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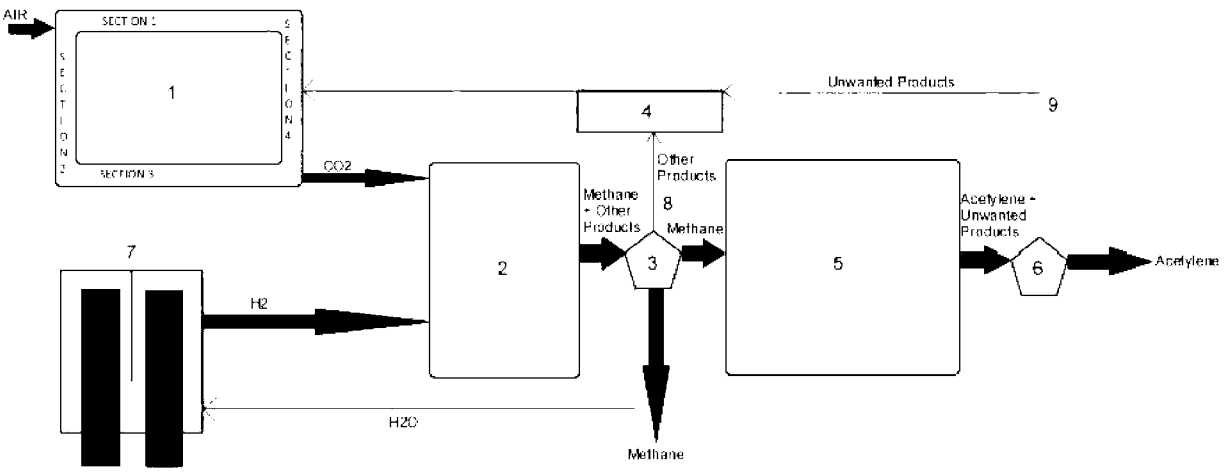

Figure 1

(57) Abstract: A method for carbon capture and recycling, the method including the steps of: (i) Capturing CO_2 from at least one CO_2 containing input; (ii) Producing a CO_2 feed stream from the captured CO_2; and (iii) Reacting the CO_2 feed stream with a H_2 feed stream to produce a methane containing output.

WO 2017/214687 A1

A METHOD AND SYSTEM FOR CARBON CAPTURE AND RECYCLING

Field of the Invention

[001] The present invention relates to a method and system for carbon capture and recycling, and in particular methods and systems for capturing CO_2 and producing methane, acetylene and/or other hydrocarbons.

Background

[002] The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that the prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

[003] Climate change is an important issue on the agenda of governments worldwide. It is proposed that climate change is accelerated by human production of "greenhouse gases". Greenhouse gases are those which get trapped in the atmosphere and enhance the "greenhouse effect". In the greenhouse effect, heat is trapped from escaping the earth due to a build up of the greenhouse gases in the atmosphere. Therefore, in seeking to address climate change, several approaches look to reduce green house gas emissions.

[004] Carbon dioxide (CO_2) is one green house gas where emissions are targeted. Several approaches have been developed to capture and/or reduce CO_2 emissions. One such approach is carbon capture and storage whereby CO_2 is captured (e.g. from air, flue gas etc.) and then stored in selected geological rock formations below the earths surface. It will be appreciated that carbon capture and storages can be expensive, and furthermore, no usable products/outputs are produced from the captured CO_2, it is simply captured and stored.

[005] The present invention seeks to provide an approach to reducing CO_2 emissions that also provides industrially applicable products.

Summary of the Invention

[006] In one broad form, the present invention provides a method for carbon capture and recycling, the method including the steps of: (i) Capturing CO_2 from at least one CO_2 containing input; (ii) producing a CO_2 feed stream from the captured CO_2; and (iii) reacting the CO_2 feed stream with a H_2 feed stream to produce a methane containing output.

[007] In one form, the method further includes the step of (iv) separating the methane containing output so as to at least provide methane and a first waste output.

[008] In one form, the first waste output is thermally treated to provide CO_2 for one of the at least CO_2 containing inputs for step (i).

[009] In one form, one of the at least one CO_2 containing inputs includes air.

[0010] In one form, the H_2 feed stream is provided by a water electrolysis process.

[0011] In one form, water produced during step (iii) is provided for the water electrolysis process.

[0012] In one form, in step (i), CO_2 is captured using a Calcium Oxide based capture process.

[0013] In one form, the method further includes the step of: (v) processing methane from the methane containing output to produce acetylene containing output.

[0014] In one form, the method further includes the step of (vi) separating the acetylene containing output so as to at least provide acetylene and a second waste output.

[0015] In one form, the second waste output is thermally treated to provide CO_2 for one of the at least one CO_2 containing inputs for step (i).

[0016] In one form, step (v) includes heating the methane with a thermal plasma reactor.

[0017] In one form, the method further includes the step of (vii) processing methane from the methane containing output to produce a hydrocarbon containing output.

[0018] In one form, the method further includes the step of (viii) separating the hydrocarbon containing output so as to at least provide one or more preselected hydrocarbon products and a second waste output.

[0019] In one form, the second waste output is thermally treated to provide one of the at least one CO_2 containing inputs for step (i).

[0020] In one form, step (vii) includes heating the methane, and the methane is heated by a thermal plasma reactor configured such that plasma is provided in feed with the methane.

[0021] In a further broad form the present invention provides a system for carbon capture and recycling, the system including a CO_2 capture apparatus configured to capture CO_2 from at least one CO_2 containing input; and a first reactor configured to produce a methane containing output from a CO_2 feed stream derived from the CO_2 capture apparatus and an H_2 feed stream.

[0022] In one form, the system further includes: a first separator configured to separate the methane containing output so as to at least provide methane and a first waste output.

[0023] In one form the system further includes a thermal treatment apparatus configured to treat the first waste output so as to provide CO_2 containing input for the CO_2 capture apparatus.

[0024] In one from, the CO_2 capture apparatus is configured to capture CO_2 from an air input.

[0025] In one form, the system further includes a water electrolysis device for producing the H_2 feed stream. In one form the water electrolysis device is configured to receive water for electrolysis produced in the first reactor.

[0026] In one form, the CO_2 capture apparatus is a Calcium Oxide based capture apparatus.

[0027] In one form, the system further includes : a second reactor configured to received methane produced in the first reactor and to produce an acetylene containing output therefrom.

[0028] In one form the system further includes: a second separator configured to separate the acetylene containing output so as to at least provide acetylene and a second waste output.

[0029] In one from, the second waste output is fed to the thermal treatment apparatus.

[0030] In one form, the second reactor is thermal plasma reactor.

[0031] In one from, the system further includes a second reactor configured to received methane produced in the first reactor and to produce a hydrocarbon containing output therefrom.

[0032] In one form, the system further includes a second separator configured to separate the hydrocarbon containing output so as to at least provide preselected hydrocarbon products and a second waste output.

[0033] In one form, the second waste output is fed to the thermal treatment apparatus.

[0034] In one form, the second reactor is a thermal plasma reactor configured provide plasma in feed with the methane.

Brief Description of the Drawings

[0035] This invention may be better understood with reference to the illustrations of embodiments of the invention in which:

[0036] Figure 1 is an overview layout of one example implementation of the method/system; and

[0037] Figure 2 is an overview of example reactions utilised in one example implementation of the method/system.

[0038] Figure 3 is a flow chart overview of an example implementation of the method/system.

[0039] Figure 4 is an example of CO_2 capture apparatus.

Detailed Description

[0040] Embodiments of the present invention provide methods and systems for carbon capture and recycling. Generally, embodiments provide a method/system for producing hydrocarbons from captured carbon, such as, for example, methane or acetylene. The presently described system captures CO_2, reducing emissions, and produces industrially applicable output in the form of common precursor materials that may be further processed to form a wide range of materials.

[0041] In the methods and systems described, carbon dioxide (CO_2) is captured from at least one CO_2 containing input/source. It would be appreciated that CO_2 may be recovered/captured from a large range of sources, such as, for example, from air, incinerator exhaust streams, or industrial plumes etc. It will also be appreciated that CO_2 may be captured using a variety of CO_2 capture devices/systems. In the presently described system/method, CO_2 is typically captured using a calcium oxide (CaO) based apparatus/system. Calcium Oxide (quicklime) based carbon capture devices/systems have advantages in that the calcium oxide is reusable as a carbon capture agent and permits continuous loop processing as per the below reactions

$$CaO + CO_2 \rightarrow CaCO_3$$

$$CaCO_3 + \Delta T \rightarrow CaO + CO_2$$

[0042] As above, CaO reacts with CO_2 to form Calcium Carbonate, and subsequent heating of the Calcium Carbonate releases the CO_2, providing the CaO for reuse (see Appendix A).

[0043] From captured CO_2, a CO_2 feed stream is produced and fed to a methane producing reactor in combination with a hydrogen (H_2) feed stream. A methane containing output is produced by the methane producing reactor. Typically, the methane producing reactor is a conventional batch reactor. It will be appreciated that the H_2 feed stream may also be provided from a variety of sources. In one example form, H_2 is provided by a water electrolysis process i.e. as per the below reaction

$$2H_2O + e^- \rightarrow 2H_2 + O_2$$

[0044] The methane containing output form the methane producing reactor typically includes methane, water and other partial products as per the reaction

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

[0045] The methane containing output is separated to so as to at least provide a substantially pure methane stream and a first waste output stream/recycle stream. It will also be appreciated that separation of the methane containing output may be performed by varying separation devices/methodologies.

[0046] The first waste output, is then typically heated by a thermal treatment apparatus (e.g. incinerator) to provide additional CO_2 e.g. as per the below reaction

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

[0047] The additionally produced CO_2 (e.g. by the incineration of soot etc.) may then be re-fed into the system via carbon capture to drive more methane production. Additionally, water produced from the production of methane may be re-fed to the water electrolysis process to drive production of additional H_2. In some examples, excess water may also be used for cooling and steam generated therefrom used to power turbines etc. Accordingly, it will be appreciated that by products from the reactions at each stage of the process can be re-fed into the system to increase the conversion efficiency, minimise waste, and maximise the methane produced.

[0048] Methane produced may further be fed into an acetylene producing reactor so as to produce acetylene containing output e.g. as per the reaction

$$CH_4 + \Delta T \rightarrow C_2H_2$$

[0049] Typically, the reaction requires heating to high temperature (7000-8000°C). The acetylene producing reactor is thus typically thermal plasma type reactor, and may, for example be like or similar to the reactors as described in the publication "*Thermal Conversion of Methane to Acetylene Final Report, J. R. Fincke, R. P. Anderson, T. Hyde, R. Wright, R. Bewley, D. C. Haggard, W. D. Swank, Published January 2000, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho 83415*".

[0050] As with the methane containing output, the acetylene containing output may be purified/separated to provide a pure acetylene stream and a second waste output stream/recycle stream. The second waste output stream may also be fed back to the thermal treatment apparatus (e.g. incinerator), so as to provide additional CO_2 to be re-fed/re-captured by the system.

[0051] Alternatively or additionally, produced methane may be processed by a reactor to provide varied/random hydrocarbon containing output. The varied hydrocarbon containing output may then be separated by a separator preconfigured to separate out preselected hydrocarbons. The non-selected output may be provided as a waste output/recycle stream that may then be re-fed to the thermal treatment apparatus, so as to again produce additional CO_2 (e.g. by incineration, gasification). The additional CO_2 produced being

returned for recapture by the carbon capture device/apparatus. The waste output/recycle stream essentially provides a CO_2 containing input for the carbon capture device/apparatus. Again the recycle streams from the reactor provide that the methane processing is energy efficient, with waste minimised.

[0052] The reactor in this variation is typically of thermal plasma type where plasma is provided in feed with the methane. For example, suitable reactors may be as described in the publication "*Thermal Conversion of Methane to Acetylene Final Report, J. R. Fincke, R. P. Anderson, T. Hyde, R. Wright, R. Bewley, D. C. Haggard, W. D. Swank, Published January 2000, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho 83415*".

[0053] One example embodiment of the system and method shall now be described with reference to figure 1.

[0054] A carbon capture apparatus (1) is provided which is configured to receive one or more CO_2 containing inputs/sources. As shown, air may be one of the CO_2 containing inputs. It will also be appreciated a range of alternate CO_2 containing inputs may be provided such as, for example, waste output streams/recycle streams.

[0055] The carbon capture apparatus (1) may take a variety of forms, however, typically, the carbon capture apparatus is a calcium oxide based apparatus. Furthermore, it will be appreciated that calcium oxide may be utilised for carbon capture in a variety of differently configured apparatuses.

[0056] The carbon capture apparatus (1) is also configured to produce a CO_2 feed gas stream for a methane producing reactor (2).

[0057] Typically, the calcium oxide based carbon capture apparatus for use with the present system/method has two preferred configurations. In both configurations, the apparatus typically comprises four chambers with an outlet (e.g. transport tube) for transporting produced CO_2 feed to a methane producing reactor (2).

[0058] In a first configuration, calcium oxide is mixed with air (containing CO_2) in the first chamber via mass transport via air with alternating fans to maximise dispersion and surfaces exposed to the air. CO_2 is captured from the air. In the second chamber, a vacuum is formed, and in the third chamber, the now calcium carbonate is baked to 700ºC whilst being stirred (to speed the process). Carbon dioxide is released and flows through outlet to methane producing reactor. A fourth chamber maintains the vacuum between chambers 2, 3, and 4, before the calcium oxide is reused and air rated once more in chamber 1. This is a continuous closed loop.

[0059] In a second configuration, calcium oxide is hydrated with water in the first chamber, with air jets on the bottom bubbling air through the mixture while it is pushed along via a spiral configuration. Chamber 2 creates a vacuum and then raises the temperature to 400ºC removing the water, which is fed to chamber 4. In chamber 3, the product is heated to 700 ºC while being stirred to release the carbon dioxide to the methane producing reactor. The calcium oxide is then sent to chamber 4, where it is re-hydrated before returning chamber 1 again. Once again, this is a closed loop full of calcium oxide.

[0060] Another example configuration of a carbon capture described at figure 4.

[0061] As shown in figure 1, H_2 gas is provided to the methane producing reactor to combine with CO_2 feed for the production of methane as per the below equation

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

[0062] It will be appreciated that the reactor (2) provides the appropriate conditions for the production of methane and water from CO_2 and H_2 (e.g. heating at > 600ºC at 1 atmosphere of pressure). Typically, the reactor is heated to about 800ºC. Typically the methane producing reactor is a conventional batch rector. It will also be appreciated that the efficiency of this process may be improved by adjusting the reaction conditions such as, for example, by increasing the pressure of the system and the temperature.

[0063] The H_2 feed stream may come from a variety sources. In the example of figure 1, the H_2 feed stream is provided by a water electrolysis device (7) which provides H_2 as per the following equation

$$2H_2O + e^- \rightarrow 2H_2 + O_2$$

[0064] As water is produced as a by product in the production of methane, the water can be redirected back to the water electrolysis device (7) for re-use (as shown). In other forms, the water may be used for cooling and/or quenching in subsequent process steps or at other at other parts of the system. Oxygen produced in the electrolysis may be utilised for cleaner combustion in other parts of the system or released to the environment. In some forms, the electrolysis reaction is conducted in a U shaped reactor with a simple barrier with the possible addition of an electrolyte to speed the reaction and lower the energy costs.

[0065] A first separator (3) is provided to separate the methane, water and other partial products produced in the methane producing reactor (2). Typically separation is achieved via distillation however it will be appreciated that other methods may be used. Any non-methane and non-water products are separated out into a first waste output and fed to a thermal treatment apparatus (4). The thermal treatment apparatus is typically an incinerator, although, it will be appreciated that it may take other forms such as, for example, a gasifier. Thermal treatment, e.g. incineration, results in additional CO_2 product which can then be re-fed to the carbon capture device.

[0066] The purified methane from the first separator (3) is directed for further processing to an acetylene producing reactor (5). The acetylene producing reactor (5) provides appropriate reaction conditions to product acetylene form the incoming methane feed stream. Typically, the acetylene is produced via heating as per to the following reaction

$$CH_4 + \Delta T \rightarrow C_2H_2$$

[0067] In one form, the reactor is a thermal plasma type reactor. In one form, the reactor utilises argon plasma to provide temperatures of about 8000ºC and rapid quenching

follows to produce the acetylene. Example reactor/process are described in the publication "*Thermal Conversion of Methane to Acetylene Final Report, J. R. Fincke, R. P. Anderson, T. Hyde, R. Wright, R. Bewley, D. C. Haggard, W. D. Swank, Published January 2000, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho 83415*". Typical yields of acetylene are described in Appendix B. In one example, graphite tubing is utilised in the reactor surrounded by heat exchanges to recapture energy to power the argon plasma jets.

[0068] A second separator (6) is used to purify the acetylene containing output, and provide a second waste output/recycle stream (9). Typically separation is achieved via temperature gradient and/or distillation although it will be appreciated a range of appropriate separation methods may be utilised. As with the first waste output stream, the second waste output stream (including soot etc.) is fed to the thermal treatment apparatus (4) for recycling. CO_2 produced at the thermal treatment apparatus (e.g. by incineration) is then fed back into the carbon capture apparatus (1). It will be appreciated that in some forms, heat generated from the thermal treatment apparatus (4) may be used to heat the methane and/or acetylene producing reactors. It is noted that the reaction processes in these reactors are exothermic.

[0069] Once purified, the acetylene and/or methane produced by the system/process can be readily converted via conventional processes into different polymers, benzo aromatics and other organic compounds for use in a wide variety of industrial applications.

[0070] In alternate forms, the acetylene producing reactor may be configured such that the argon plasma (or the like) may be provided in-feed with the methane. This typically results in varied hydrocarbon products being formed rather than mainly acetylene. It will be appreciated that in such examples, the second separator (6) would be configured to filter preselected hydrocarbon products. The remaining non-selected products would be re-fed to the thermal treatment apparatus (e.g. incinerator) for recycling. Again any produced CO_2 from combustion/gasification may re-captured for further methane production.

[0071] The presently described system/method has significant advantages over conventional carbon capture and storage approaches for reducing CO_2 emissions. In particular, there are minimal waste products as the recycle feeds (i.e. waste output streams) push the conversion rate towards 100%.

[0072] In addition, once purified, acetylene has many industrial applications and can be further processed and converted, for example, into different polymers, benzo aromatics and other organic compounds. Methane may also be extracted from the system to produce compounds other than those produced by reacting acetylene.

[0073] It will be appreciated that power for the various components/reactions may be provided/supplemented by mains electricity, renewable energy sources and waste combustion.

[0074] In particular, it will be appreciated that due to the configuration of the system, organic waste material can be directly combusted (e.g. in the thermal treatment apparatus) and filtered to provide the CO_2 for the carbon capture. Furthermore, the heat from the combustion also may be supplied to the methane and acetylene producing reactors.

[0075] Furthermore, as the methane and acetylene producing reactors are running exothermic processes, once heated, excess energy therefrom may be utilised to further provide electrical energy to the system, while energy recycling may also be used on the coolant for the argon plasma jets. Excess energy may also be harvested by steam turbines to power the argon plasma reactions.

[0076] Optional embodiments of the present invention may also be said to broadly consist in the parts, elements and features referred to or indicated herein, individually or collectively, in any or all combinations of two or more of the parts, elements or features, and wherein specific integers are mentioned herein which have known equivalents in the art to which the invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth.

[0077] Although a preferred embodiment has been described in detail, it should be

understood that various changes, substitutions, and alterations can be made by one of ordinary skill in the art without departing from the scope of the present invention.

[0078] It will be appreciated that various forms of the invention may be used individually or in combination.

Appendix A

Calcium oxide is usually made by the thermal decomposition of materials, such as limestone or seashells, that contain calcium carbonate ($CaCO_3$; mineral calcite) in a lime kiln. This is accomplished by heating the material to above 825 °C (1,517 °F),[6] a process called calcination or lime-burning, to liberate a molecule of carbon dioxide (CO_2), leaving quicklime.

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

The quicklime is not stable and, when cooled, will spontaneously react with CO_2 from the air until, after enough time, it will be completely converted back to calcium carbonate unless slaked with water to set as lime plaster or lime mortar.

Appendix B

Reference	Year	Process	Reactor Size	Feedstock	Plasma Gas	Quench Method	Conversion Efficiency	Maximum Acetylene Yield y$_{max}$	Hydrocarbon Yield other than Acetylene y$_{HC}$	Normalized Acetylene Yield y$_{norm}$	Soot Yield	Minimum SER kW-hr/kg - C_2H_2
Leutner & Stokes	1961	DC plasma jet	6.8 kW	CH_4	Ar	Wall heat transfer	92.9%	80.1	not analyzed	86.2	5.7%	72.5
Gladisch	1962	Huels DC arc	8 MW	natural gas	CH_4	Water spray	70.5%	51.4%	45.6%	72.9%	2.7%	12.1
Anderson & Case	1962	DC plasma jet	<10 kW	CH_4	H_2	Water spray	>90%	76%	not analyzed	88%	not analyzed	9.16
Holmes	1969	DuPont DC arc	9 MW	CH_4	H_2	not reported	not reported	70%	not reported		not reported	8.8
Ibberson & Sen	1976	DC plasma jet	<10 kW	CH_4	Ar	Wall heat transfer	>90%	82%	not reported	91%	not analyzed	9.0
Plotezyk	1983	DC plasma jet	10-40 kW	CH_4	H_2	Wall heat transfer	95%	80%	not analyzed	84%	not analyzed	15.5
Kovener	1983	RF plasma	4 kW	CH_4 & natural gas	He	Wall heat transfer	not reported	not reported	not reported	—	not reported	88
Plotezyk	1985	DC plasma jet	4-16 kW	CH_4	Ar	Wall heat transfer	>90%	86%	not reported	95%	not reported	23.9

The Claims

1. A method for carbon capture and recycling, the method including the steps of:

   (i) Capturing CO_2 from at least one CO_2 containing input;

   (ii) Producing a CO_2 feed stream from the captured CO_2; and

   (iii) Reacting the CO_2 feed stream with a H_2 feed stream to produce a methane containing output.

2. A method as claimed in claim 1, further including the step of

   (iv) Separating the methane containing output so as to at least provide methane and a first waste output.

3. A method as claimed in claim 2, wherein the first waste output is thermally treated to provide CO_2 for one of the at least CO_2 containing inputs for step (i).

4. A method as claimed in any one of claims 1 to 3, wherein one of the at least one CO_2 containing inputs includes air.

5. A method as claimed in claim 1, wherein the H_2 feed stream is provided by a water electrolysis process.

6. A method as claim in claim 5, wherein water produced during step (iii) is provided for the water electrolysis process.

7. A method as claimed in any one of the preceding claims wherein, in step (i), CO_2 is captured using a Calcium Oxide based capture process.

8. A method as claimed in any one of the preceding claims, further including the step of:

(v) Processing methane from the methane containing output to produce acetylene containing output.

9. A method a claimed in claim 8, further including the step of

(vi) separating the acetylene containing output so as to at least provide acetylene and a second waste output.

10. A method as claimed in claim 9, wherein the second waste output is thermally treated to provide CO_2 for one of the at least one CO_2 containing inputs for step (i).

11. A method as claimed in claim 8, wherein step (v) includes heating the methane with a thermal plasma reactor.

12. A method as claimed in any one of claims 1 to 7, further including the step of

(vii) processing methane from the methane containing output to produce a hydrocarbon containing output.

13. A method a claimed in claim 12, further including the step of

(viii) separating the hydrocarbon containing output so as to at least provide one or more preselected hydrocarbon products and a second waste output.

14. A method as claimed in claim 13, wherein the second waste output is thermally treated to provide one of the at least one CO_2 containing inputs for step (i).

15. A method as claimed in claim 12, wherein step (vii) includes heating the methane, and the methane is heated by a thermal plasma reactor configured such that plasma is provided in feed with the methane.

16. A system for carbon capture and recycling, the system including

a CO_2 capture apparatus configured to capture CO_2 from at least one CO_2 containing input;

a first reactor configured to produce a methane containing output from a CO_2 feed stream derived from the CO_2 capture apparatus and an H_2 feed stream.

17. A system as claimed in claim 16, further including:

a first separator configured to separate the methane containing output so as to at least provide methane and a first waste output.

18. A system as claimed in claim 17, further including a thermal treatment apparatus configured to treat the first waste output so as to provide CO_2 containing input for the CO_2 capture apparatus.

19. A system as claimed in any one of claims 16 to 18, wherein the CO_2 capture apparatus is configured to capture CO_2 from an air input.

20. A system as claimed in any one of claims 16 to 19, further including a water electrolysis device for producing the H_2 feed stream.

21. A system as claimed in claim 20, wherein the water electrolysis device is configured to receive water for electrolysis produced in the first reactor.

22. A system as claimed in any one of claims 16 to 21, wherein the CO_2 capture apparatus is a Calcium Oxide based capture apparatus.

23. A system as claimed in any one of claims 16 to 22 further including:

A second reactor configured to received methane produced in the first reactor and to produce an acetylene containing output therefrom.

24. A system as claimed in claim 23, further including:
a second separator configured to separate the acetylene containing output so as to at least provide acetylene and a second waste output.

25. A system as claimed in claim 24 when dependent on claim 18 wherein the second waste output is fed to the thermal treatment apparatus.

26. A system as claimed in any one of claims 23 to 25, wherein the second reactor is thermal plasma reactor.

27. A system as claimed in any one of claims 16 to 22 further including:

a second reactor configured to received methane produced in the first reactor and to produce a hydrocarbon containing output therefrom.

28. A system as claimed in claim 27, further including:

a second separator configured to separate the hydrocarbon containing output so as to at least provide preselected hydrocarbon products and a second waste output.

29. A system as claimed in claim 28 when dependent on claim 18, wherein the second waste output is fed to the thermal treatment apparatus.

30. A system as claimed in any one of claims 27 to 29, wherein the second reactor is a thermal plasma reactor configured provide plasma in feed with the methane.

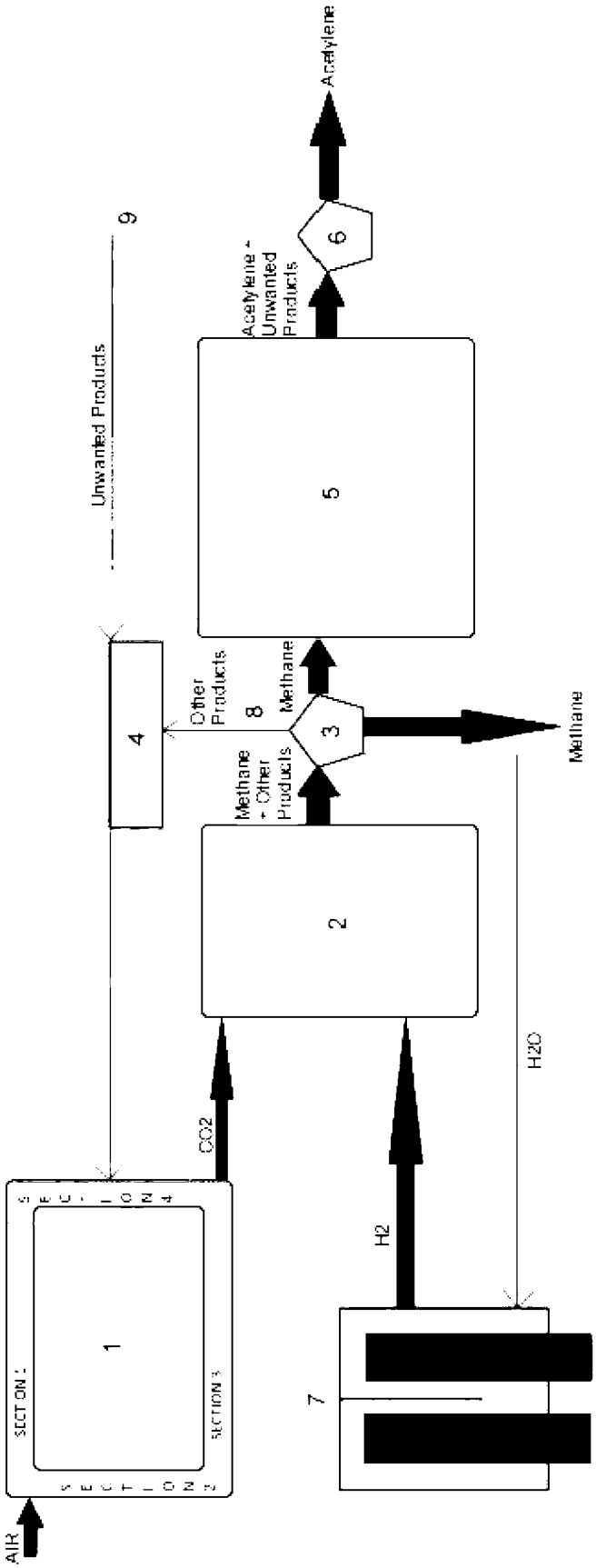
Acetylene
6
Acetylene + Unwanted Products
9
Unwanted Products
5
4
Other Products
8
Methane
3
Methane
Methane + Other Products
2
CO2
H2
H2O
7
AIR
SECTION 1
SECTION 2
SECTION 3
SECTION 4
1

Figure 1

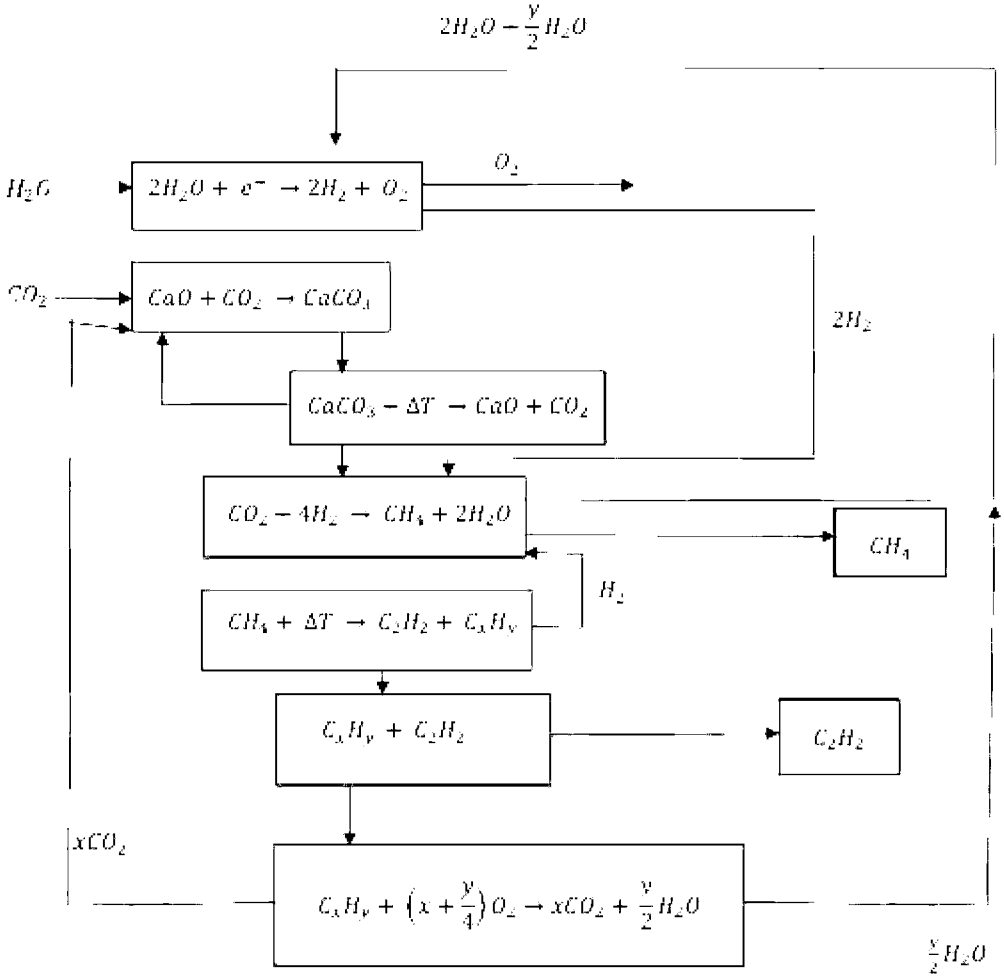
$2H_2O - \frac{y}{2}H_2O$
H_2O
$2H_2O + e^- \rightarrow 2H_2 + O_2$
O_2
CO_2
$CaO + CO_2 \rightarrow CaCO_3$
$2H_2$
$CaCO_3 - \Delta T \rightarrow CaO + CO_2$
$CO_2 - 4H_2 \rightarrow CH_4 + 2H_2O$
CH_4
H_2
$CH_4 + \Delta T \rightarrow C_2H_2 + C_xH_y$
$C_xH_y + C_2H_2$
C_2H_2
xCO_2
$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$
$\frac{y}{2}H_2O$

Figure 2

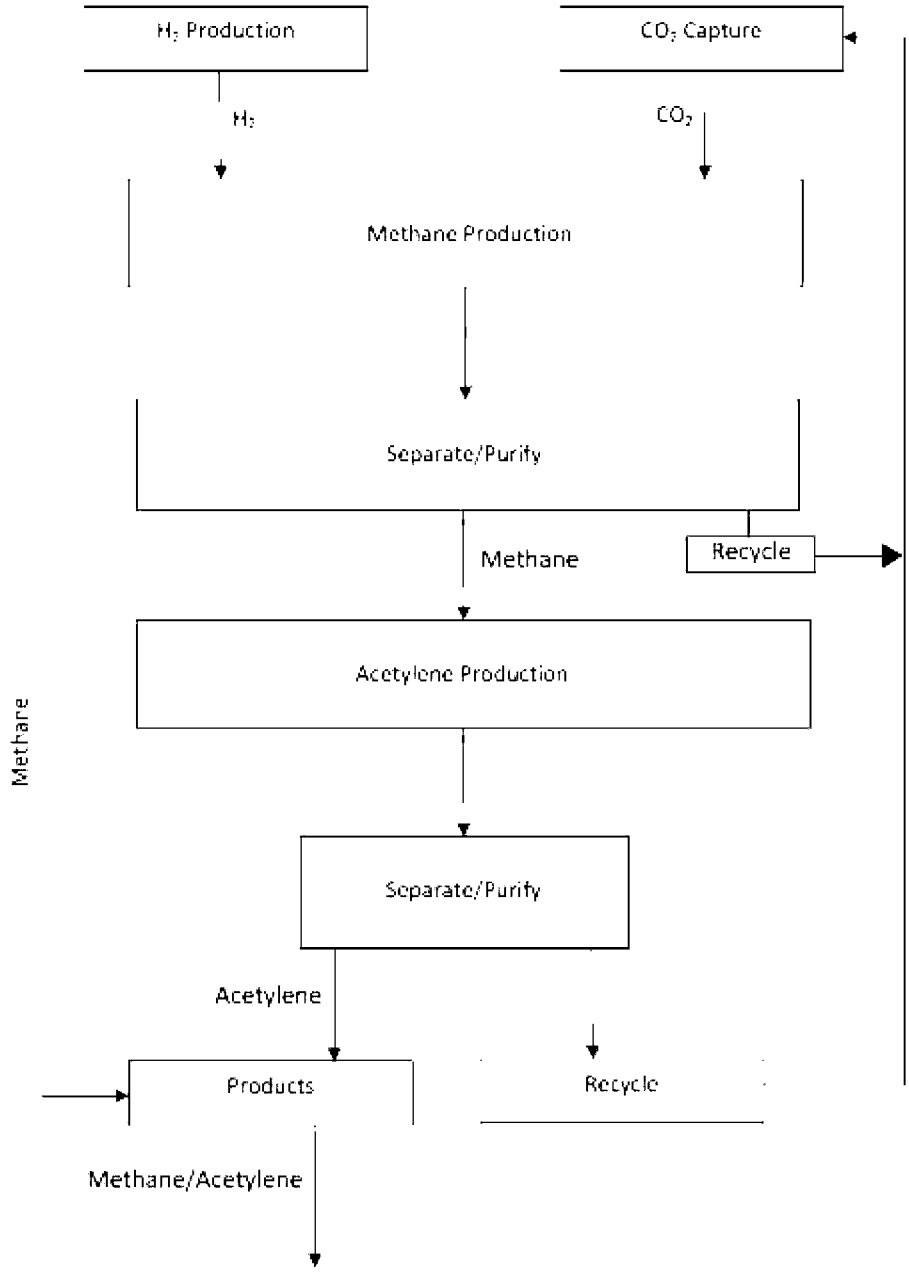
H_2 Production
CO_2 Capture
H_2
CO_2
Methane Production
Separate/Purify
Methane
Recycle
Acetylene Production
Methane
Separate/Purify
Acetylene
Products
Recycle
Methane/Acetylene

Figure 3

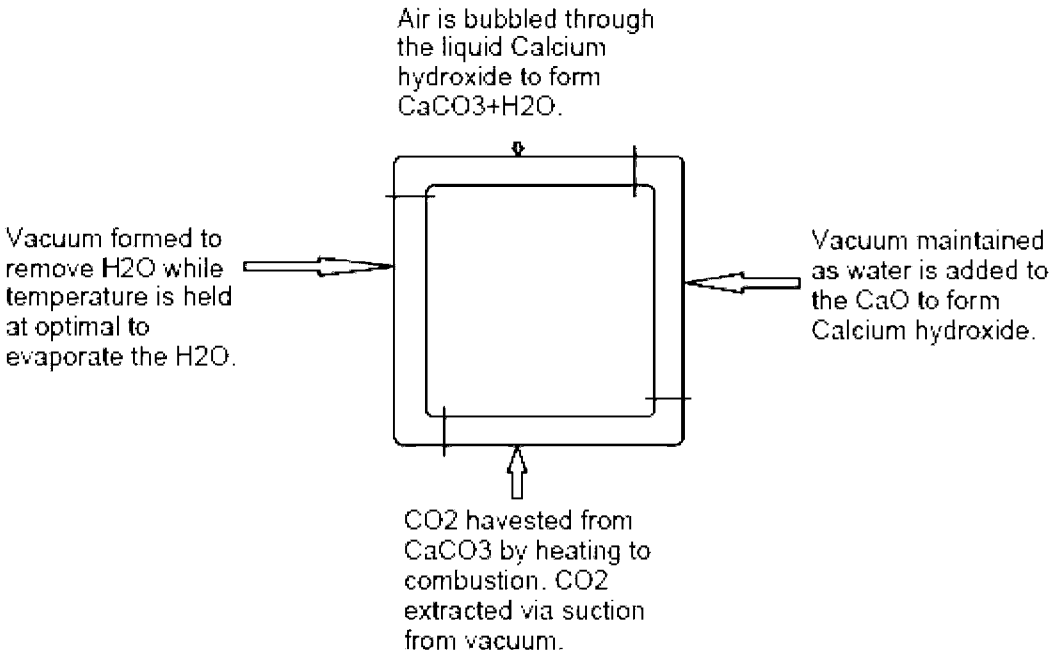
Air is bubbled through the liquid Calcium hydroxide to form CaCO3+H2O.
Vacuum formed to remove H2O while temperature is held at optimal to evaporate the H2O.
Vacuum maintained as water is added to the CaO to form Calcium hydroxide.
CO2 havested from CaCO3 by heating to combustion. CO2 extracted via suction from vacuum.

Figure 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2017/050613

A. CLASSIFICATION OF SUBJECT MATTER

C07C 1/12 (2006.01) B01D 53/62 (2006.01) C07C 11/24 (2006.01) C07C 2/76 (2006.01)

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)

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)

Database: PATENTW **IPC/CPC Symbols:** C07C1/12, C07C11/24, C07C2/76/low, C10G2/50, C10L2290/42, B01D53/62, B01D2251/404, C01B2203/1241, B01D53/14/LOW, Y02E50/34, Y02P20/152, B01D53/34 **Keywords:** METHANE, ACETYLENE, SABATIER, CARBON DIOXIDE, CALCIUM OXIDE and their like terms

Google Patents, Google, Google Scholar and Espacenet searched using a combination of the following: IPC/CPC symbols: C07C1/12, C7C11/24 and keywords: Sabatier, Plasma, Carbon Dioxide, Methane, Hydrogen, Acetylene and like keywords

Applicant/inventor search completed in ESPACENET, AUSPAT and internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[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
30 August 2017	30 August 2017
Name and mailing address of the ISA/AU	**Authorised officer**
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Thomas Yan AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. +61262832613

INTERNATIONAL SEARCH REPORT C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		International application No. **PCT/AU2017/050613**
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3488401 A (AMES) 06 January 1970 Fig. 1; col. 3, lines 1-8; col 2, lines 42-46, 58-62; col. 3, lines 1-8, 11-17	1-6, 8-21, 23-30
X	US 2016/0152528 A1 (BESTRONG INTERNATIONAL LIMITED) 02 June 2016 Figs. 2, 3; Paragraphs 34-36, 59-60	1-2, 8-9, 12-13, 16-17, 23-24, 27-28
X A	US 3852180 A (GREGORY) 03 December 1974 Figures; col. 1, line 58 to col. 2 line 7; col. 5, lines 48-51; col. 6, lines 10-28 Figures; col. 5, lines 48-51; col. 6, lines 20-28	1-6, 16-21 10, 14, 25, 29
X	US 2011/0237839 A1 (WALDSTEIN) 29 September 2011 Fig. 1; Paragraphs 27, 32, 36, 43, 72, 79-83, 87, 90, 103-105	1-2, 4-7, 16-17, 19-22
A	US 2014/0058149 A1 (UOP LLC) 27 February 2014 Fig. 5, paragraphs 61, 65	3, 10, 14, 18, 25, 29

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2017/050613**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
US 3488401 A	06 January 1970	US 3488401 A	06 Jan 1970
US 2016/0152528 A1	02 June 2016	US 2016152528 A1	02 Jun 2016
		CN 105315124 A	10 Feb 2016
		EP 3029016 A1	08 Jun 2016
US 3852180 A	03 December 1974	US 3852180 A	03 Dec 1974
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		EP 2888036 A1	01 Jul 2015
		IN 628DEN2015 A	26 Jun 2015
		MX 2015001602 A	07 May 2015
		SG 11201500565Y A	27 Feb 2015
		WO 2014031371 A1	27 Feb 2014

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.