

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
17 April 2008 (17.04.2008)

PCT

(10) International Publication Number
WO 2008/044056 A2

(51) International Patent Classification:
C10G 2/00 (2006.01) *C10L 1/00* (2006.01)
C07C 1/04 (2006.01)

(74) Agent: MCNEIGHT, David, L.; Brow Top, Lees Lane,
Wilmslow, Cheshire SK9 2LR (GB).

(21) International Application Number:
PCT/GB2007/003923

(22) International Filing Date: 11 October 2007 (11.10.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0620412.7 14 October 2006 (14.10.2006) GB
0622758.1 15 November 2006 (15.11.2006) GB

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant (*for all designated States except US*):
STRATOS FUELS LIMITED [GB/GB]; Hill Dick-
inson, 50 Fountain Street, Manchester M2 2AS (GB).

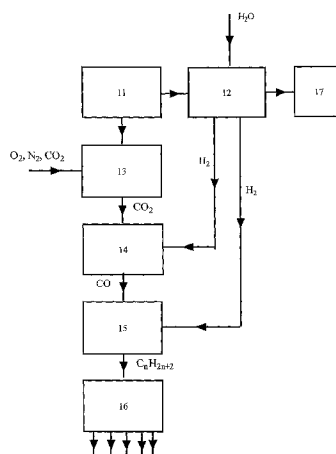
(72) Inventor; and

(75) Inventor/Applicant (*for US only*): MCNEIGHT, David,
Leslie [GB/GB]; Brow Top, Lees Lane, Wilmslow,
Cheshire SK9 2LR (GB).

Published:

— *without international search report and to be republished upon receipt of that report*

(54) Title: MANUFACTURE OF FUEL



(57) Abstract: A method for making a fuel comprises reacting hydrogen with carbon derived from an atmospheric carbon source, using renewable-source energy. Such fuel can be used in conventional engines and requires no new supply infrastructure, yet is carbon-neutral with a net-zero contribution to atmospheric carbon dioxide levels.

WO 2008/044056 A2

Manufacture of Fuel

This invention relates to the manufacture of fuel.

The use of fossil, carbon-based fuels is implicated in global climate change by the release of carbon dioxide, which traps heat in the atmosphere - the so-called greenhouse effect. Carbon dioxide concentration has increased from about 280 ppm to about 380 ppm over the last two centuries.

Mineral oils can be substituted by vegetable oils. Biodiesel can be made from palm oil, soya bean oil, corn oil and other vegetable oils. These can be made for about the same price as mineral oil fuels, and are, of course, carbon neutral inasmuch as atmospheric carbon dioxide is merely recycled through the plant growth-fuel manufacture-fuel burning processes. Ethanol made from biomass is also a useful liquid fuel. These biofuels, however, cannot be produced in sufficient quantity to satisfy more than a small fraction of the demand for fuel.

Hydrogen is promoted as an alternative, eco-friendly fuel, the sole product of combustion being water. Water is, of course, a prime source of hydrogen and is abundant. Hydrogen, as well as oxygen, can be made from water by electrolysis. Sea water is ideal, being saline, and hence conductive. Electricity is, of course, required, but can be produced without consumption of carbon-based fuels, for example from wind turbines or solar energy, as well, of course, as nuclear energy.

Hydrogen is not an ideal fuel, however. It is a gas at normal temperatures and pressures, and, having an extremely low boiling point at -253°C , cannot be liquefied, or stored or transported as a liquid, without costly cryogenic systems. It can be used in internal combustion engines, including piston engines and gas turbines, but it burns at a lower temperature than, and does not give as much power as, hydrocarbon fuels such as gasoline and diesel.

The present invention provides a method for making an improved fuel from hydrogen, which retains the ecological advantages.

The invention comprises a method for making a fuel comprising reacting hydrogen with carbon derived from an atmospheric carbon source, using renewable-source energy.

By 'atmospheric carbon source' is meant a source which is, or which is entering, the atmosphere. 'Renewable-source energy' is deemed to include nuclear energy, as being equivalent inasmuch as it does not use fossil fuel and does not emit greenhouse gas. Nuclear energy from a breeder reactor is, of course, a literally renewable-source.

The carbon source may be atmospheric carbon dioxide derived from the growing reservoir of carbon dioxide in the atmosphere, or carbon dioxide or carbon monoxide in the course of being released to the atmosphere by the burning of fossil fuel such as coal or oil or natural gas, or,

eventually, by the burning of fuel made according to the invention. There is a lower energy requirement for the recovery of carbon oxides from gases such as flue and exhaust gases that have a high concentration of such oxides than for the extraction of carbon dioxide from the atmosphere, where its concentration is relatively low, albeit too high, and increasing, for environmental comfort. However, such sources contain impurities, especially sulphur, that must be removed expensively. Extracting carbon dioxide from gases derived from burning fossil fuels is, of course, not an answer to the problem of atmospheric carbon dioxide build up, as the carbon finishes up in the atmosphere in any event, but it may to some extent reduce demand for new fossil fuel production, and may be a stop-gap measure on the way to completely carbon-neutral synthesized hydrocarbon fuels

Energy is, of course, required to recover carbon dioxide from the atmosphere and also to react it with hydrogen to produce a hydrocarbon, but this energy can be produced from renewable, non-fossil sources such as hydroelectric, solar, wind, tide, wave and nuclear energy.

Carbon dioxide may be recovered from the atmosphere cryogenically or by absorption into lime, from which it can be chemically separated. It may also be separated from other atmospheric gases using semi-permeable membranes.

Using atmospheric carbon dioxide means that, even though the end product is a hydrocarbon fuel, which releases carbon dioxide when it is combusted, just like fossil fuels, the whole process is carbon-neutral - there is a net zero addition to atmospheric carbon dioxide. Even when the carbon is derived from vegetation, as, for example, from wood charcoal, the process is still carbon neutral, as atmospheric carbon dioxide is the source of the wood carbon. Carbon recovered from burning fossil fuels is not, of course, neutral, but its recovery for re-use reduces the reliance on fossil fuels, and while such are burned makes a contribution to the control of atmospheric carbon dioxide.

Hydrocarbons may be produced from hydrogen and carbon monoxide using Fischer-Tropsch synthesis. Carbon monoxide may be produced from carbon dioxide by reaction with hot carbon, which may be produced, as charcoal, from wood, or by reaction of carbon dioxide with hydrogen to form carbon monoxide and water.

None of this is inexpensive, in commercial terms. Carbon dioxide can be recovered from the atmosphere, but it is an expensive way to produce carbon dioxide as compared to simply burning something. Recovery of carbon dioxide from the atmosphere for sequestration underground or as carbonates is, however, seriously mooted as a practical measure to combat global warming, a major problem being where and how to sequester it.

The production of hydrogen using solar power has a high capital cost, as, indeed, does almost any electricity generation from renewable energy sources. For the method of the invention, however, for making fuel, capital cost, overheads and running and transportation costs are the only substantial costs, the raw materials being, generally speaking, free.

Renewable energy power arrangements are frequently characterised by intermittent operation. Solar energy is available only for half a day, on average, and, unless steerable collectors are used, is variable during daylight hours.

5 The invention also comprises a renewable power arrangement capturing renewable power for the manufacture of fuel, in which the power arrangement supplies a fraction of its power to a fuel manufacturing plant and a fraction of its power to a store, the plant drawing on stored power when the power arrangement is not producing usable power.

10 In this way, a smaller manufacturing plant, with a lower capital cost, can be used.

In one arrangement, hydrogen produced by electrolysis during sunlit hours is used as by burning to generate heat for chemical reactions used in the manufacturing process and/or by generating electric power, using fuel cells, to drive compressors or other such equipment.

15 The manufacture of hydrocarbons based on hydrogen generation by electrolysis and recovery of atmospheric carbon dioxide may involve cryogenic separation of carbon dioxide from atmospheric air. This requires mechanical energy, the cooling process involving adiabatic cooling by expansion of compressed gas that has been cooled, after adiabatic heating through compression, by heat exchange with, for example, ambient air. The mechanical energy may
20 come from hydrogen-powered fuel cell-driven electric motors, using hydrogen produced by electrolysis. Or the hydrogen might be used as fuel for a heat-driven refrigeration system. However, electrical energy from a solar array might be stored in batteries for overnight use. As the chemical reactions used to generate hydrocarbons from hydrogen and carbon dioxide are carried out at elevated temperature, hydrogen might be burned to generate the temperatures
25 required.

Generally speaking, conversion of energy from one form to another involves losses. A fuel manufacturing plant may be arranged to operate as efficiently as possible from this point of view by involving as few conversions as possible. However, capital costs, maintenance and running
30 costs also have to be taken into account, and some conversion losses may be accepted on that basis.

Hydrocarbons synthesized in this way may comprise a single hydrocarbon, such as ethane or octane, or a mixture of hydrocarbons. From such a mixture, conventional cracking or distillation
35 processes may be used to produce required blends suitable for different fuel burning engines, such as gasoline, diesel, kerosene, avtur and the like.

The invention also comprises hydrocarbon fuel made from carbon derived from an atmospheric source. The fuel may comprise a single hydrocarbon or a mixture and may comprise additives
40 similar to those used in gasoline, diesel and other mineral-oil derived hydrocarbon fuels. Hydrocarbon fuels made by Fischer-Tropsch synthesis can be characterised by high purity.

The invention also comprises apparatus for making hydrocarbon fuel comprising carbon-producing means for producing carbon from an atmospheric source and hydrogen conversion

means for converting hydrogen to a hydrocarbon using carbon from said carbon-producing means, and a renewable energy source adapted to power at least one of said carbon-producing means and said hydrogen conversion means.

- 5 The apparatus may comprise a hydrogen producing plant, which may be powered from a renewable energy source.

10 The carbon-producing means, the hydrogen producing means, the hydrogen conversion means or any two of them, may be located together on a single site, optionally with a source of renewable electrical energy. The energy source is desirably located for optimum operation. A solar energy source may be located in a region where sunlight is plentiful, in a desert, for example, preferably in the tropics. Water can be pumped, using the solar energy, from a sea or ocean source to the hydrogen producing plant, which might be located near the sea or ocean source, electricity being delivered from, say, a desert-located solar or photovoltaic array, which might be of the order of 15 1 km square. Carbon dioxide can be extracted from atmospheric air cryogenically, again using the solar-generated electricity, and converted to carbon monoxide and then one or more hydrocarbons, all in the same location.

20 The choice of location depends to some extent on the nature of the renewable energy source. A nuclear plant may be located in a remote region, instead of near to population centres - water and air, the prime raw materials, can be sourced almost anywhere. Pipelines carrying 'refined' products are easier to maintain than pipelines carrying crude oil.

25 However, by using atmospheric moisture as the source of water, locations remote from water sources may be viable, and the invention also comprises a method for making a fuel comprising reacting hydrogen made from water recovered from atmospheric moisture with carbon derived from an atmospheric carbon source, using renewable-source energy.

30 If the carbon is derived from cryogenically separated carbon dioxide, water may also be recovered cryogenically, as part, even, of the same cooling step. Water will separate out first, of course, carbon dioxide at a lower temperature.

The invention also comprises fuel made by a method or by apparatus as set out above.

- 35 Methods and apparatus for making fuel according to the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic illustration of a basic system for producing hydrocarbon fuel;

40 Figure 2 is a diagrammatic illustration of a solar powered plant;

Figure 3 is a diagrammatic illustration of a nuclear powered system;

Figure 4 is a diagrammatic illustration of another embodiment of a system; and

Figure 5 is a diagrammatic illustration of a system recovering water as well as carbon dioxide from the atmosphere.

- 5 The drawings illustrate methods and apparatus for making fuel comprising reacting hydrogen with carbon derived from an atmospheric carbon source, using renewable-source energy.

Figure 1 illustrates a general method in which a renewable energy source 11 supplies electric power to a hydrolysis plant 12, which splits water into hydrogen and oxygen. The oxygen is of
10 no further interest to the method, and can be back to atmosphere or collected in store 17 and sold on. The source 11 also supplies electric power to a separator 13, which separates carbon dioxide from atmospheric air. Depending on the process for doing this, oxygen and nitrogen may be recovered for selling on, or may simply be returned to the atmosphere. The process may be cryogenic, to cool the air to the boiling or freezing point of carbon dioxide. A chemical process
15 may be used, however, such as reaction with an hydroxide solution.

Carbon dioxide from separator 13 and hydrogen from electrolyser 12 are delivered to reactor 14 where the carbon dioxide is reduced to carbon monoxide, which is delivered to a second reactor 15. The by-product of the reactor 14 is simply water.
20

In reactor 15, the carbon monoxide is reacted with hydrogen from electrolyser 12 to hydrocarbons by the Fischer-Tropsch reaction.

The reactions in reactors 14 and 15 take place in the presence of a catalyst and under heat and pressure. Heat may be generated by electric power from the generator 11 or by burning hydrogen with atmospheric air or oxygen produced by the electrolyser.
25

The hydrocarbons from reactor 15 may be mixtures, depending on the reaction conditions, of several hydrocarbons including ethane, pentane, octane and so forth, which may be separated by
30 cracking or distillation as in conventional refineries and remixed for various fuel uses to match mineral oil-derived fuels.

Figure 2 illustrates power generation from solar energy by solar panel 21, which can be an assembly of, say, 1 million one metre square panels, located in a desert region. At midday, the
35 enrgy flux from overhead sunlight is about 1 kilowatt per square metre, so the daily output of a square kilometer is 1000 megawatts multiplied by the panel conversion efficiency multiplied by the number of effective overhead hours, which is about 8, so the daily output is somewhere in the region of 280 megawatt hours. For transmission over a distance, the dc current produced by the panel 21 can be converted to ac, or, to minimize losses, it can be sent as dc over a
40 superconductive line maintained at a low temperature by liquid hydrogen derived fro the electrolyser 12, which is located close to a sea or ocean coast to reduce pumping costs. As before, the hydrogen and carbon dioxide are reacted - the reactors 14 and 15 are shown as a combined unit - to produce hydrocarbons which can be stored in a tank farm 18.

Figure 3 illustrates a nuclear power station 31 as the power source, which can be situated virtually anywhere, if desired, remote from habitation. If it is on a coast, the entire plant can be on a single site.

However, also illustrated in Figure 3 is the collection of carbon dioxide and carbon monoxide in a scrubber 32 of a conventional, say, coal or oil burning power station 32, supplying reservoirs 33, 34 from which the gases may be delivered by pipeline and/or vehicular transport to add to the carbon oxides produced in units 13, 14. While this is clearly not carbon neutral, inasmuch as the carbon is derived from fossil fuel, the carbon is recycled and reduces demand for fossil fuel. It is seen as a temporary expedient, helping to reduce fossil fuel usage and reduce the time till fossil fuel independence.

Although, in each of these embodiments, capital costs will be high, the raw materials are essentially free. By continuing to be able to use conventional gasoline, diesel, kerosene and avtur burning engines, which have been highly developed over many years, and by avoiding the need to build a parallel and expensive infrastructure to deliver fuel to the roadside, massive new investment required for alternative fuels such as hydrogen will be avoided.

Figure 4 illustrates an embodiment in which capital costs can be reduced by having a synthesis plant smaller than would be required to cope with peak hydrogen and carbon dioxide production. The drawing illustrates a hydrocarbon fuels manufacturing plant comprising a solar array 11 generating electricity which is used to generate hydrogen in an electrolyser 12 supplied with water, for example sea water, which is saline and therefore electrically conductive. The salt content of the sea water will, of course, have to be dealt with.

A waste product of this operation is oxygen, which, however, might be recovered for sale or use elsewhere in the arrangement.

The hydrogen produced in electrolyser 12 is split into two fractions. One part is sent to a store 14, the other part to a reactor 17, which is supplied with carbon dioxide from a cryogenic plant 18 which takes in atmospheric air. By products, or waste products, are oxygen and nitrogen. The plant 18 is powered by electricity from a battery 13 supplied from the array 11. The battery 13 has such capacity as will keep the plant 18 running through the hours when the solar array is not producing usable power.

The reactor operates at elevated temperature and pressure. Pressure is maintained by a pump 19 deriving power from the battery 13, heat from a heater 16 supplied with hydrogen from the store 15.

The reactor 17 delivers hydrocarbons and a waste or by-product, oxygen. Oxygen from somewhere in the system can be used in the heater 16 to burn the hydrogen more efficiently.

Some hydrogen from the store 14 can be converted to electric power by a fuel cell 15. Instead of the battery 13, which may need to be quite bulky and require a lot of maintenance, the fuel cell

arrangement 15 may be larger and power the cryogenic plant 18 when not supplied directly from the solar array 11. The pump 19 could also be powered in this way, and the battery 13 dispensed with..

- 5 As nuclear power can be generated constantly, the provision of stored energy to drive the plant when power is not being generated is clearly not required, but other energy sources are intermittent, and a plant driven e.g. by wind or wave power would clearly benefit. These sources tend not to be regular, as does solar power, and the optimum storage capacity required for reasonably constant hydrocarbon output would need to be worked out on the basis of the wind or
10 wave regime at the plant's location.

- Figure 5 illustrates a plant in which electrical energy from a solar array 11 powers a cooler 51, which condenses water from the atmosphere and, taking the temperature further down, separates carbon dioxide. The water is split by electrolysis into hydrogen and oxygen, the hydrogen being
15 sent to a reactor 14/15, as before to produce hydrocarbons. The electrolysis plant 12 and the reactor 14/15 are powered from the solar array 11, either directly, or indirectly as described with reference to Figure 4.

- In a variant, the water is split by heat into hydrogen and oxygen in a more complex reactor 14/15,
20 avoiding the electrolysis step, which might be problematic using water condensed from the atmosphere, which will, of course, have no ion content. Of course, high temperature dissociation of water, rather than electrolysis, could also be used in the other embodiments.

Claims:

- 1 A method for making a fuel comprising reacting hydrogen with carbon derived from an atmospheric carbon source, using renewable-source energy.
- 5 2 A method according to claim 1, in which the carbon source comprises atmospheric carbon dioxide.
- 10 3 A method according to claim 1 or claim 2, in which the carbon source comprises gas from the combustion of fossil fuel.
- 4 A method according to any one of claims 1 to 3, in which the carbon source comprises vegetation.
- 15 5 A method according to any one of claims 1 to 4, in which a carbon oxide gas is won cryogenically.
- 6 A method according to any one of claims 1 to 5, in which carbon is won chemically.
- 20 7 A method according to any one of claims 1 to 6, in which the renewable source energy comprises solar energy.
- 8 A method according to claim 7, in which the solar energy is derived from solar panels in an area such as a desert where sunlight is plentiful.
- 25 9 A method according to any one of claims 1 to 8, in which the renewable source energy comprises nuclear energy.
- 10 10 A method according to any one of claims 1 to 9, in which the carbon dioxide is converted to carbon monoxide which is reacted with hydrogen in a Fischer-Tropsch reaction to make at least one hydrocarbon.
- 30 11 A method according to any one of claims 1 to 10, in which a product which is a mixture of hydrocarbons is cracked or distilled to produce pure hydrocarbons.
- 15 12 A method according to any one of claims 1 to 11, in which a predetermined mix of hydrocarbons is produced to substitute for a conventional mineral oil derived fuel.
- 0 13 A renewable power arrangement capturing renewable power for the manufacture of fuel, in which the power arrangement supplies a fraction of its power to a fuel manufacturing plant and a fraction of its power to a store, the plant drawing on stored power when the power arrangement is not producing usable power.
- 14 An arrangement according to claim 13, in which hydrogen produced by electrolysis of

water using solar power during sunlit hours is used to produce hydrocarbon fuel by reaction with atmospheric carbon dioxide (whether directly or *via* an intermediate operation converting carbon dioxide to carbon monoxide).

5 15 An arrangement according to claim 14, in which solar electricity is stored in a battery for use when the solar power is not available.

16 An arrangement according to claim 14 or claim 15, in which hydrogen is stored for conversion to electricity,

10

17 An arrangement according to claim 16, in which the hydrogen is converted to electricity using a fuel cell arrangement.

18 An arrangement according to claim 16 or claim 17, in which the hydrogen is converted to electricity using a rotary generator driven by combusting hydrogen,

15

19 An arrangement according to any one of claims 13 to 18, in which hydrogen is burned to produce heat for endothermic reactions carried out at elevated temperature.

20 20 Fuel produced by an arrangement according to any one of claims 13 to 19.

21 Fuel according to claim 20, comprising hydrocarbon fuel made using atmospheric carbon.

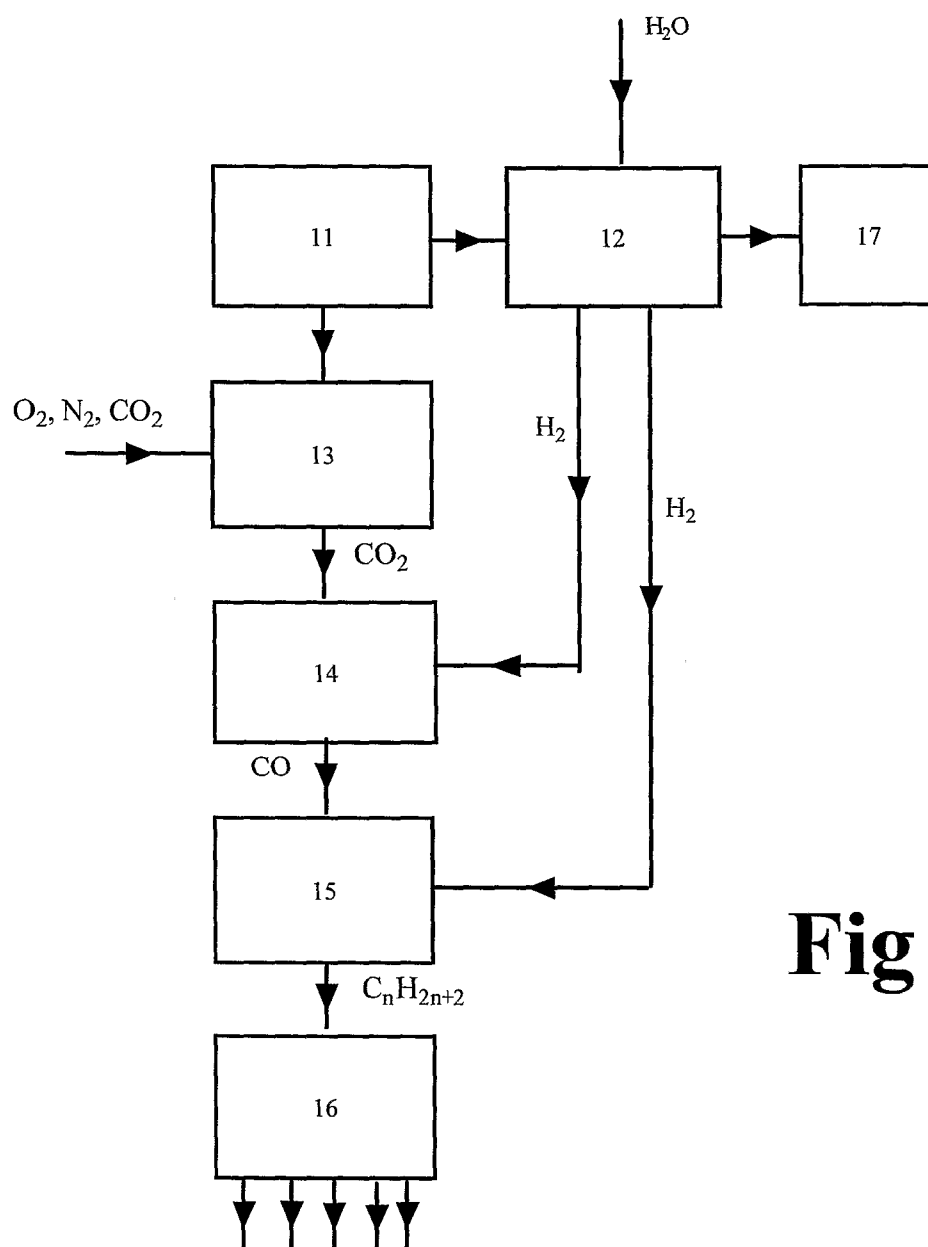
23 A method for making a fuel comprising reacting hydrogen derived from atmospheric moisture with carbon derived from an atmospheric carbon source, using renewable-source energy.

25

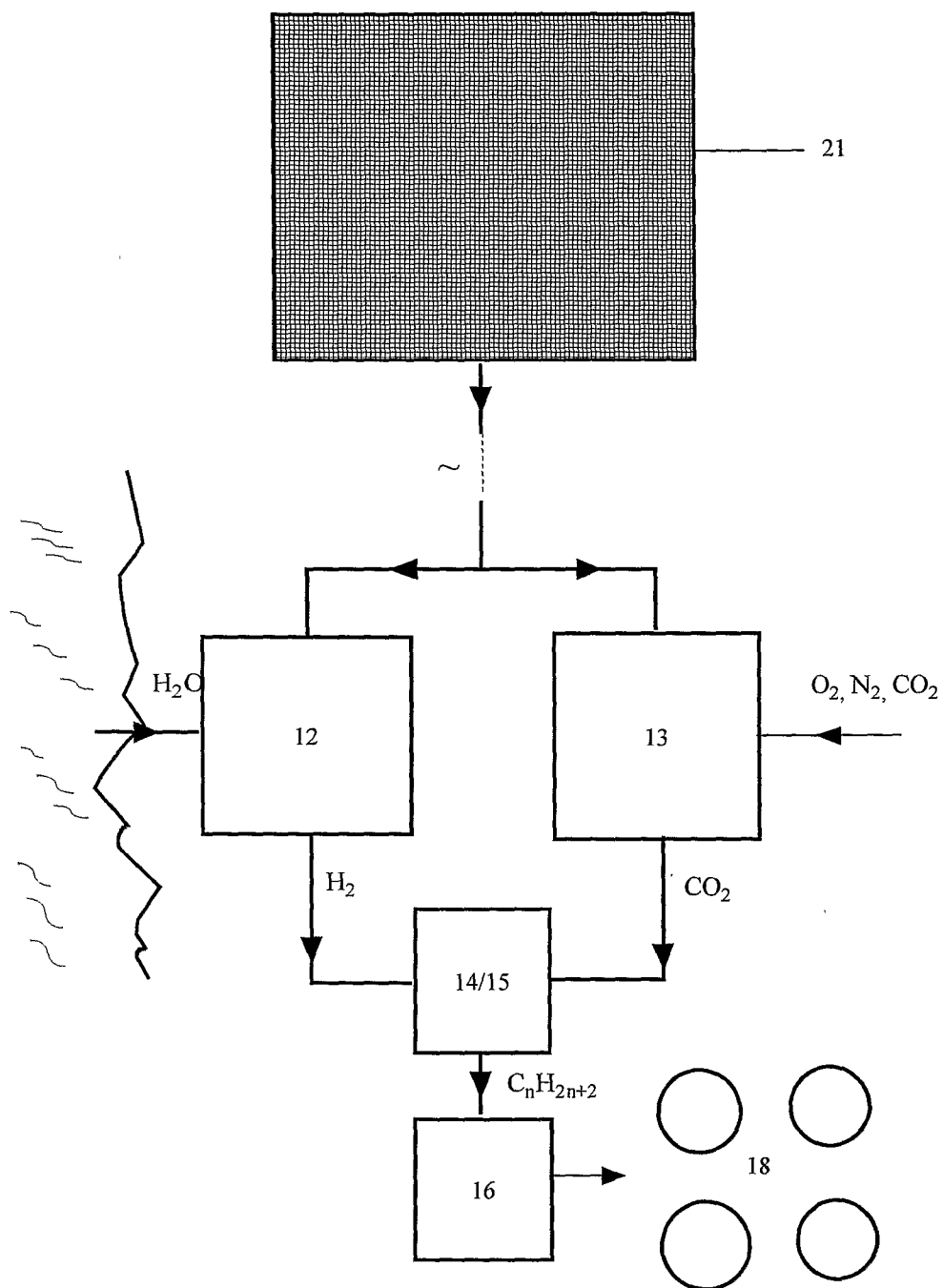
24 A method according to any one of claims 1 to 12, or an arrangement according to any one of claims 13 to 19, using hydrogen derived from atmospheric moisture.

30

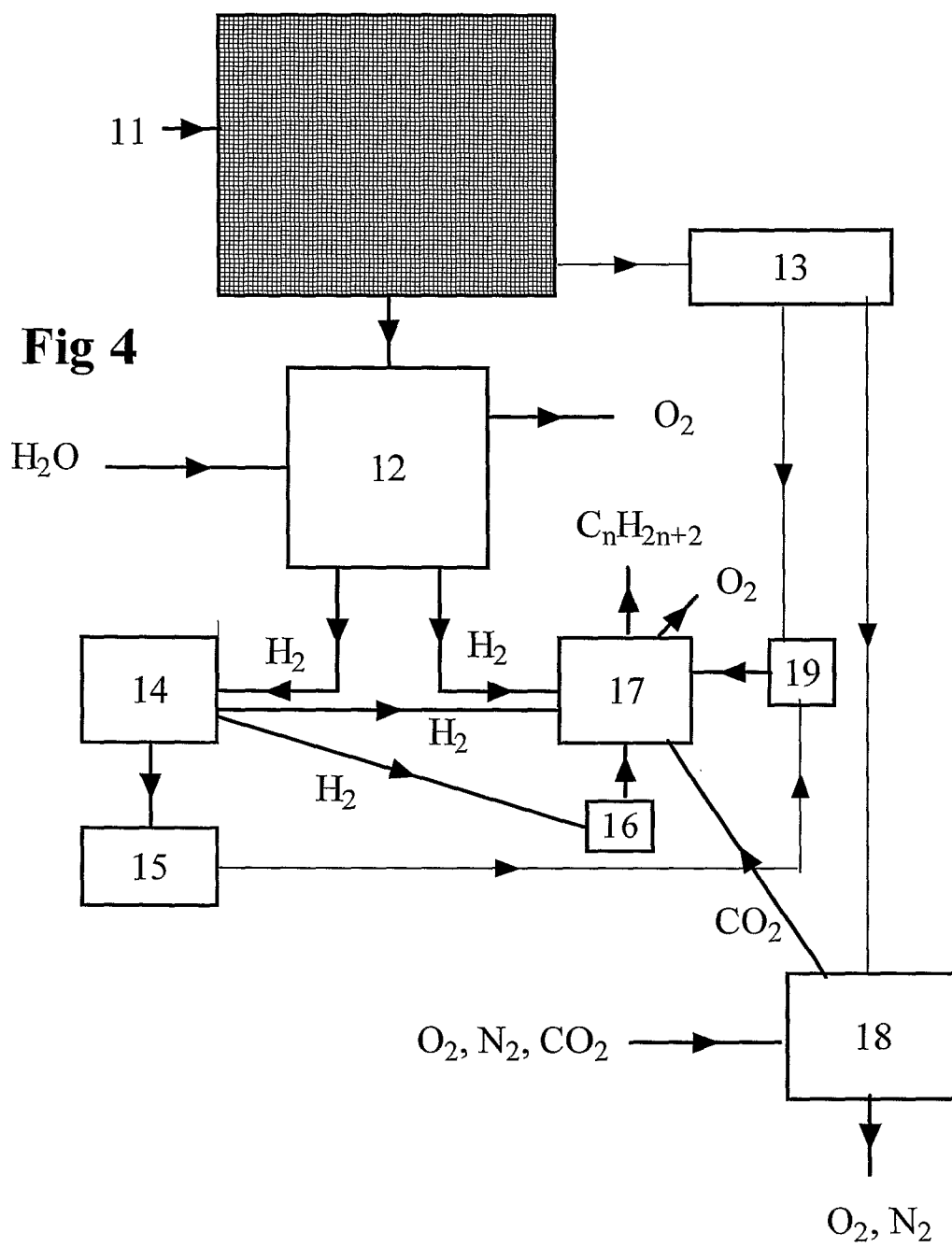
25 Fuel according to claim 20 or claim 21, made using atmospheric moisture.

1/5**Fig 1**

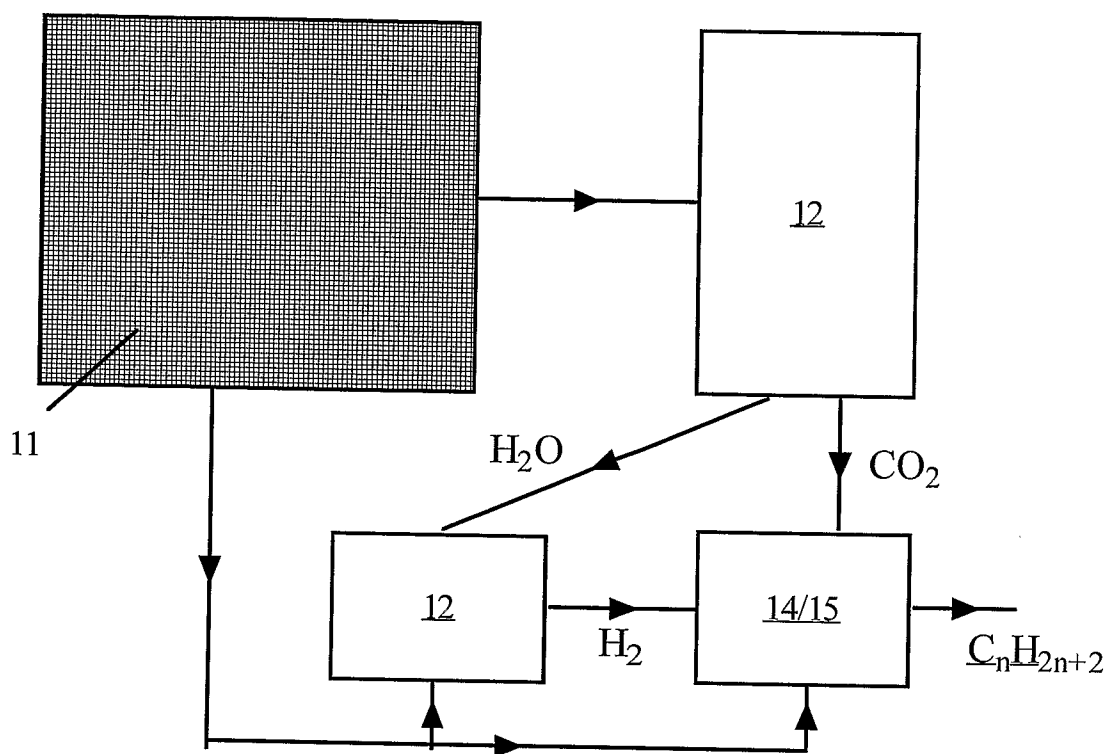
2/5

**Fig 2**

4/5



5/5

**Fig 5**