transported directly to a powderization 52 device, wherein the pellets or briquettes 1001 may be subjected to grinding and/or crushing 52 so as to cause the silicon powder to retain its original particle size.

The pellets or briquettes 1001 may optionally be extracted 51 from the web 2000 as a first step, whereby the web 2000 can be disposed of, recycled or discarded, such that individual pellets or briquettes 1001 are obtained.

Alternatively, the web 2000 carrying the pellets or briquettes 1001 can be allowed to proceed directly to the powderization 52, such that the pellets or briquettes 1001 are effectively powderized while still held by the web 2000, whereby the powderized pellets or briquettes 1001 may then be extracted from the web 2000.

The pellets or briquettes 1001 may be subjected to grinding and/or crushing 52 so as to cause the silicon powder to retain its original particle size.

In the alternative, this grinding and/or crushing may be used to convert silicon particles, having much larger particle size, into silicon powder that is suitable for combustion or hydrogen production.

Such grinding and/or crushing methods are known per se.

Extraction of energy from the energy carrier 1000 can be attained in two conceptually different ways.

According to a first alternative 53a, energy may be extracted by oxidizing the silicon in a combustion operation in the presence of oxygen, whereby heat is generated.

It may also be possible to oxidize silicon in the presence of other gases, such as, but not limited to, chlorine, fluorine, nitrogen oxide, methane, coal gas or acethylene.

For combustion type energy extraction, preferred particle sizes may be about 1-100 µm, about 100-200 µm, about 200-300 µm, about 300-400 µm or about 400-500 µm.

It is noted that for particles having a particle size of 1-5 µm, a reaction temperature may be at least about 930 degC, while for particles having a particle size of 20-30 nm, a reaction temperature may be at least about 800 degC. Hence, smaller particles provide for a lower reaction temperature.

The combustion of the silicon can be initialized by using a small amount of magnesium, combustion of which may be initialized at a temperature of about 470-700 degC. The magnesium will burn at a temperature of about 2200 degC, which is sufficient to initialize the combustion of the silicon.

Magnesium particles, having a particle size on the same order as the silicon powder, can also be incorporated, as a reaction helper, in small amounts into the silicon powder, such that magnesium is mixed into the silicon powder. As non-limiting examples, the amount of magnesium may be 0.01-0.1 wt-%.

Presence of such magnesium particles in an aerosol injected into a combustion zone may greatly facilitate the process of oxidizing the silicon.

Energy may be directly extracted from the silicon powder by oxidizing it in a combustion process, wherein $Si + O_2 \rightarrow SiO_2$.

According to a second alternative 53b, energy may be extracted in an oxidizing operation in the presence of water, whereby hydrogen gas is generated. The hydrogen gas can be stored for later use, or used in a combustion operation or in a fuel cell.

For hydrogen production, nano particles of 10 nm may be expected perform considerably better (faster) than 100 nm silicon. Improvements in reaction rates of about 100 times may be expected.

The hydrogen generation can be enhanced by addition of e.g. NaCl or sodium polyacrylate in the water.

For hydrogen gas production, preferred particle sizes may be of about 1-100 nm, about 100-200 nm, about 200-300 nm, about 300-400 nm, about 400-500 nm, about 500-600 nm, about 600-700 nm, about 700-800 nm, about 800-900 nm or about 900-1000 nm.Energy may thus be indirectly extracted by generating hydrogen gas by contacting the silicon powder with water, wherein $Si + 2H_2O \rightarrow SiO_2 + 2H_2$. The thus generated hydrogen gas may be stored or used immediately, either in a combustion type application or in a fuel cell.

In either case, the residual silicon dioxide can be collected 54 and recycled 6.

Referring to fig. 5, there will now be disclosed a method and system for storing thermal energy.

Silicon dioxide is supplied 100, in the same manner as disclosed with reference to fig. 1.

The silicon thus supplied 100 is processed 200 into pure silicon, also as disclosed with reference to fig. 1.

Purity level should be at least about 95 wt.-% (percent by weight), preferably at least about 96 wt.-%, at least about 97 wt.-%, at least about 98 wt.-% or at least about 99 wt.-%.

Resulting silicon may, but need not, be provided in the form of polycrystalline silicon, which may take the form of small rocks or pebbles, having a particle size of about 5-100 mm.

Alternatively, the silicon may be provided in the form of powder having any particle size as described above.

The resulting silicon is pressed 300 into a silicon block, which may have a mass of about 10-2000 kg. Such pressing can be achieved without the need for a binder.

The silicon block may optionally be transported 400 to a site where it is to be used. Optionally, the silicon may be stored at this site.

The silicon block may be used to store 500 thermal energy, which may be generated at the site. Such thermal energy may, as non-limiting examples, be generated by a combustion process, a heat pump process or otherwise by capture of heat from a heat source, including solar energy or geothermal energy.

Thermal energy may be transferred to the block by convection and/or by conduction.

It is noted that silicon can be used to store energy at temperatures higher than e.g. water.

The heated silicon block may be encapsulated in insulation.

The heated silicon block may be stationary, such that the thermal energy is extracted in the same location where it was stored in the block.

Optionally, the heated silicon block may be transported from a thermal energy storage site to a geographically remote thermal energy extraction site.

In particular, the heated silicon block may be used to supply the heat needed in the production of silicon from silicon dioxide in steps 2 or 200 referred to above.Referring to figs 6a-6b, there is illustrated an energy carrier for use in the system described with reference to figs 1-4.

Fig. 6a discloses an energy carrier 1000, comprising a silicon powder body 1001 formed of a pressed silicon powder comprising particles 1002 having a particle size of less than about 0.5 mm.

Optionally, the energy carrier 1000 may be provided with a coating 1003.

Optionally, the energy carrier 1000 may be attached to a web 2000.

In some embodiments, a silicon particle size can be about 1-100 µm, about 100-200 µm, about 200-300 µm, about 300-400 µm or about 400-500 µm.

Such embodiments find particular use in energy extraction by combustion.

In other embodiments, a silicon particle size can be about 1-100 nm, about 100-200 nm, about 200-300 nm, about 300-400 nm, about 400-500 nm, about 500-600 nm, about 600-700 nm, about 700-800 nm, about 800-900 nm, about 900-1000 nm.

Such embodiments find particular use in energy extraction by hydrogen gas production.

The silicon powder body 1001 can have any suitable shape, such as spherical, half-spherical, cuboid, cylindrical, etc.

The silicon powder body 1001 can be provided with a coating 1003 on at least faces of the body 1001 that are outwardly exposed.

The coating may be formed from a polymeric material, such as a thermoplastic material or a thermosetting material.

The coating may protect the silicon powder body 1001 from moisture, pollutants and/or from inadvertent abrasion during transport and/or storage.

The coating may be applied by a spraying, dipping or thermoshrinking operation.

The coated or uncoated energy carriers 1000 may be attached to a web 2000.

The web 2000 may be provided as a flexible web, which may be formed of a fabric or a film. Particular examples include woven or nonwoven fiber materials and polymer films.

The web 2000 may have the form of a strip, whereby energy carriers 1000 may be arranged along a length direction of the strip.

The web 2000 may have the form of a sheet, whereby silicon energy carriers 1000 may be arranged approximately in a 2D matrix on the sheet.

The energy carriers 1000 may be adhered to the web 2000 by an adhesive or a glue.

Alternatively, the energy carriers 1000 may be encased by the web 2000.

For example, the web 2000 can be folded along its length direction, or laminated from two or more layers, so as to form pockets in which the energy carriers 1000 can be encased.

Webs 2000 or web portions can be stitched, welded or adhered to each other to form the pockets.

Alternatively, the web 2000 may be formed as a rigid member, such as a strip or a sheet, to which the energy carriers 1000 may be attached as described above.

Fig. 6b discloses a web 2000 supporting a plurality of energy carriers 1000, which are arranged along a length direction of the web 2000.

Referring to fig. 7, there is illustrated an energy carrier in the form of a silicon block for use in the system described with reference to fig. 5.

Fig. 7 discloses a silicon block 3000 comprising a silicon body 3001 formed of a plurality of pressed together silicon particles 3002 having a particle size of at least 1 mm.

The particle size may be at least about 1 µm.

The particles 3000 may, but need not, be formed of polycrystalline silicon.

As a maximum, the particle size may be on the order of about 2-3 m, about 1-2 m, about 0.5-1 m or about 0.1-0.5 m.

In various embodiments, the particle size may be about 1-250 mm, about 5-100 mm, about 10-100 mm, about 20-80 mm or about 10-80 mm.

As non-limiting examples, the silicon block 3000 may have a volume of 1-2000 $dm^3$, preferably 50-1000 $dm^3$. However, larger blocks 3000 are not excluded.

In use, a plurality of such silicon blocks 3000 may be arrayed, such as stacked, or otherwise arranged to form a larger thermal accumulator.

In a silicon block 3000 as described above, energy can be stored at a capacity of more than 1 MWh per cubic metre of silicon at a temperature of 1400 degC. Hence, energy may be stored in the silicon block at 120-1400 degC and in particular at 120-200 degC, 200-300 degC, 300-400 degC, 400-500 degC, 500-600 degC, 600-700 degC, 700-800 degC, 800-900 degC, 900-1000 degC, 1000-1100 degC, 1100-1200 degC, 1200-1300 degC, 1300-1400 degC or 1400-1414 degC.

Higher temperatures, up to about 3265 degC, which is the boiling temperature of silicon, can be used. Provided appropriate measures are taken, it may be desirable to allow a plurality of silicon blocks to melt or fuse into a single block, and/or to store energy in silicon when it is in liquid state.

Optionally, heat conductors may be arranged in spaces between such arrayed silicon blocks 3000.

Alternatively, or as a supplement, channels can be formed in the silicon block 3000, in which a heated medium may be conveyed.

Magnesium combustion starters which may be used for initialization of the silicon combustion operation can be formed as small droplets, powder or pellets. Each such pellet may, as non-limiting examples have a weight of 0.5-5 gram.

Combustion starters can be provided coated or uncoated, in bulk or on a transport web, similar to that the transport web 2000 used for the energy carriers 1000.

The silicon block 3000 may be formed according to a standardized size, such that silicon blocks 3000 can be stacked and handled rationally. To this end, the silicon block may be provided with connectors, for interconnection of two or more silicon blocks 3000. Such interconnectors may, as a non-limiting example, be provided in a manner similar to the basic Lego® blocks, i.e. with one or more downwardly open receptacles and one or more upwardly protruding projections matching said receptacles.

At higher temperatures, such as above 1350 degC, in particular above 1400 degC, i.e. close to the melting point of silicon, silicon blocks may bond thermally to each other.

CLAIMS

1. A method of forming an energy carrier, comprising:

providing (2) silicon having a level of purity corresponding at least to metallurgical grade silicon,

formatting (31) the silicon into a silicon powder having a predetermined particle size, and

pressing (32) an amount of said silicon powder into a silicon powder body (1001).

2. The method as claimed in claim 1, wherein the silicon powder comprises at least about 95 wt.-% silicon, preferably at least about 98 wt.-% silicon.

3. The method as claimed in claim 1 or 2, wherein said formatting comprises grinding (31) the silicon into silicon powder.

4. The method as claimed in claim 3, wherein the silicon powder has a particle size of less than about 5 mm.

5. The method as claimed in claim 4, wherein the silicon powder has a particle size of about 0.5 µm to about 5 mm.

6. The method as claimed in claim 4, wherein the silicon powder has a particle size of about 0.1-0.2 mm, about 0.2-0.5 mm, about 0.5-0.7 mm, about 0.7-1 mm, about 1-3 mm, about 3-4 mm or about 4-5 mm.

7. The method as claimed in claim 4, wherein the silicon has a particle size of about 1-100 µm, about 100-200 µm, about 200-300 µm, about 300-400 µm or about 400-500 µm.

8. The method as claimed in claim 4, wherein the silicon powder has a particle size of about 1-100 nm, about 100-200 nm, about 200-300 nm, about 300-

400 nm, about 400-500 nm, about 500-600 nm, about 600-700 nm, about 700-800 nm, about 800-900 nm, about 900-1000 nm.

9. The method as claimed in any one of the preceding claims, wherein said pressing (32) comprises supplying thermal energy, such that the silicon powder is pressed at an elevated temperature.

10. The method as claimed in any one of the preceding claims, wherein said pressing (32) is performed at a pressure of less than about 300 $kN/cm^2$, preferably of about 100-300 $kN/cm^2$ or about 150-250 $kN/cm^2$.

11. The method as claimed in any one of the preceding claims, further comprising coating (33) an outwardly exposed surface of the silicon powder body.

12. The method as claimed in any one of the preceding claims, further comprising transforming (52) the silicon powder body into silicon powder.

13. The method as claimed in any one of the preceding claims, further comprising extracting (53a, 53b) energy directly or indirectly from the silicon powder by oxidizing the silicon powder.

14. The method as claimed in claim 13, further comprising collecting (54) a residual product from said oxidization, said residual product consisting essentially of silicon dioxide.

15. The method as claimed in claim 13, further comprising converting said silicon dioxide to reprocessed silicon having a level of purity corresponding at least to metallurgical grade silicon.

16. The method as claimed in claim 14, wherein said step of providing (2) silicon comprises providing said reprocessed silicon.

17. The method as claimed in any one of the preceding claims, further comprising transporting the silicon powder body (1001) to an energy extraction site where energy is to be extracted from the silicon powder body (1001).

18. The method as claimed in any one of the preceding claims, further comprising providing the silicon powder body (1001) in a fuel receptacle of a vehicle, in which energy is to be extracted from the silicon powder body.

19. An energy carrier, comprising a silicon powder body (1001) which is formed of a silicon powder, said silicon powder having a level of purity corresponding at least to metallurgical grade silicon and a particle size which is less than about 0.5 mm.

20. The energy carrier as claimed in claim 19, further comprising a coating on an outwardly exposed surface of the silicon powder body (1001).

21. The energy carrier as claimed in claim 19 or 20, wherein the silicon powder body (1001) has a density near room temperature of less than 2329 kg/m$^3$.

22. The energy carrier as claimed in any one of claims 19-21, further comprising at least one reaction helper, such as magnesium, in an amount of about 0-01-0.1 wt-%, said reaction helper preferably having a particle size which is 50-150 % of that of the silicon powder.

23. An energy carrier device, comprising:
a web (2000), and
a plurality of energy carriers (1000) as claimed in any one of claims 19-22, wherein said energy carriers (1000) are attached to the web (2000).

24. The energy carrier device as claimed in claim 23, wherein the web (2000) is essentially planar and defines a web plane, and wherein the energy carriers (1000) are spaced from each other in at least one direction in said web plane.

25. Use of an energy carrier (1000) as claimed in any one of claims 19-24 for transferring an amount of energy between two geographically spaced apart locations.

26. Use of an energy carrier (1000) as claimed in any one of claims 19-25 for extracting energy directly or indirectly from the silicon powder by oxidizing the silicon powder.

27. A method of forming an energy carrier (3000), comprising:

providing (200) silicon having a level of purity corresponding at least to metallurgical grade silicon and a particle size of at least about 1 µm, preferably about 1-250 mm, about 5-100 mm, about 10-100 mm, about 20-80 mm or about 10-80 mm, and

pressing (300) an amount of said silicon into a silicon block (3001).

28. The method as claimed in claim 27, further comprising coating an outwardly exposed surface of the silicon block (3001).

29. The method as claimed in claim 27 or 28, further comprising charging said silicon block (3000) with an amount of thermal energy.

30. An energy carrier (3000), comprising a body which is formed of silicon particles (3002) having a level of purity corresponding at least to metallurgical grade silicon and a particle size of at least about 1-250 mm, about 5-100 mm, about 10-100 mm, about 20-80 mm or about 10-80 mm.

31. The energy carrier (3000) as claimed in claim 30, wherein the body (3001) has a mass of at least about 50 kg, preferably about 50-3000 kg.

32. The energy carrier as claimed in claim 30 or 31, wherein the body (3001) has a density near room temperature of less than about 2329 kg/m$^3$.

33. Use of an energy carrier (3000) as claimed in any one of claims 30-32 for accumulating thermal energy, said thermal energy having a temperature greater than 120 degC, preferably greater than 200 degC, greater than 300 degC, greater than 400 degC or greater than 500 degC, and less than about 3265 degC, preferably less than about 2500 degC or less than 1414 degC.

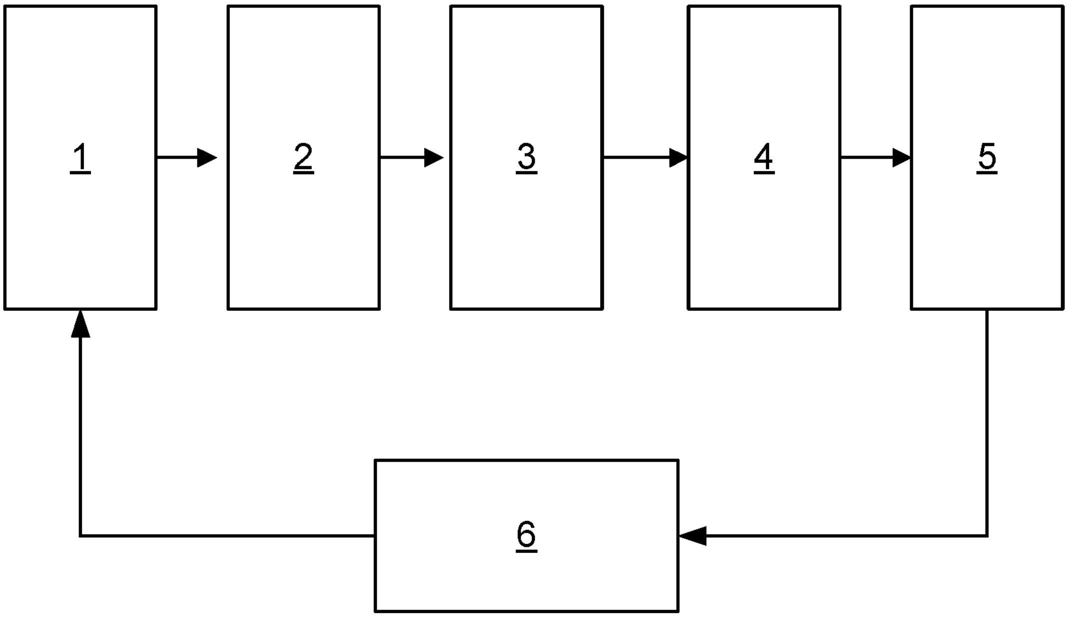


Fig 1

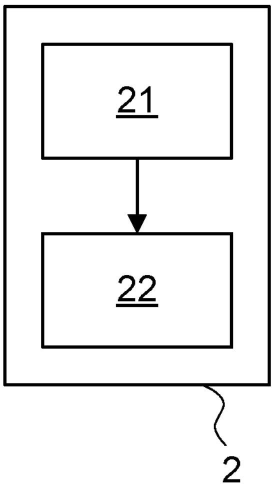


Fig 2

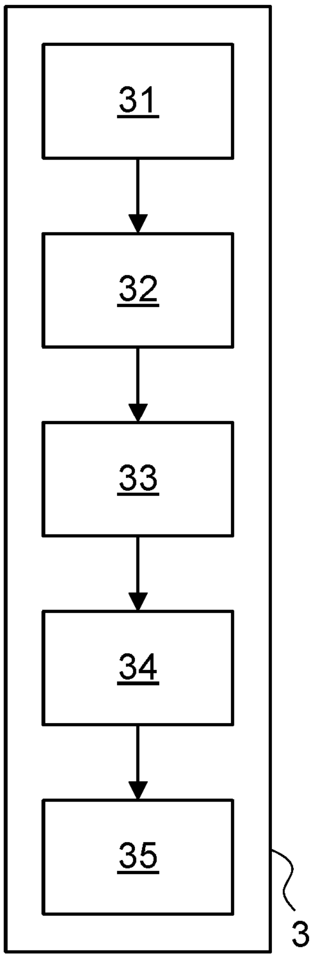


Fig 3

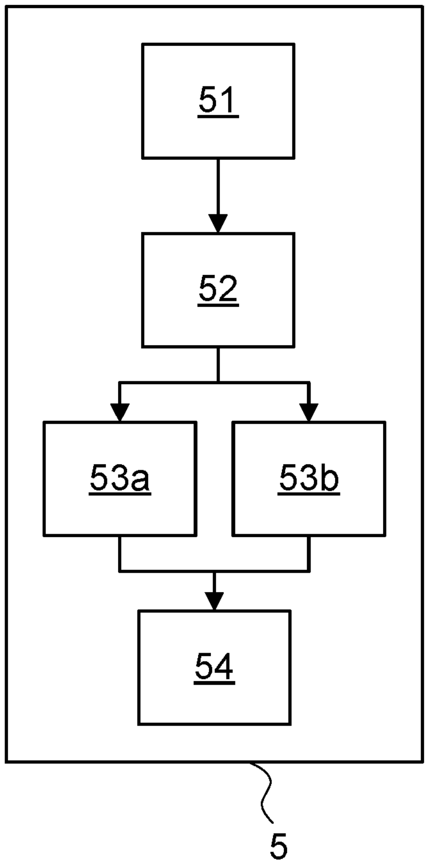


Fig 4

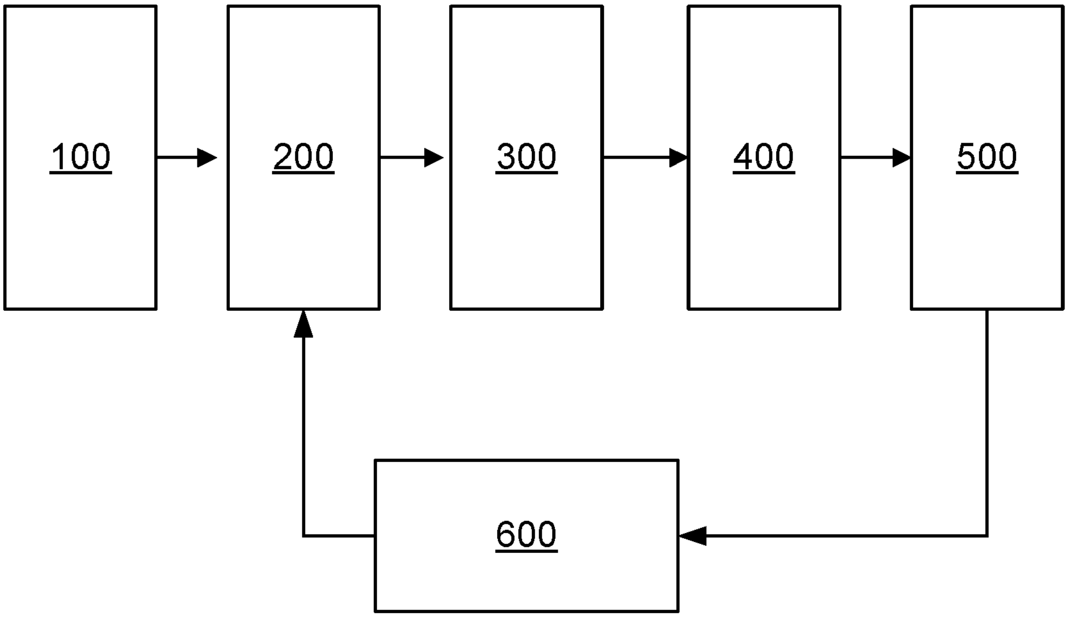


Fig 5

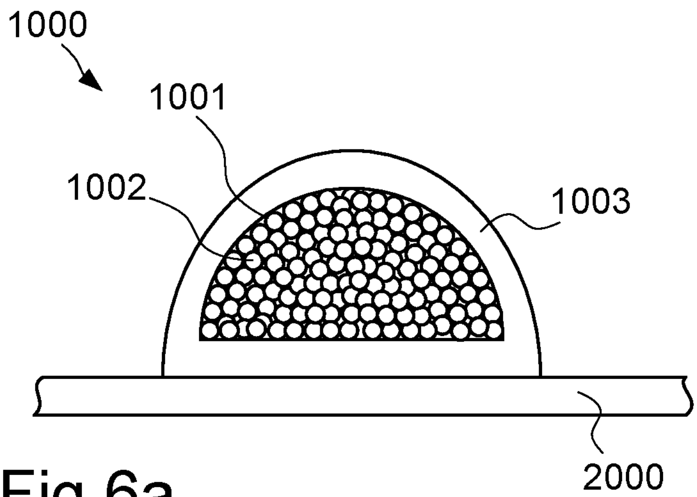


Fig 6a

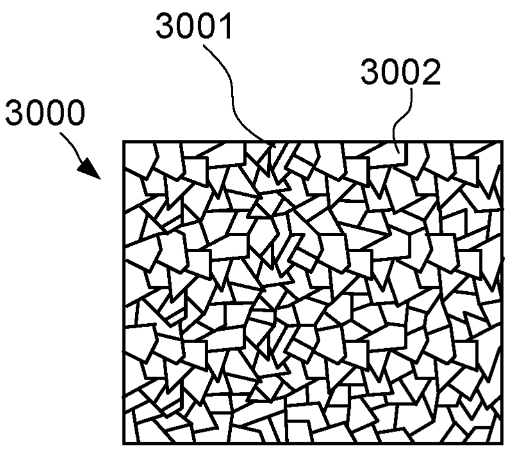


Fig 7

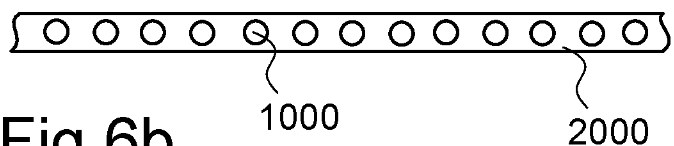


Fig 6b

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/053293

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. C22B1/24 C01B33/02 B01J2/00 C01B3/02 C01B33/033
C30B35/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
C01B C30B C01C B01J C22B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | ALEXANDROU SOTIRIS ET AL: "Silicon Fuel: A hydrogen storage material", INTERNATIONAL JOURNAL OF HYDROGEN ENERGY, ELSEVIER, AMSTERDAM, NL, vol. 46, no. 2, 1 November 2020 (2020-11-01), pages 1627-1633, XP086426706, ISSN: 0360-3199, DOI: 10.1016/J.IJHYDENE.2020.10.049 [retrieved on 2020-11-01] | 1-10,13, 14 |
| Y | page 1629, left-hand column, paragraph 5 - right-hand column, paragraph 3 | 12,15-18 |
| A | page 1629, right-hand column, paragraph 4 - page 1630, right-hand column, paragraph 1; figures 1-3<br>the whole document<br>----- | 11 |

-/--

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 8 September 2023 | 09/11/2023 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Follens, Lana |

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2022/029408 A1 (WATER LANE 6 SF LTD [GB]) 10 February 2022 (2022-02-10) | 1-11,13, 14 |
| A | page 8, line 7 - page 11, line 20; claims 12-23; example 1<br>the whole document<br>----- | 12,15-18 |
| Y | US 2016/046486 A1 (STARK DOUGLAS [US]) 18 February 2016 (2016-02-18)<br>cited in the application | 12,15-18 |
| A | paragraphs [0010] - [0023]<br>the whole document<br>----- | 1-11,13, 14 |

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# INTERNATIONAL SEARCH REPORT

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
1-18

**Remark on Protest**

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-18

   Method to make silicon powder body

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2. claims: 19-26

   energy carrier comprising silicon powder body (powder size below 0.5 mm), a device thereof and use

   ---

3. claims: 27-29

   method to make silicon block

   ---

4. claims: 30-33

   energy carrier comprising body of silicon particles (particles size of 1-250 mm) and use

   ---

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No

PCT/EP2023/053293

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2022029408 A1 | 10-02-2022 | CN 116323476 A | 23-06-2023 |
| | | GB 2597789 A | 09-02-2022 |
| | | WO 2022029408 A1 | 10-02-2022 |
| US 2016046486 A1 | 18-02-2016 | US 2016046486 A1 | 18-02-2016 |
| | | US 2016046487 A1 | 18-02-2016 |