



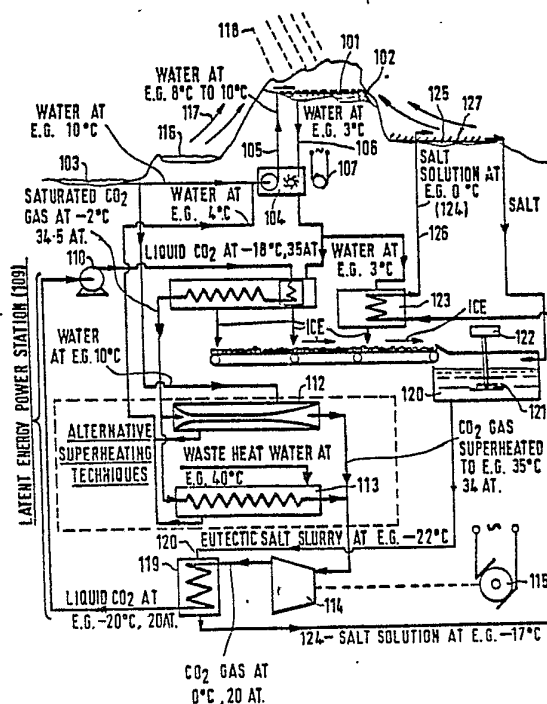
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ³ : F03G 7/04; F01K 25/10; F24J 3/02; F22G 1/00	A1	(11) International Publication Number: WO 80/01593 (43) International Publication Date: 7 August 1980 (07.08.80)
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(54) Title: APPARATUS FOR AND METHODS OF GENERATING ELECTRICAL POWER

(57) Abstract

Electric power generation apparatus comprises a closed circuit through which a working fluid such as carbon dioxide is conducted in a working cycle such as the Rankine cycle between a hot and a cold reservoir which receive heat from their environment and are capable of releasing heat isothermally. In one embodiment a hot reservoir (101) of water under natural environmental conditions at or immediately above 0°C releases its latent heat of fusion to boil the working fluid. A cold reservoir (120) of a eutectic salt/ice slurry at -22°C also under natural environmental conditions provides a supply of slurry for cooling the working fluid in the condenser (119), ice in the slurry being melted by extracting its latent heat of fusion from the working fluid.



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APPARATUS FOR AND METHODS OF GENERATING ELECTRICAL POWER

The present invention relates to the generation of electrical power.

5 Electrical power produced in accordance with the present invention is intended for direct transmission to national and local electrical distribution grids; however the present invention also provides additionally for the generation of mechanical power: thus, in some
10 embodiments, the invention may be used for example to lift large masses of water to elevated reservoirs whereby such water may be used in emergency drought situations for drinking, washing, irrigation and fire-fighting as well as for hydro-electric conversion to
15 electrical power; in yet other embodiments the present invention may be used to collect and store large quantities of substances whose chemical and physical properties are valuable in motive power-producing systems, for example to power cars and trains. Such
20 power-producing systems are described more fully in my U.K. Application No. 35603/78 which is incorporated herein for reference and which disclosed a car employing calcium chloride as a heat sink and calcium as fuel: the present invention discloses a particular
25 embodiment in which calcium chloride is collected and stored in large quantities; not only for use in the said embodiment of the present invention, but also for later



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use in cars, trains and ships etc. (wherein some of the calcium chloride has been electrolysed to produce the calcium fuel) as described in U.K. Application No. 35603/78.

5 All forms of terrestrial energy as now used to generate electricity, to provide heating and to provide motive power for cars, trains and ships etc. are, the present invention argues, derived from stored solar energy. Examples of this argument are the biological storage of
10 solar energy in wood, coal, oil and gas; the meteorological storage of solar energy in rainfall collected in hydro-electric power installations and in the kinetic energy of winds and waves; the short term gravitational storage of solar energy in tides; and the
15 long term thermal storage of solar energy (at the time the Earth was formed) as geothermal heat. It may even be argued that uranium deposits, and the traces of hydrogen isotopes present in terrestrial water, are consequences of high-temperature nuclear processes which occurred
20 during the formation of the solar system and, therefore, again represent stored solar energy.

Despite the energy crisis, the great majority of our energy still comes from coal, oil, gas and uranium. These sources of energy are, the present invention
25 proposes, not only very short-lived but also very inefficient when seen as methods of storing solar energy. Thus, in my U.K. Application No. 40639/78 entitled "Energy from sky heat exchange", it was calculated that electricity produced by coal-fired power stations was, in
30 effect, solar energy converted to electricity at only about 0.8% efficiency and that solar energy stored in the form of coal is being depleted at a rate of about a million times faster than the rate at which the coal was created; and that the overall conversion efficiency
35 of solar energy into electricity via oil and gas-fuelled power stations was unlikely to be greater than 0.001%.



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Likewise, the present invention proposes that if due regard is given to the solar energy input which was required during the formation of the solar system in order to create uranium deposits and hydrogen isotopes the overall conversion efficiency of present atomic fission and future atomic fusion power stations may be as low as 0.0001% to 0.00001%.

Therefore conventional energy sources such as coal, and especially oil, gas and nuclear power, will come to be seen as extremely inefficient short-term stratagems, justified only on grounds of expediency, and any lasting source of renewable energy must, in the long term, rest upon much more effective methods of capturing, storing and converting solar radiation.

The present search for renewable sources of energy appears to be concentrated in two broad areas: firstly those which may be termed "indirect conversion" of solar radiation and which include wind power, wave power, thermal gradients in deep water, biomass, ethanol and methanol production, photo-chemical production of hydrogen from ammonia etc., and of course hydro-electric power; and secondly those which may be termed "direct conversion" of solar radiation and which include solar panels for heating water, solar power stations which concentrate collected solar radiation to boil a working fluid, and photo-voltaic cells producing electricity.

Unfortunately, most of the above do not produce what is often termed "hard" power, that is, power produced at the time that it is needed: they are therefore unattractive for want of a means of storing the energy they produce, until such time as it is needed. For example, wind speeds are often low during clear frosty weather when electrical demand is at its highest; thermal gradients in deep water are smaller at the northerly



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and southerly latitudes where electricity is needed in populous areas; and the sun is often obscured at the very time that hot water and electrical heating is needed. Those of the above that overcome this problem by, in effect, storing the energy they have collected from the sun, unfortunately suffer from other disadvantages: for example, the production of biomass and ethanol from vegetation requires large areas of arable land that could be used for vital food production in many countries; the storage of ethanol and hydrogen poses quite severe problems of safety and, in the case of methanol, toxicity; hydro-electric schemes require large areas of land at a relatively low altitude that could often be used for habitation and agriculture; and hot water from solar panels tends to cool down rather rapidly, especially in cold weather when it is needed.

In addition the renewable sources of energy which rely on "direct conversion" of solar radiation into electricity, e.g. solar power stations and photo-voltaic cells, are very expensive in terms of capital cost and land usage. For example, very large (and thus least expensive in unit terms) solar power stations now being designed in the U.S.A. are expected to be competitive in cost terms with only the most expensive alternatives for "peak-logging" of electrical demand in the 1990's; again at Odeillo in the French Pyrénées, the sunniest place in France, a new solar power station will require 50 acres of mirrors on land valuable for livestock rearing in order to generate only 3MW, a bare 2% of Roussillon's needs; yet again, the most recent photo-voltaic power panels being produced by Ferranti Electronics are offered at a price (in quantity) which equals approximately £9500 per installed kilowatt (and this compares with less than £1000 per installed kilowatt for nearly all our present and projected power stations)



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and have a rated output of only 75 watts per square metre approximately whereas - the present invention will disclose - it is relatively easy to produce such an output from naturally-occurring land of negligible value for any other purpose, and at very low capital cost of equipment, with inherent means which in effect store solar energy for months or years.

The present invention is based on fundamental principles and necessary consequences which are described and disclosed respectively as follows:

1. The solar constant for the Earth (the average rate at which solar energy falls on a surface positioned on the line of the Earth's orbit and facing directly at the sun) of 1.35 kw/m^2 is the greatest rate at which energy can be collected on Earth at mid-day.
2. In consequence of the changing elevation of the sun during daytime and the latitude of a given point on the Earth's surface, the average rate at which energy can be collected in daytime cannot be greater than $1.35 \times 2/\pi = 0.86 \text{ kw/m}^2$ at the Equator and in the Tropics, and will decrease from this peak value with increasing latitude.
3. Atmospheric attenuation (especially haze and cloud) causes the solar energy rate to fall, at ground level, to average levels near zero under heavy cloud, 0.1 to 0.2 kw/m^2 in European latitudes on clear days, and 0.3 to 0.5 kw/m^2 in low-lying tropical desert regions on clear days.



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4. In consequence the solar energy rate will be highest on clear days near the tops of the highest mountains, where it may reach a peak of 1.0 kw/m^2 and an average of 0.64 kw/m^2 typically.
5. The rate at which incident solar radiation energy may be absorbed by any material is limited by the power absorptivity and the absolute temperature of the said material.
- 10 6. In consequence and in general, wherever material is used to absorb incident solar radiation energy in order to provide a source of heat for e.g. a thermodynamic power-producing system, the rate at which the said material may absorb the said energy will be greater if the said material has a high coefficient of power absorptivity and is colder than its surroundings.
- 15 7. In consequence, a preferred material for use as an absorber of solar radiation energy for use in a thermodynamic power-producing system will be a material having a power absorptivity coefficient approaching 1.0 (at which figure it would be termed an "ideal black body") and having the capacity to absorb heat without rising in temperature i.e. the preferred material will employ an isothermal process to absorb incident solar energy.
- 20 8. Any thermodynamic power-producing system (hereinafter abbreviated to the term "heat engine") must reject the balance if any, of the heat supplied to it that is not converted to a useful output, to a heat sink that has a lower temperature than that of the heat source which
- 25
- 30
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supplies heat to the said heat engine.

9. The thermal efficiency of any heat engine cannot exceed that of a heat engine which rejects the said balance of heat to a heat sink having a temperature of absolute zero and, the closer the heat sink temperature is to absolute zero the higher will be the thermal efficiency of the heat engine, i.e. the greater will be the proportion of the heat or radiation energy supplied to the heat engine that is converted into a useful output..
10. The coldest sink of adequate capacity for terrestrial heat engines producing outputs of significant national interest is the background of outer space which has a temperature of 3K approximately.
11. In consequence, no large terrestrial heat engine can have a higher thermal efficiency than one using the background of outer space as its heat sink.
12. The only means available for rejecting large quantities of terrestrial heat to outer space is by radiation.
13. In consequence, a large terrestrial heat engine that rejects heat by effective radiation-communication with outer space cannot be bettered.
14. The rate at which heat may be rejected by any material to outer space is limited by the thermal emissivity and the absolute temperature of the said material.



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15. In consequence and in general, wherever material is used to reject heat from e.g. a heat engine, the rate at which the said material may reject the said heat will be greater if the said material has a high coefficient of thermal emissivity and is warmer than its surroundings.
16. In consequence, a preferred material for use as an emitter of rejected heat to space will be a material having a thermal emissivity coefficient approaching 1.0 (at which figure it would be termed an "ideal black body") and having the capacity to lose heat without falling in temperature i.e. the preferred material will employ an isothermal process to emit rejected heat to space.
17. The rate at which energy; especially electrical energy, is consumed by communities is strongly correlated to the coldness of the weather, and the coldness of the weather is strongly correlated to the rate at which terrestrial heat is radiated naturally to space. (These strong correlations were well demonstrated by the sudden cold and frosty weather in England on the 27th and 28th November 1978, which it was observed, followed exceptionally clear skies in both day and night-times during which terrestrial heat was particularly effectively radiated away to space, and which caused a record demand for electricity over 700 MW greater than previously recorded.)
18. In consequence, haze and cloud cover tend to reduce the demand for electricity, by providing a "blanket" for electricity-consuming



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communities.

19. In general, electricity-consuming communities
tend to reside at low altitudes, underneath
the majority of haze and cloud.
20. In consequence and in general an electricity-
generating heat engine whose output is
governed by radiation-communication with outer
space and which employs a radiative energy-
absorber or (and) a radiative energy-emitter
that is (are) elevated above the electricity-
consuming community (and, from 19 above, above some
of any haze and cloud) will generally be able
to increase its output by a proportion greater
than the proportional increase in demand for
electricity by its electricity-consuming
community.
21. In consequence, an electricity-generating heat
engine such as in 20. above will have an inherent
"peak-logging" output and so may be equated
in value to equivalent-output peak-logging
power stations, which are in general the most
expensive power stations, at least in terms of
unit electricity cost.
22. A large element of the capital cost of solar
power generators, e.g. those employing mirrors
or photo-voltaic arrays to collect solar
radiation, is determined by the value of the
Earth's surface that is barred from other use
or enjoyment, for example, agriculture,
livestock-rearing, forestry, habitation,
recreation and aesthetic application.



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23. In consequence, a large terrestrial power station that relies upon large-scale radiative communication with the sun and outer space will have a lower capital cost if those parts of the Earth's surface that are required for such radiative communication have little value for the use and enjoyment given in 22. above or whose value in respect of such use and enjoyment is not significantly diminished by the means for large-scale radiative communication.
24. In consequence and in general, the parts of the Earth's surface which have little capital value are the deserts, icy wastes, oceans and seas; therefore a large-scale power station employing such parts of the Earth's surface is likely to be the least costly in terms of this element of capital cost.
25. Another large element of the capital cost of present solar power generators is the material and fabrication cost of e.g. solar mirrors and photovoltaic arrays.
26. In consequence, a large-scale power station that requires little or no material or fabrication in order to collect solar energy or (and) to radiate heat to outer space, is likely to be the cheapest possible in terms of this element of capital cost also.
27. A third large element of the capital cost of solar power stations which collect solar energy in order to boil a working fluid is the material and fabrication cost of the boilers,



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superheaters, expanders and condensers etc. required to process the working fluid: this cost is largely determined by the temperature and pressure of the working fluid as it effects the strength and corrosion of the boilers, superheaters, expanders and condensers etc. (hereinafter referred to as "heat engine components").

10 28. In consequence, a large-scale power station employing heat engine components that are not subject to severe temperatures and pressures (by, for example, being limited to temperatures within the band of -50°C to 100°C and to pressures between 1 and 50 absolute atmospheres, employing an inert working fluid, and using low temperatures to reduce corrosion) is likely to be the cheapest possible in terms of this third element of capital cost also.

20 29. A solar power station employing a working fluid and requiring to boil that working fluid at a temperature above local ambient temperature must necessarily use a significantly large proportion of its heat supply in order to boil the working fluid. Unless the working fluid is superheated to a very high temperature (and this temperature is limited to the "Metallurgical limit" in conventional steam power stations, at which point the already high capital cost of the heat engine components rises very rapidly) then it follows that the average temperature of the total heat input will be substantially depressed by the



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relatively low temperature of the boiling heat input with a consequent substantial fall in the thermal efficiency of the heat engine.

5 30. In consequence a large scale power station
 employing a working fluid which if it does
 require to be boiled is boiled at a temperature
 low enough to employ freely-available heat
 (for example river or sea water etc.,) and whose
10 superheating and condensing if any is performed
 also by freely-available or very low cost
 heat input and heat rejection is likely to be
 the cheapest possible in terms of its heat
 input and heat rejection.

15

 The above fundamental principles and necessary
consequences will be referred to in the following pages
of this specification for the sake of brevity, by
quoting the item number of the thirty items given above:
20 for example the phrase "as in 12.above" is intended in
 this specification to mean "according with the principle
 that the only means available for rejecting
large quantities of terrestrial heat to outer space is
by radiation" (q.v. page 7 of this specification).

 Throughout the specification the expression a
buffer substance should be taken to mean a substance
which over the relevant operating conditions, exhibits a
change of state (whether physical or chemical) which, under
a falling temperature is accompanied by a release of heat
and, under a rising temperature is accompanied by taking in
of heat.

 The invention provides an apparatus for
generating power which comprises, means to generate
power by expansion of a working fluid, means to
conduct a working fluid through a closed cycle including
heating, expansion, cooling and compression

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stages, a hot reservoir of one buffer substance (as hereinbefore defined) which receives heat from its natural environment, and is capable of releasing heat isothermally to the heating stage of the working fluid cycle to heat the working fluid, and a cold reservoir of a further buffer substance which releases heat to its environment and is capable of receiving heat isothermally from the cooling stage of the working cycle to condense the working fluid.

The invention also provides a method for generating power comprising taking a working fluid through a closed cycle in which the fluid is heated at a relatively high temperature T_1 by heat exchange with one buffer substance (as hereinbefore defined) at a temperature T_H which is higher than T_1 , heat being released from the buffer substance to the working fluid and the buffer substance changing its state accordingly to a lower energy level, expanding the fluid and generating an electric power output derived from the energy released in expansion of the fluid, rejecting heat from the expanded fluid to a cold buffer substance at a relatively low temperature level T_2 , the cold buffer substance being at a temperature T_C below that of the fluid T_2 and extracting heat from the fluid accompanied by a change of state of the cold buffer substance to a higher energy level and returning the working fluid to the beginning of the working cycle.

Generally the preferred embodiments of the present invention have the following elements:

A. . . A sensibly-isothermal emitter of rejected heat.

As was concluded in 16. above, a preferred material for rejecting heat to space (which cannot be bettered, as concluded in 13. above) will have an emissivity



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coefficient approaching 1.0 and will reject heat isothermally.

Referring to 23. and 24. above - in which it was concluded that the least costly parts of the Earth's surface available for radiative communication were the deserts; icy wastes, oceans and seas - the present invention proposes that snow, ice and ice crystals (and the formation thereof from water and water vapour) provide extremely effective and inexpensive isothermal emitters. Firstly, the thermal emissivity coefficient of ice is usually over 0.90 and often as high as 0.99; secondly, the formation of ice from water requires an unusually large amount of heat, at least equal to the latent heat of fusion of water which is 333 joules per gram approximately - to be lost; thirdly, the formation of ice is an isothermal process occurring at 0°C approximately (depending upon altitude) at which temperature ice will radiate up to 0.3155 kw/m² to space (according to Kirchoff's law whereby the radiation rate is governed by the fourth power of absolute temperature of the emitter); fourthly, icy wastes especially at altitude are usually swept by air colder than the ice during its formation and so may lose further heat by "wind-scrubbed" convection and conduction, which may increase the rate of heat loss to 2kw/m² or more; and fifthly, icy wastes - and the means to form them i.e. the water are extremely abundant on the Earth's surface.

Accordingly, although the present invention may employ other sensibly-isothermal emitters of rejected heat such as e.g. polyethylene glycols and clathrates having freezing points higher than 0°C so as to

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increase the radiative component of the heat-rejection rate, the preferred embodiments of the present invention propose to employ material largely composed of freezing water but sometimes including other substances such as
5 e.g. dissolved salts which may, for instance, reduce the freezing point for other purposes within the present invention.

Reference is made to my U.K. Application No. 48204/78
10 entitled "Improvements to Stored Energy Systems" and to my U.K. Application No. 40639/78 entitled "Energy from sky heat exchange", both of which are incorporated herein for reference, in which heat-rejection means adapted to promote the rejection of heat from
15 cold reservoirs were disclosed. The present invention proposes that such like means of heat rejection, especially but not exclusively employing radiative heat rejection to outer space, should be employed within the present invention in embodiments wherein it is
20 advantageous to do so, for example in relatively small-scale power generators for e.g. a remote industrial plant which may not have ready access to natural ice and snow.

B. A substantially-isothermal absorber of energy.

25 Again referring to the principles and consequences on pages 5 et seq. of this specification it was concluded in 6. and 7. above that a preferred material for absorbing solar energy would be relatively cold, have a power absorptivity coefficient approaching 1.0, and would
30 employ an isothermal process to absorb energy.

Again seeking to employ the least costly parts of the Earth's surface, the present invention proposes that (especially in its large-scale embodiments) advantage may be gained from at least three types of sensibly-isothermal
35 energy absorbers, as follows:



i) Snow and ice fields, glaciers and the like,
which also may absorb incident solar radiation
particularly effectively, having thermal absorptivity
coefficients often above 0.9 (especially when the
5 tendency of ice to reflect incident solar radiation
back into space is reduced by the "heat acceptance means"
disclosed in my U.K. Application No. 40639/78). In
addition, ice again provides a large-capacity isothermal
process (via its circa 333 joules per gram latent heat),
10 producing water from the incident solar radiation.

Now water has one of the highest known liquid
thermal conductivities (apart from liquid metals) and
is particularly suitable, both for that reason and its
high latent heat of fusion, as a "buffer substance"
15 for use in embodiments of U.S. Patent No. 4092830,
that is as a means to boil and superheat the working
fluid used in a Rankine cycle, and thereby to provide
the heat input which is collected solar energy.

ii) Water from the oceans, seas, lakes and rivers
20 all of which was at some time melted from ice or condensed
from water vapour (both of these having required, at some
time in the past, the absorption of solar energy) is also,
by virtue of its great abundance on 71% of the Earth's
25 surface rather than by virtue of its power absorptivity,
a substantially isothermal absorber of large amounts of
solar energy. Water in its liquid form does not
change greatly in temperature when present in large
quantities owing in addition to its high sensible heat.

30 Thus, the oceans' mean temperature changes by less
than 1°C throughout the year despite its absorption of
prodigious quantities of solar energy. Again, the water
of deep lakes at low altitudes in temperate countries
rarely falls below 6°C despite many weeks of
freezing weather. Yet, again, the sea water



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around the coasts of most European and American countries etc. resists so well any tendency to cool down that it is often at its warmest in November and December.

Further still, currents such as the Gulf Stream in
5 effect convey collected solar energy several thousand miles with little fall in temperature, and thereby keep land masses of large area and mass relatively warm.

In some embodiments of the present invention the use of appropriate bodies of water as the major
10 heat reservoir is therefore proposed, to accord with the principle and consequence of 30.above.

iii) Change-of-state-absorbers in desert regions (and other hot and arid regions which, because they lack
15 liquid water, can rise rapidly in temperature in daytimes) are defined herein as substances which undergo a change of physical, chemical, crystallographic, adsorptive, persorptive, associative, reversible physico-chemical or other state including state of hydration or solution
20 whilst absorbing incident radiation, the said change of state tending to suppress a rise in temperature of the said substances.

By virtue of the qualities given in the above definition, such change-of-state absorbers may not only
25 approach the ideal of an isothermal process as in 7. above (although such ideality is less important than it is in emitters of heat, because solar energy absorbers will usually be employed in radiative-communication with the sun which, having a temperature of 5776K, may
30 still readily communicate energy to an absorber at, say, 350K) but, more importantly in some embodiments of the present invention, may also accept solar energy from nearby surroundings that being non-isothermal absorbers themselves are hotter than the change-of-state
35 absorbers to which therefore they may convey heat.



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Examples of such change-of-state absorbers include normally-solid materials such as clathrates and polyethylene glycols etc. which melt at a temperature for example between 10°C and 30°C and absorb their high latent heats of fusion; adsorbers such as silica gel, charcoal and alumina which may absorb solar energy as they desorb for example water and, later, release heat as they adsorb further e.g. water; persorbers such as chabazite and the zeolites which, after dehydration, are commonly known as molecular sieves and which also may desorb and persorb e.g. water with considerable absorption and release respectively of heat; reversible physico-chemical compounds e.g. calcium hydroxide which will absorb much heat (at temperatures typically of 400°C, which would require a moderately-high-concentration solar collector) as it changes to calcium oxide during dehydration, etc. etc.: U.K. Application No. 35603/78 entitled "Power devices using anti-bumping and related materials" is incorporated herein for reference to a fuller discussion of the nature and qualities of most of these examples.

An important group of change-of-state absorbers (insofar as the present invention is concerned) include solutions of e.g. salts such as calcium chloride, sodium chloride and lithium bromide in, for example, water. Such solutions may absorb considerable amounts of solar energy during dehydration and, later, release a good deal of that energy as heat of hydration and solution when later mixed with water. Of equal or greater significance is that such like materials may also, when mixed with ice or snow, fall to temperatures of e.g. -20°C to -55°C and thereby provide means to, for example, condense the working fluid in some embodiments of the present invention as described later in this application. Thus, the evaporation of salt solutions



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by solar radiation provides an easy means to store solar energy for long periods and, furthermore, to produce either heat or cold.

Now again, this is a naturally-occurring isothermal process for absorbing solar energy, just as are oceans and snow-fields; dried salt lakes exist in many desert regions and one important one, the Great Salt Lake Desert of Utah, U. S. A. covers more than 10,000 square kilometres. Even this is very small when seen in terms of all the world's deserts, which cover many millions of square kilometres, and which have little value at present.

C. A hot reservoir comprising material at a temperature

T_H and which also comprises or is in thermal communication with the sensibly-isothermal absorber of energy as in B. above.

D. A cold reservoir comprising material at a temperature

T_C lower than T_H and higher than 3K and which also comprises or is in thermal communication with either:-

i) the sensibly-isothermal emitter of rejected heat as in A. above.

or ii) a sensibly-isothermal absorber of energy as in B. above and which when combined with added substance, e.g. ice, falls in temperature.

E. An energy converter adapted to accept heat from the said hot reservoir and to reject heat to the said cold reservoir and to provide an output of electrical energy.

One preferred embodiment described later in this application discloses a means to generate 1000 MW of electricity for 1000 hours a year (i.e. so as to meet the peak demands of a consuming network during that year, for instance for an average of 10 hours a day for the 100 highest-demand days of the year) for a town or



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industrial complex, whilst at the same time putting into storage large quantities of salt for later use, either in other embodiments of the present invention; or in embodiments of my U.K. Application No. 35603/78 which may
5 employ it (and sodium electrolysed from sodium chloride) to power cars, trains and ships; or as a means to store solar energy by solar evaporation of water; or as a means to store surplus-to-baseload electricity. However it is emphasized that the present invention may be
10 adapted so as to perform other functions, for example, the pumping of water to elevated reservoirs for drinking, washing, irrigation and fire-fighting; the provision of domestic or industrial heating, cooling and air-conditioning alone; the provision of emergency electrical
15 supplies such as require expensive stand-by generators at present; the storage of waste heat from thermal power stations; the storage of geothermal or other low-grade heat; the creation of salt flats for recreational and other purposes; the melting of ice fields.

20 Although the present invention may be adapted to employ a variety of effects in order to convert or use the stored energy that the present invention provides - for example: thermo-electric effects such as the Peltier and Seebeck effects for the conversion of temperature
25 differences to electricity and vice versa; osmotic effects for the uphill pumping of solutions (for example solutions of the salts provided in some embodiments of the present invention); electro-chemical effects such as the production of electricity from metals, salt solutions
30 and air (for example an aluminium-air-seawater battery) the preferred embodiments of the present invention generally employ thermo-physical effects so as to provide a flow of thermal energy (i.e. heat) through a heat engine.

35 Again, the heat engines which may employ the present



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invention are of numerous types and include those using the Stirling cycle, the Brayton cycle, the Otto cycle, the Ericsson cycle and the Rankine cycle: these and other cycles may be adapted to employ the present invention to provide the needed heat flow.

However it is believed that the present invention will be most useful in embodiments using the closed Rankine cycle to provide an output of work to drive e.g. an electrical alternator to supply grid electricity or to drive a pump to lift water to an elevated reservoir, etc. etc. This belief arises from the need to conserve the working fluid (because most working fluids other than H_2O and air are too valuable to be discarded to the atmosphere) by recycling and because the Rankine cycle provides means when used in accordance with the present invention whereby the majority of the heat supplied to and rejected from a heat engine may not only be very inexpensive (as in item 30. above) but may also be derived from natural isothermal processes for absorption of solar radiation and rejection of heat to outer space, as in items 7 and 16 above which concluded that such processes are to be preferred.

The following is a description of some specific embodiments of the invention reference being made to the accompanying drawings, in which:

Figure 1 is a schematic diagram of one power generation apparatus;

Figure 2 is a longitudinal cross-section approximately one fiftieth full size, of a subsonic duct which acts as a heat pump for superheating the working fluid of the present embodiment;

Figure 3 entitled "LATENT HEAT CYCLE" represents the thermodynamic processes of the closed Rankine cycle



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through which the working fluid carbon dioxide is taken in the present embodiment;

Figure 4 entitled "DESERT REGION EMBODIMENT" is an abbreviated representation of the apparatus of Figure 1; and

Figures 5 to 9 show further embodiments in diagrammatic form.

The power generation systems described below all use carbon dioxide as the working fluid but it is emphasized that carbon dioxide is only one example of a working fluid which may be used being chosen for its non-inflammability, low toxicity, low corrosion of metal, low cost, ready availability and reasonably low operating pressures. Many other alternative working fluids may be used however, for example the halocarbons known as the FREONS (Registered Trade Mark), any of the refrigerant working fluids, and any other gas which is condensible at familiar climatic temperatures under the action of pressure alone. It is further emphasized that the temperatures, pressures, flow rates and other parameters quoted in the present embodiment again suffice only as examples within the present invention; other embodiments may advantageously employ other temperatures, pressures and other parameters according particularly to climatic conditions of the regions of the Earth in which such other embodiments are intended to operate; Figure 5 entitled "Sub Arctic or Mountain Region Embodiment" and Figure 6 entitled "Special Temperate Region Embodiment" as described later in this application give two further examples of embodiments according to the present invention wherein the embodiment may be adapted so as to gain in thermal efficiency, compactness, efficacy, acceptability to the environment and ecology, compatibility with the local climate and geography, etc. by variation of the temperatures and other qualities of the embodiment according to the region in question.



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Turning now to Figure 1, a high lake 101 is provided at about 3000 metres above mean sea level and in a suitable Valley or depression which may be filled with water so as to create a relatively small lake of about 4km^2 surface area. If necessary a dam 102 may be provided to close the boundaries of the lake. Advantageously the base of the proposed lake should be of leak-free impervious rock but the present invention discloses that small leaks may be sealed completely and cheaply with a slurry of calcium montmorillonite, otherwise known as calcium bentonite or as non-swelling bentonite, mixed as necessary with added soda ash to cause it to swell and fill leak paths. Thus "undersealing" material is impervious, waterproof and very inexpensive, being about 10% of the cost of butyl plastics sheet which is another material which is and may be used for undersealing lakes, ponds, canals, etc.

Advantageously the site of the proposed lake is selected from a region of relatively high rain and snow precipitation, with a relatively large surrounding catchment area from which not only rainfall may be drained into the lake but also from whose slopes natural and contrived avalanches of snow may fall towards and into the proposed lake. In addition it is advantageous to choose a site over which relatively brisk and cold winds are known to blow in winter especially - a valuable feature which may be augmented by the shape of the windward terrain: a proposed high lake site in a col bounded by mountain flanks which approximate the form of a venturi may increase the heat-rejection capacity of the lake considerably owing to the funnelling effect of such a shape, the cooling of air which accompanies its acceleration, and the higher heat-transfer rates brought about by higher air velocities.



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Once undersealed and dammed as necessary, the high lake may then fill gradually to a depth of perhaps 50 metres by natural means (rainfall, snowfall and natural and contrived - by small explosive detonations etc. - avalanches) during the several years construction period of the power station of the present embodiment. Following construction of the power station, the high lake may be filled to greater depths with water gradually pumped from lower sources, and thereby permit not only greater "equilibrium" power outputs from the station but also very much larger (e.g. ten times greater) "short term" power outputs for periods of several weeks during a winter so as to meet unusually high electricity demand for instance as may be caused by several weeks of exceptionally cold weather - when of course the power station's output may naturally increase in any case, by the principle given in item 12. above (q.v. page 7).

The lake is selected so that the average year round air temperature above the lake may be expected to be about -5°C at 3000 metres altitude. However in winter, when the power station of the present embodiment is intended to produce the overwhelming majority of its output, the air temperature may be expected to fall generally in the band 0°C to -15° . Thereby the high lake may acquire a mean temperature in the region of $+3^{\circ}\text{C}$ in winter and at this temperature radiate heat to the sky at the rate of 0.2 to 0.3 kw/m^2 as well as losing heat to the air blowing over it at the rate of 0.1 to 1.5 kw/m^2 . The rate of heat loss by radiation may be increased by one or more of the "heat rejection means" described in my U.K. Patent Application No. 40639/78 entitled "Energy from sky heat exchange" as desired, though this optional measure may be desirable only if a lake of 4 km^2



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surface area is difficult to achieve, or for other reasons.

Taking the average winter heat rejection rate at the conservative level of 0.5 kw/m^2 and a high lake surface area of 4km^2 , the total heat rejection rate will be 2000 MW which is adequate to support the 1000 MW rated electrical outout of the present embodiment, as will become apparent.

Freshwater is drawn from the lake 103 (or alternatively but less desirably seawater) at a rate of approximately 65 tonnes/second and a temperature of about 10°C and pumped by the turbine/ pump 104 to the high lake through the pipeline 105. Advantageously this pipeline may comprise between two and six pipes of 5 metres bore (depending on the frictional pressure loss acceptable to the scheme), constructed of steel strips embedded in epoxy resin in the known manner of DUNLOPIPE (Registered Trade Mark) so as to have very low frictional pressure drop and high corrosion resistance at relatively low cost.

Simultaneously, water flows from the high lake through a downcomer pipeline 106 similar to the pipeline 105 and through the turbine/pump 104 which advantageously may comprise several Pelton wheel turbines driving high-efficiency centrifugal or other pumps. By suitable design and location of the high lake, the turbine/pump and the power station (especially as regards the latter's altitude), the potential energy released by the water flow from the high lake (which will include natural precipitation and so increase the downward flow rate to 67 to 70 tonnes/second) can be sufficient to provide a slight surplus of power output from an alternator 107 coupled to the turbine/pump.

In order to cool 65 tonnes/second of water from 10°C to 3°C , approximately 1904 MW of heat must flow out



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of it. The heat-rejection capacity of the high lake (approximately 2000 MW) coupled with the latent heat of fusion absorbed by snow falling onto and into the high lake may provide this heat flow easily.

5 The downward-flowing water at about 3°C is fed by the downcomer to the boiler 108 of the Latent Energy Power Station 109. Carbon dioxide (CO_2) in saturated liquid form at -20°C and 20 atmospheres is pumped by the boiler feed pump 110 (of known cryogenic or other
10 type) at a rate of 63 tonnes/second to a pressure of 35 atmospheres. A feed preheater 111 within or nearby the boiler heats the liquid carbon dioxide to -2°C , so causing the 3°C feed water to cool to freezing point and to begin to freeze, thereby transferring its latent
15 heat of fusion to the CO_2 .

Referring to Figure 3 there is shown the thermodynamic process of the closed Rankine cycle, superimposed on a section of the Temperature-Entropy Diagram for carbon dioxide by Plank and Kuprianoff
20 dated 1932. The above described feed-preheating is represented on the Temperature-Entropy Diagram by the CO_2 condition moving from point 2 (enthalpy 90.3 cal/gm) to point 3 (enthalpy 99.3 cal/gm) during which each gram of CO_2 must absorb 9.0 cal. (i.e. $99.3 - 90.3$) from
25 the feed water. During subsequent boiling of the CO_2 , its condition moves to point 4 (enthalpy 156 cal/gm) and so absorbs a further 56.7 cal. of heat from the feedwater, per gram of CO_2 . Thereby a total of 65.7 cal. is needed to boil each gram of CO_2 ,
30 this heat input coming mainly from the latent heat of fusion of the feedwater, which equals 79.72 cal/gm.

H_2O .

This technique whereby the latent heat of a "buffer substance" (in the present embodiment water or
35 H_2O is employed to boil a working fluid is disclosed



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and described in my U.K. Application Nos. 1689/76 and 25600/76 and in the subsequent granted U.S. Patent No. 4092830 of June 6th, 1978, and is now a proven technique of high reliability and low capital cost, according as it does with items 28. and 30. above (q.v. page 11 of this specification).

In the present embodiment it is proposed that the heat-exchanger components of the feed pre-heater and boiler should advantageously be constructed in the known and proven manner of ice-making equipment such as used in the "FLAKICE" and "PAKICE" systems, or in the later systems which produce ice on the inner and outer surfaces of vertical tubes, and which produce ice crystals, briquettes or segments in a nearly-continuous flow which may be transported away from the heat-exchanging surfaces by conveyor belt or other suitable means.

After being boiled to saturated gas at -2°C and 34.5 atmospheres, the CO_2 is next superheated to a temperature of 35°C at 34 atmospheres pressure, by means either of the subsonic duct 112 (an optional facility) or of the waste heat superheater 113. Either of these two alternatives will take the CO_2 from condition point 4. (see Figure 3) to condition point 5 which has an enthalpy of 168 cal/gm; this superheating process thus requires a heat input of $168 - 156 = 12$ cal/gm.

Considering first the alternative of using waste heat from e.g. the effluent of a thermal power station or a hot spring, the present embodiment would require a source of water at approximately 40°C to supply the 12 cal/gm of CO_2 . In the waste heat superheater 113 alternative of the present embodiment, the waste heat water supply is cooled to 4°C - a drop of 36°C which releases approximately 36 cal. per



gram of waste heat water - whilst supplying 12 cal./gm of CO₂. Thus, one gram of waste heat water suffices for three grams of CO₂, and so the flow rate of waste heat water is $63 \div 3 = 21$ tonnes/second. Such a flow rate is approximately equal to the used cooling water discarded by a thermal power station of 1400 MW electrical output operating at 36% thermal efficiency. Therefore, in this alternative mode of superheating, the present embodiment would allow the output of a 1400 MW coal, oil or gas-fired or nuclear powered power station to be increased by the 1000 MW output of the present embodiment, that is, an increase of $1000/1400 \times 100\%$ which is 71%. This is in the region of six times the improvement expected from modern coal-fired stations employing fluidised-bed combustion, but of course it consumes no fossil or nuclear energy in the present embodiment.

Furthermore the ensuing waste heat water is cooled to 4°C, having started at perhaps 12°C at inlet to the e.g. thermal power station. Thus the present embodiment in effect extracts 8 cal. per gram of natural water which, at the design superheater water flow rate of 21 tonnes/sec, equals 703 MW of heat flow from that water - which is stored solar energy.

Finally, such water being cooled to about 4°C may if desired be pumped to the 3°C high lake 101 and so provide a significantly increased source of cold water for the power station of the present embodiment or for further such power stations in such cases where the present embodiment is intended to "breed" new capacity - without putting any further load on the heat-rejection capacity of the high lake.

Considering next the alternative of using the subsonic duct 112 as the means of superheating the CO₂, the present invention discloses that, if a compressible



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gas (such as the wet, saturated, or partially superheated, CO₂ of the present invention) is passed through a convergent duct such as that shown in Figure 2, then the said gas will accelerate as it approaches the throat 201 of the duct. In so doing its pressure and temperature will fall. If then the walls of the duct (or in other embodiments the gas itself) are put in thermal communication with substance 203 at a temperature higher than that of the flowing gas, heat will flow from the said substance into the gas and so tend to restore its temperature to that of the said substance. In addition if the gas at entry to the subsonic duct is at or close to saturation then it will partially condense as it is expanded to a lower pressure in the duct and droplets of condensate will (with suitable design) come into contact with the relatively-warm walls of the duct.

If then the walls of the subsonic duct diverge gradually as shown in Figure 2 the gas flowing through the duct will decelerate as it approaches the exit 202 and, in so doing, will recover the majority of its pressure as at inlet to the duct. However, in addition, this compression process will cause the temperature of the gas to increase to a value above that at inlet to the duct, owing to the heat flow to the gas (and to the aforementioned droplets of condensate) from the said substance. If such a duct is supplied with, for example, CO₂ saturated gas at -2°C at a flow rate sufficient to cause the CO₂ almost to reach sonic velocity at the throat 201, then the CO₂ temperature at the throat will be approximately -30°C, causing heat to flow through the walls 204 from the substance 203 and, with a suitably



long throat 201 as shown in Figure 2, to heat the CO₂ gas at the beginning of the diffuser 205 to approximately 5°C. Then, as the CO₂ gas (and some liquid condensate droplets, evaporating in the diffuser) decelerates in the diffuser and recovers most of the pressure-drop which it experienced during acceleration, the CO₂ temperature will rise to approximately 35°C at the exit 202. This subsonic duct superheating process is shown as the alternative 112 in Figure 1.

The present invention also discloses that the above -described duct superheating technique may be extended if desired to produce greater superheat temperature-increases, by operating a convergent/divergent duct such as shown in Figure 2 at supersonic gas velocities. Thus, if the flow rate of the gas through the duct is gradually increased to the condition known as "choking flow" wherein the gas flow velocity at the throat is equal to its sonic velocity and if the gas pressure at the exit 202 is held below the gas pressure at the throat 201 by a sufficient rate of withdrawal of gas from the exit 202, then the gas will accelerate to supersonic velocity in the diffuser section 205 and so fall even further in temperature and pressure than at the throat 201. Thereby it may encourage still further flow of heat from the substance 203. If, then, the supersonic gas flow is decelerated (for example by the step 206 and the bullet 207 so as to cause shock waves 208 to form) its pressure and temperature will rise again. Such techniques may permit the CO₂ temperature downstream of the bullet 207 to reach for example 50°C, with some further slight loss in pressure to perhaps 33 atmospheres.

Such a supersonic duct superheater may be used in embodiments of the present invention if such higher



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superheating temperatures are desired, though it is pointed out that a supersonic convergent/divergent duct such as depicted in Figure 2 must be operated precisely at its design "choking flow" rate and therefore does not permit flexibility in gas flow rate and, consequently, in power output.

However it is emphasized that the use of either a subsonic or a supersonic duct as described above in effect provides a very high efficiency heat pump (as measured by its coefficient of performance) and allows embodiments of the present invention to operate without any artificial heat supply (e.g. fossil or nuclear waste heat) at all. As shown in Figure 3 - see the box at the bottom of Figure 3 headed "Thermal efficiency in terms of Fuel (or waste) Heat needed. B. Using Duct Heat Pump" - this allows the thermal efficiency η , defined as Net Work Output divided by Fuel or Waste Heat Input, to reach infinity. Thereby, embodiments of the present invention may produce useful power without relying on any terrestrial source of energy, other than that exchanged with the sun and outer space, for the life of the solar system.

Returning to Figure 1, the superheated CO_2 gas may now be expanded to produce a useful work output by means of the expander 114 which may be any suitable expander such as are known for example in steam-turbines, reciprocating piston/cylinder combinations and many other known devices.

However it is emphasized firstly that the present embodiment, as shown in Figure 3 permits a low expansion ratio of only 1.52 to 1.00 (which allows very high isentropic efficiencies of e.g. over 90% to be easily achieved, and also permits the use of



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simple diaphragm and rolling-diaphragm types of expander which are very inexpensive, efficient and reliable) and, secondly, that the expansion process from point 5 (at 35°C and 34 atmospheres) to point 6 (at 0°C and 20 atmospheres) on Figure 3 is at unusually low temperature and moderate pressure - which allows the expander to be constructed very cheaply (e.g. using many parts of plastics material). This accords with the principle of item 28. (q.v. page 11 of this specification).

In the present embodiment the expander 114 is shown coupled to an electrical alternator 115 which supplies electricity to the national or local grid. However, alternatively the expander could drive known types of pump in order to pump water to an elevated reservoir 116 so as to provide a source of emergency drinking, irrigation or fire-fighting water and also by using means such as a water turbine and alternator (not shown), to provide additional electricity to meet demand as required. In addition such an elevated reservoir may, by suitable positioning, cause low-potential energy water vapour 117 to be swept upwards by local winds to the high lake 101 where, with suitable geography, a significant proportion of it (perhaps 10%) may condense and fall as rain and snow precipitation 118 onto and into the high lake, thereby increasing the capacity of the embodiment.

After expansion the CO₂ is led to the condenser 119, which may be of many types known (particularly in the refrigeration industry as used for instance in cold stores), and condensed back to liquid CO₂ at approximately -20°C and 20 atmospheres, for inlet to the boiler feed pump 110. This condensation process is achieved in the present embodiment by means of a eutectic slurry 120 largely of common salt (sodium chloride NaCl) - providing approximately



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24% by weight of the slurry - and ice (produced by the boiler 108, the feed preheater 111 and the heat exchanger 123) providing approximately 75.5%, the balance being melt water. This slurry is mixed in
5 the mixer 121 by the motor 122 and then flows to the condenser where it takes in its remaining latent heat of fusion and melts to produce a concentrated salt solution 124. This salt solution is passed to the heat exchanger 123 where it is heated to e.g.
10 -2°C (by means of cooling water at e.g. 3°C from the high lake and producing further ice for the eutectic slurry) and then piped to the salt bed 125 for evaporation.

In addition the salt solution at e.g. -2°C from the heat exchanger 123 could if desired, be passed
15 through a further heat exchanger (not shown in Figure 1) fed with the water at e.g. 10°C from the lake 103, thereby to heat the salt solution to perhaps 8°C and so to ease its subsequent evaporation in the salt bed, and secondly to cool the e.g. 10°C water to
20 perhaps 1°C before it is fed to the turbine/pump 104: thereby the heat-rejection load on the high lake 101 may be reduced and in, consequence, the power output of the present embodiment increased.

As may be deduced from the calculations shown
25 in Figure 3, wherein 1.66 grams of eutectic coolant slurry are calculated as being necessary for each gram of CO_2 , the flow of salt solution to the salt bed will be at the rate of approximately 105 tonnes/second, requiring between five and fifteen pipes 126 of 5 metres bore
30 (depending upon the admissible frictional pressure drop) again advantageously being of steel embedded in epoxy resin in the known manner of DUNLOPIPE (Registered Trade Mark).

Recent experiments indicate that, in the arid



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environment of a desert the said 105 tonnes/second flowing for the 1000 hours per year of the present embodiment may be evaporated by natural incident solar energy falling on a salt bed measuring approximately 3 miles by 6 miles, i.e. approximately 47 km², without any sophistication in the means of evaporation that is, without doing any more than discharging the salt solution onto the ground. Various means exist (such as e.g. described as alternative "Heat Acceptance Means" in my U.K. Application No. 40639/78) to increase the rate of evaporation from the salt bed and such means may be employed if desired so as to reduce the salt bed area to for instance 25 km² or even 15 km². However, 47 km² is a relatively small area and it is believed that it would not constitute any environmental or ecological disturbance and, indeed may increase its value firstly by providing a flat firm surface for recreational pursuits such as "sand-yachting" and drag-racing, and secondly may be of ecological value in stimulating a little rainfall downward of the salt-bed and rain and snowfall in the region of the high lake 101 if appropriately sited.

Reference is now made to Figure 5 of the drawings which shows a further embodiment of the invention which is applicable to a sub-Arctic or mountainous region. The embodiment employs a latent energy power station 109 which is generally similar to that described in detail above with reference to Figures 1 to 3 of the drawings. As in the previous embodiment, the power station has a boiler 108 for the working fluid; a superheater in one of the alternative forms 112, 113 described above for superheating the working fluid, an expander (coupled to an electrical alternator, not shown) through which

the superheated working fluid is expanded to extract energy therefrom and generate electrical power, a condenser 119 for condensing the working fluid and a feed pump (not shown) for returning the condensed
5 working fluid to the boiler at the beginning of the cycle. As in the previously described embodiment, the working fluid used is carbon dioxide.

Water is drawn from a sea or lake 300 at a rate of 65 tonnes per second and a temperature of
10 about 3°C along a pipeline 301 to the boiler 108 and is passed in heat exchange with the working fluid in the boiler. As the water passes into heat exchange with the working fluid in the boiler, sensible heat is
15 extracted from the water lowering its temperature to freezing point and then latent heat of fusion is extracted from the water causing a portion of the water to freeze and the working fluid is boiled by the heat extracted from the water. An outlet pipeline
20 302 is provided from the boiler for the slurry of ice and water produced in the boiler. A proportion of the ice slurry flowing along the pipeline 302 is extracted into branch pipeline 303 which leads to a mixer
304 where the ice slurry is mixed with hydrated calcium chloride $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$). The slurry of ice and calcium
25 chloride is lifted by a pump 305 through a pipeline 306 to a high level lake as described below. The pipeline 302 extends to a further power station and supplies the slurry of ice, water (and salt from a separate source, in addition to the salt mixed with the ice in the case
30 where the original supply was the sea) for use as a cooling mixture in the next station.

A high level lake 307 (which may be an artificial lake) at a height of about 4000 metres is used.



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The lake bottom may be sealed as described above and a dam 102 may be provided to form or raise the level of the lake. A membrane 308 formed from an insulating material such as plastics foam sandwiched between
5 two sheets of aluminized MYLAR (Registered Trade Mark) film with their aluminized surfaces facing each other is stretched over the bottom of the lake to divide the lake into an upper layer 309 and a lower layer 310. The upper layer of the lake contains a eutectic slurry
10 of water and salt at minus 22°C. The upper layer of the lake receives snow fall which assists in maintaining the low temperature level of the lake and the surface of the lake may be provided with the heat rejection means described in my U.K. Patent Application No. 40639/78
15 to assist radiation from the lake and thereby maintain the temperature level of the lake at minus 22°C. Eutectic salt slurry is allowed to fall under gravity through a turbine/pump 311 and thence to the condenser 119 to condense the expanded working fluid
20 in the power station. The melted eutectic slurry is then returned by the turbine pump to the top layer 309 of the lake. In certain cases, additional salt can be added to the melted slurry after it leaves the condenser and power can be extracted from the
25 turbine/pump.

As indicated earlier, ice produced from the boiler is mixed with hydrated calcium chloride in the mixer 304. Calcium chloride is endothermic in an ice water mixture lowering the mixture to a temperature
30 in this embodiment of about minus 40°C. The resulting cooled mixture is pumped by the pump 305 through pipeline 306 to the lower section 310 of the lake to form a cold layer at approximately minus 40°C below the



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upper layer 309 of eutectic salt slurry. The cold layer provides a barrier between the ground and the lake to prevent flow of heat into the upper layer of the lake.

5 In a further modification to the embodiment shown in Figure 5, a heat absorber may be arranged on the surface of the part of the sea or lake 300 from which pipeline 301 extracts cold water for the boiler.

10 Reference is now made to Figure 6 of the drawings which shows a power station embodiment suitable for temperate regions. Again the latent energy power station indicated at 109 comprises the same basic components, that is a feed pump 110,
15 a feed preheater 111, a boiler 108, a superheater 112/113, an expander (not shown) and a condenser 119. The working fluid used in the power cycle is carbon dioxide operating under approximately similar conditions to those described previously.

20 The boiler 108 for the working fluid is located in a large floating or fixed tank 400 positioned in the sea and preferably in a region swept by a warm stream such as the Gulf Stream having a temperature of, for example, 10°C . The walls of the tank are
25 insulated to prevent loss of heat from the tank. One suitable insulation material is known as Micropore (Registered Trade Mark). The tank contains a buffer substance such as a polyethylene glycol or a clathrate having a freezing point of approximately
30 20°C . During the summer and autumn months, the buffer substance is totally melted by solar radiation and is preserved from rapid freezing during the winter months by the insulated walls of the tank and also by means of a heat absorber arrangement extending over
35 the surface of the tank. The feed preheater 111



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for the working fluid is arranged in the sea between the shore and the tank and the boiler 108 itself is arranged in the tank. The working fluid in passing through the tank extracts latent heat of fusion from the buffer substance in the tank, the heat being partially restored by solar radiation as described so that total solidification of the buffer substance is delayed until the spring. The superheater 112/113 comprises a heated convergent divergent duct for superheating the working fluid or a conventional heat exchanger heated by waste heat as described earlier.

A high level lake 404 is used in the system, the lake being formed by a high level dam 405 if necessary. The level of the lake is such that its temperature is maintained at 0°C and comprises a slush of water and snow. Slush from the lake is allowed to fall under gravity through a turbine/pump 406 to the condenser 119 to condense the working fluid issuing from the expander stage of the working cycle. The water (at approximately 1°C) resulting from melting of the slush is returned to the lake by the turbine / pump 406 where it is sprayed over the surface of the lake.

Snow fall on the lake during the winter time assists in creating the necessary supply of slush at 0°C for delivery to the condenser. The surface of the lake may be provided with a heat rejection means as described in my U.K. Patent Application No. 40639/78 to assist in maintaining the desired temperature level of the lake.

Referring to Figure 7 there is shown a power station at a northerly latitude of about 50° . However the present embodiment may be adapted to latitudes of, for instance, from 30° to 70° in either the northern or the southern hemisphere so as to provide renewable



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energy for nearly all the populated regions of the world, because over 90% of the world's peoples live between these latitudes.

A hot reservoir 501 comprising largely
5 water (fresh or seawater) is provided at a suitable altitude which may be at or below sea level in a first instance, where it is maintained relatively warm (e.g. about 15°C), but which may alternatively
10 be elevated above sea level in a second instance, for example to employ the melt water of glaciers and snow-fields and the like in the case of mountainous countries of which over 40 exist between latitudes 30° and 70°. Although this second instance has the considerable
15 advantage of being applicable to a large majority of the countries of the world and also permits elimination or simplification of the heat-collecting components of the present embodiment (because glaciers and snow fields act as heat collectors themselves, in
20 providing melt water which may provide the heat input to the present invention in the form of the sensible and latent heat of fusion of that melt water), the present embodiment is now described primarily in terms of a hot reservoir at or near sea level so that the naturally-collected solar energy in for example the
25 Gulf Stream may provide much of the initial heat input and so that the further heat-collecting components of the present invention may be described.

Therefore the temperatures and absolute altitudes quoted first in this description apply to the
30 present embodiment using a sea-level hot reservoir however the second figure in parentheses in each case refers to the temperature which would apply to the present embodiment using a high-level hot reservoir.



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The hot reservoir 501 comprises largely water at a temperature of approximately 15°C (3°C) held in a shallow lagoon 502 advantageously over a source of geothermal heat 503 and at the base of a substantially south facing cliff 504 which has a near-vertical face advantageously covered with a reflecting material such as aluminised MYLAR (Registered Trade Mark) or coated or otherwise treated so as to provide a reflecting surface 505 whereby incident solar radiation 506 may be reflected onto the hot reservoir. In addition solar radiation may fall directly onto the hot reservoir as shown by the example ray 507. Advantageously in the sea-level instance of the embodiment, the site of the hot reservoir should be in a region of low wind velocity: preferably the surface of the hot reservoir should be protected from wind by means of a windbreak 508 which may be an artificial screen for example, or tall evergreen trees as depicted in Figure 7, or other suitable means. Also the hot reservoir may incorporate or be covered by the heat-acceptance means 510 of U.K. Application No. 40639/78 so as to promote collection and minimize loss of heat. The depth of water in the hot reservoir may be in the range of 0.5 to 50 metres or more depending on the desired thermal storage capacity.

A cold reservoir 509 comprising largely seawater at a temperature of -7°C (-21°C) held in a deep ravine 530 is provided on the north side of an opaque shield which in this embodiment is a hill or mountain 511 whose shadow edge 512 falls substantially outside the cold reservoir except perhaps for a short period before and after noon at the vernal and autumnal equinoxes as depicted in Figure 7.



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The surface of the cold reservoir should ideally be at the highest reasonably-possible altitude for the site in question, such that there is an altitude difference H between the surfaces of the cold and hot reservoirs. The temperature of the air and rock surrounding the cold reservoir will be lower than that of the air or other material surrounding the hot reservoir by an amount depending largely on the value of H and in general equal to between 6°C and 12°C for each 1000 metres of the parameter H . Advantageously the site for the present embodiment should be chosen in a region known for its cold winds in the proximity of the cold reservoir and for its absence of overlying haze or clouds so as to permit desired thermal radiation 513 from the surface of the cold reservoir. Thus a thermal reflector 516 of aluminised MYLAR (Registered Trade Mark) or other reflecting material may in some cases be advantageous on the north-facing flank of the hill or mountain. Again prevailing cold northerly winds 514 or cold east-west winds 515 of an air temperature lower than that of the cold reservoir may greatly increase the rate of heat rejection from a still-air rate of approximately 0.2 kw/m^2 to a wind-scrubbed rate of over 1 kw/m^2 . At a heat-rejection rate of 1 kw/m^2 and an overall thermal efficiency of 10% a 1000 MW output power station according to the present embodiment would require a cold reservoir surface area of 9 km^2 i.e. 3.47 square miles. However this area may be reduced firstly to below 3 square miles by means of incorporating thermal conducting rods or sheets of for example steel or aluminium into the thermal reflector 516 and extending such metallic rods or sheets below the surface of the



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cold reservoir; and secondly to 2 square miles or less by increasing the depth of the cold reservoir to 100 metres or more so as to increase its thermal capacity. This may be compared with an area of about
5 15 square miles needed for a conventional solar heat-collecting power station and about 5 square miles for a photovoltaic power station - both of which can provide little or no output in cloudy conditions or at night.

10 To the seawater in the cold reservoir it is advantageous to add common salt, sea salt or other solute which both depresses the freezing point and increases the density of the seawater, and to add such
15 solute(s) first to the lower levels of the cold reservoir in the form either of solid solute or a slurry of solute and ice, or a concentrated solution as in the known manner of setting up linear density gradient columns for laboratory determination of material densities, for example as in the TECAM (Registered Trade Mark)
20 linear density gradient column. By this means the freezing point may be controlled so as to fall from approximately -5°C (-10°C) at the surface to approximately -10°C (-22°C) at the lowest levels of the cold reservoir. By this means a layer of ice 517
25 may form on the surface at the nominal cold reservoir temperature of -7°C (-21°C), and so provide a surface which, having a coefficient of thermal emissivity usually over 0.90, will provide an effective means of radiating thermal energy to the sky; and also, by
30 virtue of its roughness, will provide an effective surface for convective heat transfer to the air by means of wind-scrubbing. It is advantageous also to encourage the formation of ice floes with intervening salt water so as to permit greater evaporation



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from the cold reservoir and, thereby, further heat rejection: such ice-floe formation may be promoted by the salt content, by winds, by natural rainfall running in streams so as to break up the ice layer at specific points, by natural and contrived avalanches of snow (especially in the high-level instance of the present embodiment), and by various artificial means such as gas-inflated booms and open-necked expandable plastic bags immersed in the upper layers of the cold reservoir, and by permitting some of the CO₂ working fluid of the present embodiment to escape from the condenser 518 so as to rise upwards in the form of gas bubbles so as to fracture and break up any continuous ice layer on the surface. This process using CO₂ or other liquefied gases such as nitrogen, may also be useful as a means to cool the cold reservoir in various circumstances.

However, in particularly cold and windy weather it is as advantageous to permit the cold reservoir to freeze to progressively greater depths, though never as deep as the condenser because the presence of liquid around the condenser is preferably so as to permit higher heat transfer from it. The progressively deeper freezing to form ice which contains little or no salt or other solute will concentrate the solution immediately below the ice layer, and, if continued, cause the salt or other solute to precipitate out of solution and settle as a sediment 519 on the bottom of the ravine 530. Such a process is very valuable as a means, in effect, of storing energy in a period of particularly cold weather because, at the end of such a period, the deeply-frozen ice will in consequence of the heat rejected to it by the condenser 518 of the power station absorb a great deal of rejected heat as it progressively melts again. Such melting



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requires the ice to absorb its latent heat of fusion of 333 joules per gram and this process is substantially isothermal, as in 16. above. Furthermore, especially in the high level second instance of the present embodiment, the presence of solid salt or other solute at the bottom of the cold reservoir in the proximity of the condenser together with water and nearby ice will permit the liquid surrounding the condenser to approach the eutectic temperature of -21.3°C in the case of sodium chloride NaCl as the solute and still lower temperatures in the case of hydrated calcium chloride $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ and other solutes.

In some sites for a power station according to the present embodiment, for example those wherein the rock or other material of the ravine 530 is a poor thermal insulator such as granite, or wherein there is an undesirable flow of geothermal heat towards the ravine, it is advantageous to provide a lining of thermal insulation 520 in the ravine.

The condenser 518 may comprise a bank or layer of parallel pipes of steel or other adequately heat-conductive material such as DUNLOPIPE (Registered Trade Mark) at the lower levels of the cold reservoir. However it is emphasized that the performance and economy of the power station may be improved by positioning the condenser at an altitude "h" metres above the altitude of the hot reservoir's boiler 521, the value of h being chosen so that the pressure head of the liquid working fluid flowing downward from the condenser is, by virtue of gravity alone, sufficient to provide most or all of the necessary increase in pressure from the condenser to the boiler. Thus for example in the case of a CO_2 working fluid which is condensed at -10°C and boiled at $+10^{\circ}\text{C}$, the head h should be

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approximately 230 to 250 metres. By this means the boiler feed pump 522 may be much reduced in power consumption and cost, or eliminated altogether in some instances.

5 The boiler 521 may comprise a bank or layer of parallel pipes of thermally-conducting material positioned in heat-conductive relationship with the material of the hot reservoir. Advantageously, the parts of the boiler in which the working fluid is
10 to be evaporated should contain anti-bumping material 523 such as fused alumina so as to permit the boiling temperature to approach closely the wall temperature of the boiler.

 It is strongly emphasized that, in the high-
15 level second instance of the present embodiment wherein the hot reservoir comprises natural water such as may flow for example in a mountain stream from a glacier, the boiler may comprise merely two banks of conventional heat exchangers through which the said
20 natural water may flow, preferably on the "shell-side" of such heat exchangers, with the working fluid being boiled on the "tube-side". In transferring its sensible and latent heat of fusion so as to boil
the working fluid, the natural water will freeze in
25 part at least and so, for example every two minutes of operation, will at least partly coat the boiling tubes with ice and at some stage impair heat transfer. However the present invention proposes that at such a stage the working fluid should be diverted
30 instead to the second bank of heat exchangers, so that the ice in the first bank may be washed away by the natural water flow through the shell-side, whereupon the working fluid may once again be directed to the first bank instead of the second bank which now may



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be similarly de-iced whilst the first bank is in operation.

By the above means the land area occupied by the boiler in the high-level instance of the present embodiment may be reduced to a small fraction of one square kilometre, so that the whole power station may be many times more compact than one employing conventional solar radiation falling on mirrors, solar panels or photo-voltaic cells.

However, for the purpose of describing the further novel features of the present invention that are necessary in the sea-level instance of the present embodiment, the following description relates to a power station wherein the hot reservoir comprises largely water which is held at a temperature of approximately 15°C by means largely of incident solar radiation 506 falling on and reflected onto the lagoon 502 as depicted in Figure 7 and supplemented by Figure 8 and Figure 9.

Referring to Figure 8 a fusible thermal insulating means 524 constituted for example by polyethylene glycol of average molecular weight 600 and 16°C freezing point is provided as a layer approximately 10 centimetres thick floating on the surface of the water in the hot reservoir 501. Alternatively the fusible thermal insulating means could comprise a suitable grade of petroleum wax such as occurs in many crude oils or one of a variety of alternative substances which float on and do not mix with water to any great degree and which exhibit a change of state slightly above the temperature of the hot reservoir, the said change of state causing a release of heat with falling temperature and causing, preferably, an increase in thermal insulating capacity combined with an increase in opacity.

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Polyethylene glycol of average molecular weight 600 (hereinafter abbreviated to "PEG 600") has many of these desirable qualities including a latent heat of fusion of approximately 177 joules per gram which is valuable as a means of storing collected solar energy. Advantageously the PEG 600 may be mixed with additives such as black-coloured vermiculite (or other thermal insulators coloured or treated so as to have a high thermal absorptivity and a low thermal emissivity such as has the coating material known as MAXORB (Registered Trade Mark) Solar Foil) so as to enhance the absorption of solar radiation and to insulate the underlying water against heat loss at night especially.

Each of the boiler pipes 525 advantageously constructed of thin-walled e.g. steel pipe of approximately 15 centimetres bore is held in good thermal connection (by for example resistance seam welding) with the heat collecting means 526 which is constituted by a sheet of thin e.g. steel folded and corrugated as shown in Figure 8 so as to present surfaces approximately normal to both the direct solar radiation 527 and to the reflected solar radiation 528, whereby the effective surface area of the hot reservoir may be increased by 30% to 40% above that of its horizontal surface area. The upper surface of the heat collecting means is preferably coated with material such as MAXORB (Registered Trade Mark) Solar Foil so as to have a solar absorptance of 0.95 to 0.98 and a thermal emissivity of 0.15 to 0.30. To assist buoyancy the underside of the heat collecting means is advantageously provided with buoyant material 529 in the form for example of closed-end polyethylene plastics tubes or closed-cell plastics foam so that the assembly shown



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in Figure 8 may float with the absorbing surface of the heat collecting means predominantly above the surface of the fusible thermal insulating means 524 but with its lower surface in contact with the latter so as to convey collected solar radiation energy to the latter. Thereby the fusible thermal insulating means may be maintained in a molten stage during at least the majority of daylight hours, storing its latent heat of fusion for conversion to electrical output in the hours after daylight or between sunny periods.

The just-described thermal storage capacity may also be greatly increased by means of the thermal conductors 531 which comprise metal tubes in the form of legs extending downwards from the boiler pipes 525 and advantageously terminating in metal heat transfer plates 532 which not only provide means to convey heat to the lower levels of the water in the hot reservoir but also provide convenient "feet" for the easy assembly of the boiler as a whole.

As shown in Figure 9 the thermal conductors 531 are advantageously hollow so that, at night especially and at other times when the power station output may be reduced towards zero, the working fluid 542 may be caused to condense in the thermal conductors (and if desired in the boiler pipes also) so as to decrease their buoyancy and to cause the heat collecting means 526 to sink to a level below or within the fusible thermal insulating means 524. At such times (when solar radiation is low or absent) the fusible thermal insulating means will freeze, preferably over a period of one to ten hours after sundown during which period the demand for electricity is maintained, thereby giving up its latent heat of fusion to the boiler pipes and so maintaining electrical power output. After this period

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is over, the fusible thermal insulating means will have frozen, so preventing convection currents within its body and in addition becoming substantially opaque. Thereby heat loss from the underlying water in the hot reservoir and from the heat collecting means may be minimized and a large store of thermal energy maintained for later use.

The "variable buoyancy means" just described may be quite easily controlled from a distance by means of the boiler feed pump 522 and the CO₂ storage tank 533. Thus, by opening the valve 534 and at least partly closing the valve 535, operation of the boiler feed pump 522 can take CO₂ liquid from the storage tank, pump it to a higher pressure than its saturation pressure at the temperature of the boiler, and so cause it to condense and collect in the lowest parts of the boiler which include the thermal conductors 531. In addition to causing the heat collecting means and the boiler pipes to sink to the required degree, this operation incidentally causes a transfer of thermal energy (from the CO₂ condensing in the boiler) to the hot reservoir with obvious benefit.

The just-described operation whereby the hot reservoir components are switched from the "heat-collecting mode" to the "heat-trapping mode" may be easily reversed at any desired time. Usually such reversal will be done after sunrise, when incident solar radiation will cause the thermal insulating means to soften and melt, permitting the heat collecting means to rise to the surface and collect further energy. Such reversal is easily accomplished by opening the valve 535 and allowing the condensed working fluid 542 in the thermal conductors 531 and in



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other parts of the boiler to boil off: this process incidentally provides a high electrical output from the expander/generator 536 in the early morning when demand is high. The excess CO₂ may be returned to the CO₂ storage tank 533 by means of at least partly closing the valve 537 and operating an auxiliary pump (not shown in Figure 7) in the pipeline incorporating the valve 534.

The duct heat pump technique described earlier in this application may be adapted as shown in Figure 9 so as to permit a significant increase in the thermal efficiency of the present embodiment as now described. The boiler pipes 525 at that end of the hot reservoir which leads to the expander/generator 536 are each coupled to a convergent/divergent duct 538 of proportion such that the working fluid velocity in each throat section 539 may approach or equal sonic velocity. Thereby the wet working fluid (i.e. containing a significant proportion of its liquid phase) may be pumped into the convergent/divergent ducts at a pressure corresponding to the working fluid's saturation pressure at for instance 25°C by means of the boiler feed pump 522. In each throat section 539 the working fluid temperature will fall to for example 0°C and the reduced pressure in the throat section will also cause partial further liquefaction of the working fluid. Heat flow from the hot reservoir at approximately 15°C will cause the working fluid in the throat section to heat up to for example 10°C and cause the liquid phase to evaporate so that the working fluid is approximately saturated at the end of the throat section. Thereafter, in the divergent section 540, the working fluid's pressure will rise

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as it decelerates to a relatively low velocity, causing its temperature to rise to, for example, 35°C at a pressure of 63 atmospheres. In order to prevent heat loss to the hot reservoir at 15°C the working
5 fluid is then piped immediately to the expander/generator. By such means the overall thermal efficiency of the present embodiment may be increased from approximately 5% to the region of 10%, thereby reducing the size of the hot and cold reservoirs and associated components by
10 as much as half.

Finally, the heat-collecting and boiling and thermal conducting components of each assembly depicted in Figure 8 are adapted as shown in Figure 9 by means of the quick-connect couplings
15 541 so as to permit low-cost mass production, inexpensive transportation by lorry, train or ship to the site of the power station, and quick and easy erection on site. This "modular" design permits very substantial savings in power station capital cost,
20 compared with existing types of power station for which the on-site construction and erection costs, delays and organisational difficulties are proving to be a major and growing embarrassment to the energy programmes of several countries.



CLAIMS:

1. An apparatus for generating power which comprises:
 - 5 means to generate electrical power by expansion of the working fluid, means to conduct a working fluid through a closed cycle including heating, expansion, cooling and compression stages,
 - a hot reservoir of one buffer substance which
 - 10 receives heat from its environment and is capable of releasing heat isothermally in communication with the cycle at the heating stage to heat the working fluid,
 - and a cold reservoir of a further buffer substance for releasing heat to its environment and
 - 15 capable of receiving heat isothermally from the cycle at the cooling stage to cool the working fluid.
2. An apparatus as claimed in claim 1 wherein
- 20 the hot and cold reservoirs comprise bodies at least partially of liquid (any remainder being solid phase) and exposed to natural environmental conditions.
3. An apparatus as claimed in claim 1 or claim 2
- 25 wherein the hot and cold reservoirs are so arranged that the air temperature over the hot reservoir is higher than that over the cold reservoir.
4. An apparatus as claimed in claim 3
- 30 wherein the cold reservoir is located at a higher altitude than the hot reservoir.



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5. An apparatus as claimed in any of claims 2 to 4 wherein the means to conduct the working fluid through a closed cycle include heat exchangers at the heating and cooling stages for heat exchange between the hot and cold reservoirs respectively and the working fluid.

6. An apparatus as claimed in claim 5 wherein the hot reservoir comprises water at or immediately above its freezing point to pass in heat exchange with the working fluid to produce a slurry of ice and water, the cold reservoir comprises a salt solution and means are provided for mixing ice resulting from heat exchange of the water from the hot reservoir with the working fluid with the salt solution to produce a cold eutectic salt slurry for heat exchange with the expanded working fluid to cool the working fluid.

7. An apparatus as claimed in claim 6 wherein the hot reservoir comprises an ocean, sea, lake or river.

8. An apparatus as claimed in claim 6 or claim 7 wherein the cold reservoir is located at a higher altitude than the hot reservoir and comprises a lake, containing a eutectic salt/ice slurry.

9. An apparatus as claimed in claim 8 wherein the reservoir is divided into upper and lower sections, the upper section containing the ice/salt slurry and the lower section containing a hydrated calcium chloride/ice mixture and means being provided for mixing ice produced from the heating of the working fluid and hydrated calcium chloride and supplying the resulting mixture to the lower section of the reservoir.



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10. An apparatus as claimed in any of claims 2 to 4 wherein the hot reservoir comprises a vessel located in and insulated from the sea and containing a liquid having a melting point between
5 10 and 30°C and having a surface means for absorbing radiated heat from the environment and the cold reservoir comprises a lake at an altitude above sea level and containing a slush at between -5°C and 3°C.

10 11. An apparatus as claimed in any of claims 1 to 5 wherein the hot reservoir comprises a stream of water at or immediately above its freezing point, the working cycle is provided with parallel heat exchangers for heat exchange with the liquid of
15 the hot reservoir and means are provided for alternately causing the stream of water to flow over one or other heat exchanger so that when ice has accumulated on one heat exchanger, the flow can be diverted to the other to allow the ice on the first heat
20 exchanger to disperse and the cold reservoir comprises a deep salt lake located in a position substantially away from the direction of radiation from the sun.

12. An apparatus as claimed in any of
25 claims 1 to 5 wherein the hot reservoir comprises a body of water having a layer of liquid of higher melting point and of less density covering its surface and means are provided for floating heat exchange means for the hot reservoir in the surface layer of
30 liquid on the lake and, the lake being located in the position to receive direct solar radiation and the cold reservoir comprises a deep salt lake at the higher altitude than the hot reservoir and located out of direct solar radiation.

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13. An apparatus as claimed in claim 12
wherein the flotation means for the heat exchanger
comprise sheets of corrugated metal supported on the
surface of the lake to receive solar radiation
5 on opposite sides of the respective corrugations and
having means to float the sheets and also to support
the heat exchanger.

14. An apparatus as claimed in claim 13
10 wherein a plurality of heat conductors extend from
said sheets of corrugated metal downwardly into the
body of water to conduct heat from the sheets into the
water.

15 15. An apparatus as claimed in claim 13
or claim 14 wherein means are provided for sinking the
heat exchanger through the layer of liquid on the
surface of the lake into the body of water in the lake.

20 16. An apparatus as claimed in any of claims
11 to 15 wherein the salt concentration in the deep
salt lake is arranged to increase from the surface of
the lake towards the lake bottom so that as the air
temperatures over the hot and cold reservoirs fall, the
25 formation of ice on the cold reservoir to an increasing
depth leaves a more concentrated salt solution below
having a lower freezing point and, thereby,
continuing to act as a buffer at progressively
lower temperatures to preserve a temperature difference
30 between the hot and cold reservoirs.

17. An apparatus as claimed in claim 16
wherein heat conductors are provided in the lake



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extending from the body of the lake above its surface to encourage release of heat from the lake.

18. An apparatus as claimed in claim 17
5 wherein the heat conductors have means at their upper ends to release heat by radiation.

19. An apparatus as claimed in any of
claims 11 to 18 wherein heat exchange means for
10 cooling the working fluid are located in a lower part of the lake and the hot reservoir with its heat exchange means are located at a lower altitude so that the resulting pressure head of the cooled fluid provides at least a part of the pressure
15 head required in the compression stage of the working cycle.

20. An apparatus as claimed in any of the preceding claims wherein means are provided in the working
20 cycle for heating and/or superheating the working fluid before the expansion stage.

21. An apparatus as claimed in claim 20 wherein the means for superheating the working fluid
25 comprise means for passing heat extracted from the earth or a source of waste heat in heat exchange with the working fluid.

22. An apparatus as claimed in claim 20
30 wherein the means for heating and/or superheating comprises one or more ducts each having a convergent section, a parallel bore section and then a divergent section, means being provided for heating the parallel bore section of the or each duct to heat and/or superheat the working fluid vapour
35 passing through the ducts.

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23. An apparatus as claimed in any of the preceding claims wherein the working fluid is carbon dioxide or one of the FREONS (Registered Trade Mark) or other refrigerant.

5

24. An apparatus as claimed in any of the preceding claims and in the case where the heat exchanger for the hot reservoir is supported at the surface of a lake comprising water with an upper layer
10 of a further liquid, wherein the heat exchanger comprises a plurality of convergent/parallel/divergent tubes and the working fluid is both heated and superheated in said tubes.

15

25. An apparatus as claimed in any of the preceding claims wherein the means to conduct the working fluid through the closed cycle are arranged to conduct the fluid through the Rankine cycle, the cooling of the working fluid by the cold reservoir condensing the fluid.

20

26. A method of generating power comprising taking a working fluid through a closed cycle in which the fluid is heated at a relatively high temperature T_2 by heat exchange with one buffer substance (as herein-
25 before defined) at a temperature T_H higher than T_2 (release of heat from the buffer substance being accompanied by a change of state of the substance to a lower energy level) expanding the fluid and generating a power output derived from the energy released in
30 expansion of the fluid, rejecting heat from the expanded fluid to a cold buffer substance (as hereinbefore defined) at a relatively low temperature the cold buffer substance being at a temperature T_C below that of the expanded fluid T_2 and extracting heat
35 from the expanded fluid accompanied by a change of state of the cold buffer substance to a higher energy level and returning the working fluid to the beginning of the working cycle.



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27. A method as claimed in claim 25 wherein the cycle through which the working fluid is taken is a Rankine cycle and the cooling of the working fluid by the cold buffer substance condenses the fluid prior to compression and return to the beginning of the cycle.

28. A method as claimed in claim 26 or 27 wherein the release of heat from the first buffer substance to heat the working fluid is derived from the latent heat of fusion of the buffer substance.

29. A method as claimed in claim 28 wherein at least a proportion of the buffer substance remains in liquid form during the transfer of heat.

30. A method as claimed in any of claims 25 to 29 wherein the cold buffer substance comprises a liquid-solid mixture, the change of state of the substance to extract heat from the working fluid comprising melting of the solid component of the said mixture.

31. A method as claimed in claim 30 wherein the buffer substance comprises water, at least a proportion of the water being solidified to form ice and thereby releasing its latent heat of fusion in heat exchange with the working fluid and the cold buffer substance comprises ice and water from the buffer substance together with salt to form a eutectic salt slurry at a temperature below the freezing point of water.



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32. A method as claimed in claim 30 wherein the salt solution formed from the cold buffer substance after heat exchange with the working fluid is allowed to dry under atmospheric conditions and the resulting salt is extracted to provide the salt supply of the cold buffer substance.

33. A method as claimed in claim 32 wherein the salt solution is passed in heat exchange with water of the buffer substance prior to drying to create further ice to supplement the supply of ice for the cold buffer substance.

34. A method as claimed in claim 32 or claim 33 wherein the buffer substance comprises a supply of water taken from a reservoir above sea level so that heat is radiated and convected from the surface of the reservoir, water is allowed to fall under gravity to a location below the level of the reservoir at which heat exchange with the working fluid takes place and water is supplied to the reservoir from a source at or near sea level to replenish the reservoir.

35. A method as claimed in claim 34 wherein power is extracted from the water falling from the reservoir for heat exchange with the working fluid that power being used with supplemental power to pump the replenishing water up to the reservoir.

36. A method as claimed in claim 29 wherein the cold buffer substance comprises a eutectic salt slurry held in a reservoir, a supply of the slurry is allowed to fall under gravity from the reservoir to a level at which heat exchange with the working fluid takes place and the resulting salt solution is returned to the reservoir from which heat is emitted to maintain the reservoir at the required



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temperature level.

37. A method as claimed in claim 36 wherein
the buffer substance comprises water immediately
5 above its freezing point and the resulting ice produced
after heat exchange with the working fluid is formed
into a slurry with a substance which is endothermic in
solution to lower the temperature level of the slurry and
the resulting slurry is delivered for heat exchange
10 with the body of liquid in the reservoir to assist in
cooling the reservoir.

38. A method as claimed in claim 37
wherein the endothermic substance added to the ice
15 water slurry is hydrated calcium chloride.

39. A method as claimed in any of claims
30 to 38 wherein the cold buffer substance comprises
a slush of water and ice, the slush being delivered
20 for heat exchange with the working fluid from a
reservoir of the slush and returned as water to
the reservoir, heat being emitted from the surface of
the reservoir to maintain the slush of water and ice
at the required temperature level.

25 40. A method as claimed in claim 39
wherein the buffer substance comprises a store of
a liquid having a melting point of above 0°C, the
liquid being held in an insulated reservoir with a
30 surface arranged to absorb heat from its environment
to maintain the temperature level of the reservoir,
and the working fluid is passed through the reservoir
in heat exchange with the liquid to extract the latent
heat of fusion therefrom.

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41. A method as claimed in claim 38
wherein the reservoir is located in or adjacent a sea or lake
or ocean and the working fluid is passed in heat exchange
with the sea or lake or ocean prior to heat exchange
5 with the reservoir.

42. A method as claimed in any of claims
26 to 41 wherein the working fluid cycle comprises
boiling of a liquid by heat exchange with the buffer
10 substance to form a gas and superheating the gas.

43. A method as claimed in claim 42
wherein the gas is vapourised or superheated by
passing the gas through a duct having a convergent
15 section, a parallel bore section and then a divergent
section, the duct wall being heated to raise the
temperature of the gas as it flows through the parallel
bore section so that the resulting gas exiting from
the duct is vapourised or superheated.

20

44. A method as claimed in claim 43 wherein
the gas is superheated by heat exchange with a supply
of liquid at an appropriate temperature.



AMENDED CLAIMS

(received by the International Bureau on 14 January 1980 (14.01.80))

1. An apparatus for generating power which comprises means to conduct a working fluid through a closed cycle including heating, expansion, cooling and compression stages, the means to generate electrical power by expansion of the working fluid, a hot reservoir which receives heat from its environment and is capable of releasing heat in communication with the cycle of the heating stage to heat the working fluid, the hot reservoir comprises a buffer substance which is capable of releasing heat substantially isothermally to heat the working fluid, and a cold reservoir for releasing heat to its environment capable of receiving heat from the cycle at the cooling stage to extract heat from the working fluid, the cold reservoir comprising a further buffer substance capable of receiving heat substantially isothermally from the working fluid, characterised in that the cold reservoir (120) has an upper surface facing the sky for releasing heat thereto by radiation.

2. An apparatus as claimed in claim 1 wherein the hot and cold reservoirs comprise bodies at least partially of liquid (any remainder being solid phase) and exposed to natural environmental conditions.

3. An apparatus as claimed in claim 1 or claim 2 wherein the hot and cold reservoirs are so arranged that the air temperature over the hot reservoir is higher than that over the cold reservoir.

4. An apparatus as claimed in claim 3 wherein the cold reservoir is located at a higher altitude than the hot reservoir.



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5. An apparatus as claimed in any of claims 2 to 4 wherein the means to conduct the working fluid through a closed cycle include heat exchangers at the heating and cooling stages for heat exchange between the hot and cold reservoirs respectively and the working fluid.

6. An apparatus as claimed in claim 5 wherein the hot reservoir comprises water at or immediately above its freezing point to pass in heat exchange with the working fluid to produce a slurry of ice and water, the cold reservoir comprises a salt solution and means are provided for mixing ice resulting from heat exchange of the water from the hot reservoir with the working fluid with the salt solution to produce a cold eutectic salt slurry for heat exchange with the expanded working fluid to cool the working fluid.

7. An apparatus as claimed in claim 6 wherein the hot reservoir comprises an ocean, sea, lake or river.

8. An apparatus as claimed in claim 6 or claim 7 wherein the cold reservoir is located at a higher altitude than the hot reservoir and comprises a lake, containing a eutectic salt/ice slurry.

9. An apparatus as claimed in claim 8 wherein the reservoir is divided into upper and lower sections, the upper section containing the ice/salt slurry and the lower section containing a hydrated calcium chloride/ice mixture and means being provided for mixing ice produced from the heating of the working fluid and hydrated calcium chloride and supplying the resulting mixture to the lower section of the reservoir.



10. An apparatus as claimed in any of claims 2 to 4 wherein the hot reservoir comprises a vessel located in and insulated from the sea and containing a liquid having a melting point between 5 10 and 30°C and having a surface means for absorbing radiated heat from the environment and the cold reservoir comprises a lake at an altitude above sea level and containing a slush at between -5°C and 3°C.

10 11. An apparatus as claimed in any of claims 1 to 5 wherein the hot reservoir comprises a stream of water at or immediately above its freezing point, the working cycle is provided with parallel heat exchangers for heat exchange with the liquid of 15 the hot reservoir and means are provided for alternately causing the stream of water to flow over one or other heat exchanger so that when ice has accumulated on one heat exchanger, the flow can be diverted to the other to allow the ice on the first heat 20 exchanger to disperse and the cold reservoir comprises a deep salt lake located in a position substantially away from the direction of radiation from the sun.

12. An apparatus as claimed in any of 25 claims 1 to 5 wherein the hot reservoir comprises a body of water having a layer of liquid of higher melting point and of less density covering its surface and means are provided for floating heat exchange means for the hot reservoir in the surface layer of 30 liquid on the lake and, the lake being located in the position to receive direct solar radiation and the cold reservoir comprises a deep salt lake at the higher altitude than the hot reservoir and located out of direct solar radiation.

13. An apparatus as claimed in claim 12
wherein the flotation means for the heat exchanger
comprise sheets of corrugated metal supported on the
surface of the lake to receive solar radiation
5 on opposite sides of the respective corrugations and
having means to float the sheets and also to support
the heat exchanger.

14. An apparatus as claimed in claim 13
10 wherein a plurality of heat conductors extend from
said sheets of corrugated metal downwardly into the
body of water to conduct heat from the sheets into the
water.

15 15. An apparatus as claimed in claim 13
or claim 14 wherein means are provided for sinking the
heat exchanger through the layer of liquid on the
surface of the lake into the body of water in the lake.

20 16. An apparatus as claimed in any of claims
11 to 15 wherein the salt concentration in the deep
salt lake is arranged to increase from the surface of
the lake towards the lake bottom so that as the air
temperatures over the hot and cold reservoirs fall, the
25 formation of ice on the cold reservoir to an increasing
depth leaves a more concentrated salt solution below
having a lower freezing point and, thereby,
continuing to act as a buffer at progressively
lower temperatures to preserve a temperature difference
30 between the hot and cold reservoirs.

17. An apparatus as claimed in claim 16
wherein heat conductors are provided in the lake



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extending from the body of the lake above its surface to encourage release of heat from the lake.

18. An apparatus as claimed in claim 17
5 wherein the heat conductors have means at their upper ends to release heat by radiation.

19. An apparatus as claimed in any of
claims 11 to 18 wherein heat exchange means for
10 cooling the working fluid are located in a lower part of the lake and the hot reservoir with its heat exchange means are located at a lower altitude so that the resulting pressure head of the cooled fluid provides at least a part of the pressure
15 head required in the compression stage of the working cycle.

20. An apparatus as claimed in any of the preceding claims wherein means are provided in the working
20 cycle for heating and/or superheating the working fluid before the expansion stage.

21. An apparatus as claimed in claim 20 wherein the means for superheating the working fluid
25 comprise means for passing heat extracted from the earth or a source of waste heat in heat exchange with the working fluid.

22. An apparatus as claimed in claim 20
30 wherein the means for heating and/or superheating comprises one or more ducts each having a convergent section, a parallel bore section and then a divergent section, means being provided for heating the parallel bore section of the or each duct to heat and/or superheat the working fluid vapour
35 passing through the ducts.

23. An apparatus as claimed in any of the preceding claims wherein the working fluid is carbon dioxide or one of the FREONS (Registered Trade Mark) or other refrigerant.

5

24. An apparatus as claimed in any of the preceding claims and in the case where the heat exchanger for the hot reservoir is supported at the surface of a lake comprising water with an upper layer
10 of a further liquid, wherein the heat exchanger comprises a plurality of convergent/parallel/divergent tubes and the working fluid is both heated and superheated in said tubes.

15

25. An apparatus as claimed in any of the preceding claims wherein the means to conduct the working fluid through the closed cycle are arranged to conduct the fluid through the Rankine cycle, the cooling of the working fluid by the cold reservoir condensing the fluid.

20

26. A method of generating power comprising taking a working fluid through a closed cycle in which the fluid is heated at a relatively high temperature T_2 by heat exchange with one buffer substance (as herein-
25 before defined) at a temperature T_H higher than T_2 (release of heat from the buffer substance being accompanied by a change of state of the substance to a lower energy level) expanding the fluid and generating a power output derived from the energy released in
30 expansion of the fluid, rejecting heat from the expanded fluid to a cold buffer substance (as hereinbefore defined) at a relatively low temperature the cold buffer substance being at a temperature T_C below that of the expanded fluid T_2 and extracting heat
35 from the expanded fluid accompanied by a change of state of the cold buffer substance to a higher energy level and returning the working fluid to the beginning of the working cycle.



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27. A method as claimed in claim 25 wherein the cycle through which the working fluid is taken is a Rankine cycle and the cooling of the working fluid by the cold buffer substance condenses the fluid prior to
5 compression and return to the beginning of the cycle.

28. A method as claimed in claim 26 or 27 wherein the release of heat from the first buffer substance to heat the working fluid is derived from
10 the latent heat of fusion of the buffer substance.

29. A method as claimed in claim 28 wherein at least a proportion of the buffer substance remains in liquid form during the transfer of heat.
15

30. A method as claimed in any of claims 25 to 29 wherein the cold buffer substance comprises a liquid-solid mixture, the change of state of the substance to extract heat from the working fluid
20 comprising melting of the solid component of the said mixture.

31. A method as claimed in claim 30 wherein the buffer substance comprises water, at least
25 a proportion of the water being solidified to form ice and thereby releasing its latent heat of fusion in heat exchange with the working fluid and the cold buffer substance comprises ice and water from the buffer substance together with salt to form a eutectic
30 salt slurry at a temperature below the freezing point of water.



32. A method as claimed in claim 30 wherein the salt solution formed from the cold buffer substance after heat exchange with the working fluid is allowed to dry under atmospheric conditions and the resulting
5 salt is extracted to provide the salt supply of the cold buffer substance.

33. A method as claimed in claim 32 wherein the salt solution is passed in heat exchange with
10 water of the buffer substance prior to drying to create further ice to supplement the supply of ice for the cold buffer substance.

34. A method as claimed in claim 32
15 or claim 33 wherein the buffer substance comprises a supply of water taken from a reservoir above sea level so that heat is radiated and convected from the surface of the reservoir, water is allowed to fall under gravity to a location below the level of the reservoir
20 at which heat exchange with the working fluid takes place and water is supplied to the reservoir from a source at or near sea level to replenish the reservoir.

35. A method as claimed in claim 34
25 wherein power is extracted from the water falling from the reservoir for heat exchange with the working fluid that power being used with supplemental power to pump the replenishing water up to the reservoir.

36. A method as claimed in claim 29
30 wherein the cold buffer substance comprises a eutectic salt slurry held in a reservoir, a supply of the slurry is allowed to fall under gravity from the reservoir to a level at which heat exchange with the working fluid takes place and the resulting salt
35 solution is returned to the reservoir from which heat is emitted to maintain the reservoir at the required



temperature level.

37. A method as claimed in claim 36 wherein
the buffer substance comprises water immediately
5 above its freezing point and the resulting ice produced
after heat exchange with the working fluid is formed
into a slurry with a substance which is endothermic in
solution to lower the temperature level of the slurry and
the resulting slurry is delivered for heat exchange
10 with the body of liquid in the reservoir to assist in
cooling the reservoir.

38. A method as claimed in claim 37
wherein the endothermic substance added to the ice
15 water slurry is hydrated calcium chloride.

39. A method as claimed in any of claims
30 to 38 wherein the cold buffer substance comprises
a slush of water and ice, the slush being delivered
20 for heat exchange with the working fluid from a
reservoir of the slush and returned as water to
the reservoir, heat being emitted from the surface of
the reservoir to maintain the slush of water and ice
at the required temperature level.

25
40. A method as claimed in claim 39
wherein the buffer substance comprises a store of
a liquid having a melting point of above 0°C, the
liquid being held in an insulated reservoir with a
30 surface arranged to absorb heat from its environment
to maintain the temperature level of the reservoir,
and the working fluid is passed through the reservoir
in heat exchange with the liquid to extract the latent
heat of fusion therefrom.

41. A method as claimed in claim 38
wherein the reservoir is located in or adjacent a sea or lake
or ocean and the working fluid is passed in heat exchange
with the sea or lake or ocean prior to heat exchange
5 with the reservoir.

42. A method as claimed in any of claims
26 to 41 wherein the working fluid cycle comprises
boiling of a liquid by heat exchange with the buffer
10 substance to form a gas and superheating the gas.

43. A method as claimed in claim 42
wherein the gas is vapourised or superheated by
passing the gas through a duct having a convergent
15 section, a parallel bore section and then a divergent
section, the duct wall being heated to raise the
temperature of the gas as it flows through the parallel
bore section so that the resulting gas exiting from
the duct is vapourised or superheated.

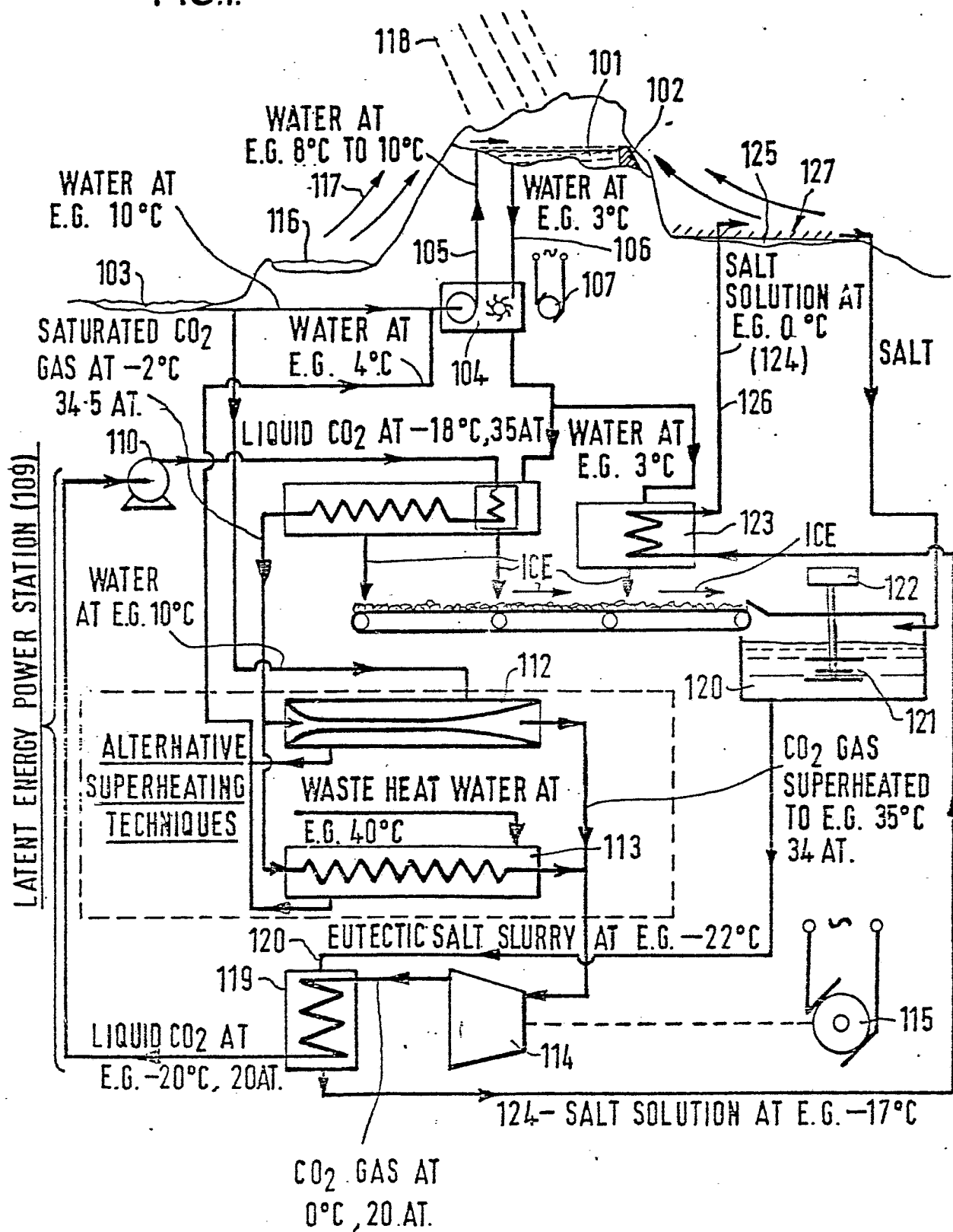
20

44. A method as claimed in claim 43 wherein
the gas is superheated by heat exchange with a supply
of liquid at an appropriate temperature.



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FIG.1.



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FIG. 6.—SPECIAL TEMPERATE REGION EMBODIMENT
(E.G. WESTERN SCOTLAND/IRELAND IN WINTER)

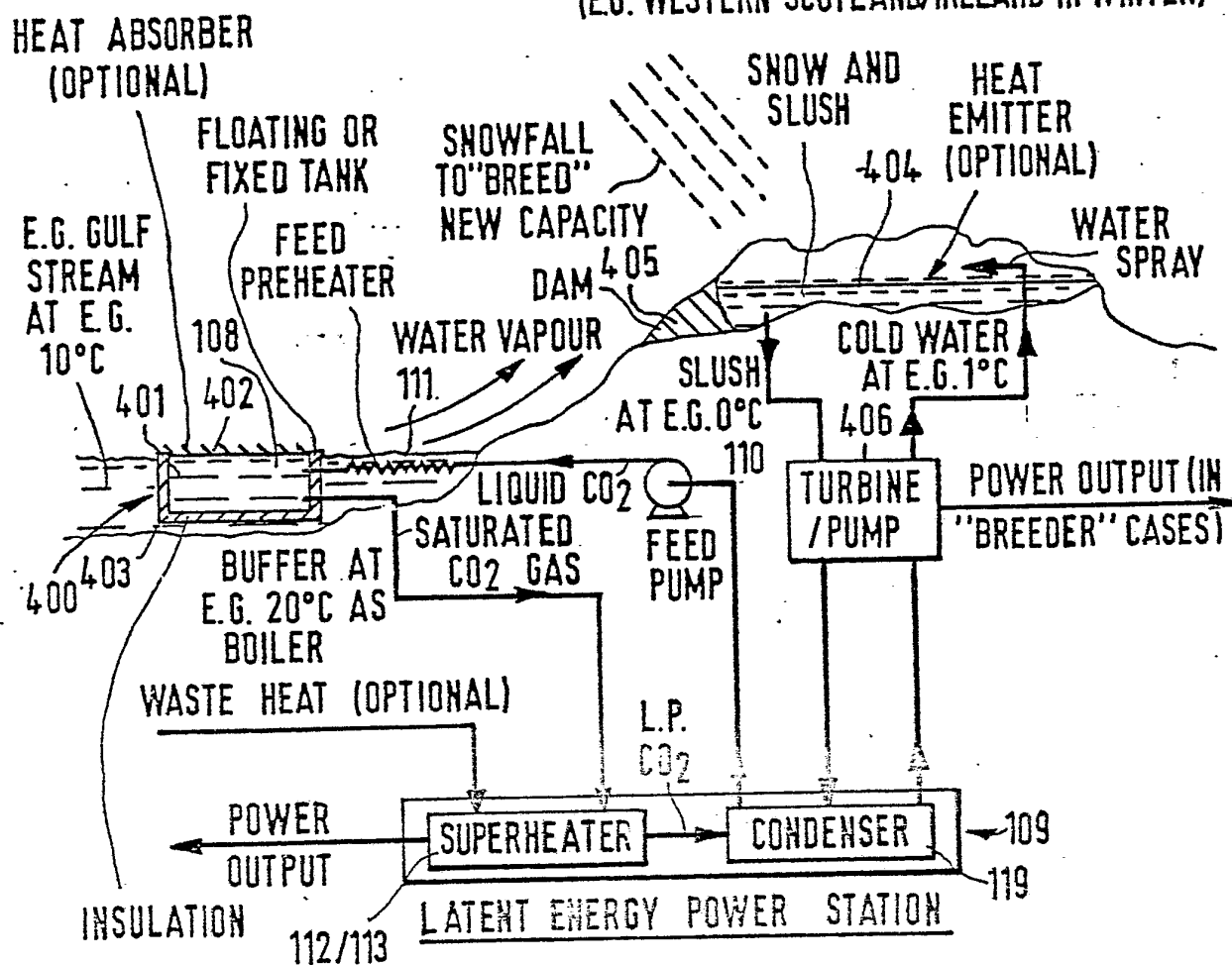


FIG. 2.

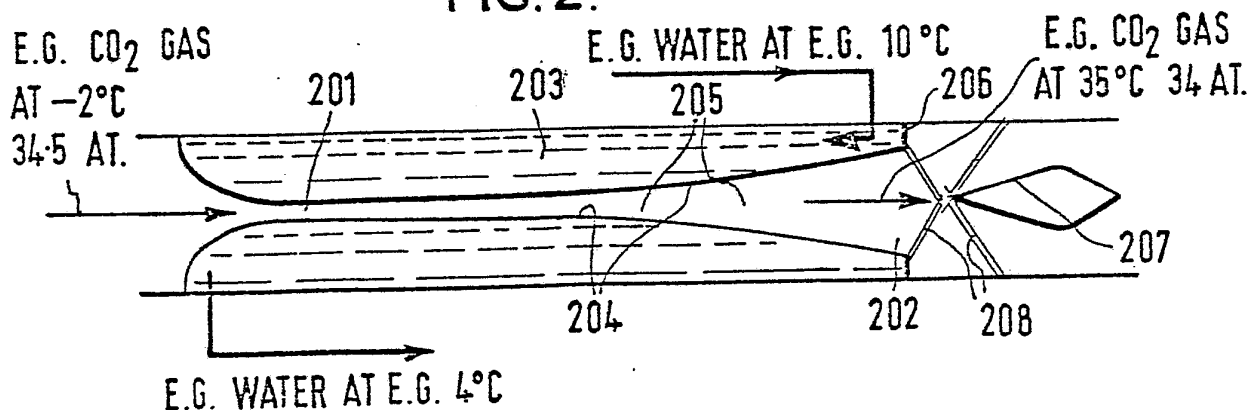
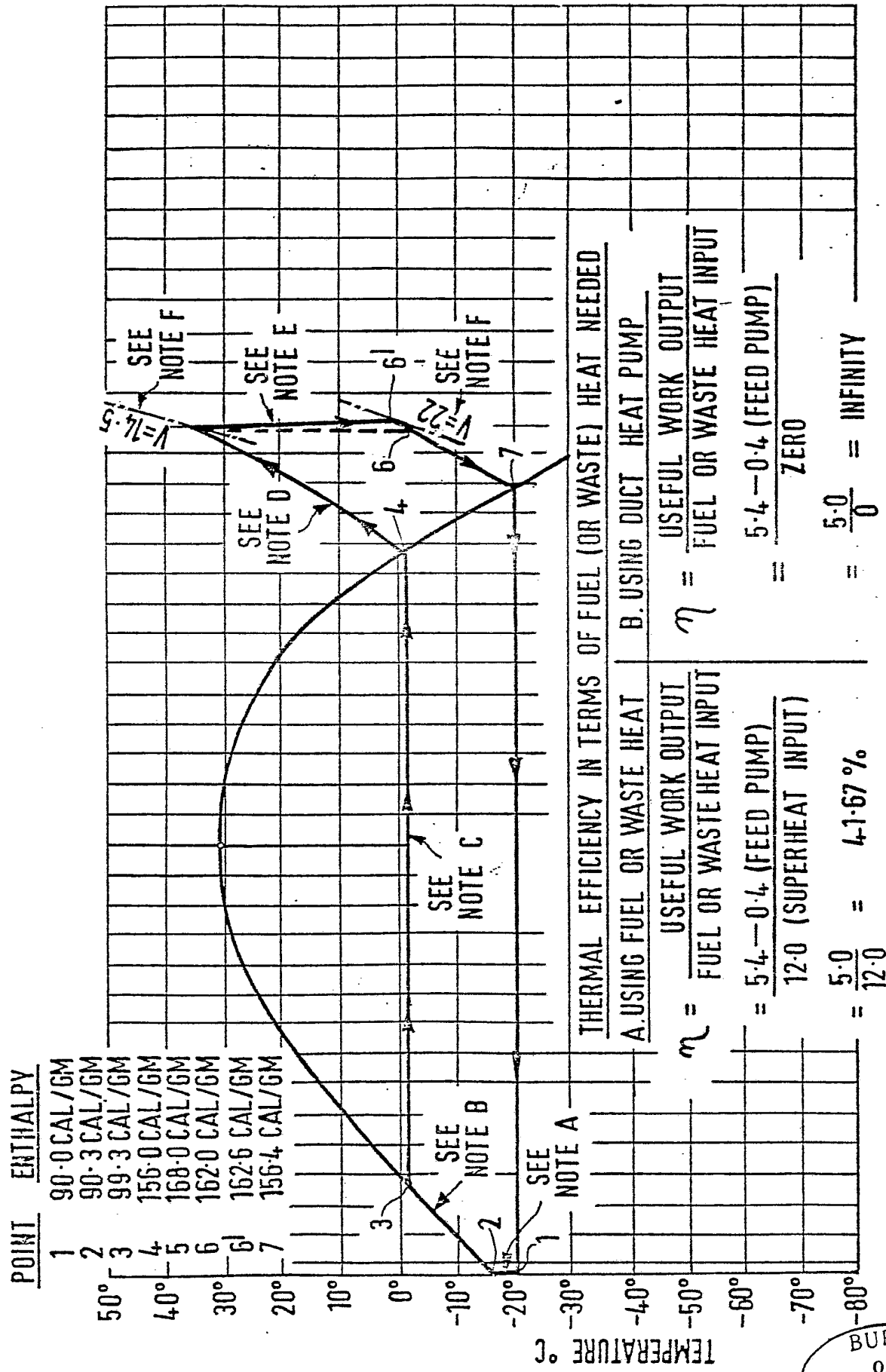


FIG. 3.



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SUPPLEMENTARY SHEET TO FIG. 3.

NOTE A: BOILER FEED PUMP WORK INPUT =

$$\frac{\text{ENTHALPY INCREASE FROM POINT 1 TO POINT 2}}{\text{EFFICIENCY OF BOILER FEED PUMP}} \\ = \frac{90.3 - 90.0 \text{ CAL/GM}}{0.75 \text{ (SAY)}} = \frac{0.3 \text{ CAL/GM}}{0.75} = 0.4 \text{ CAL/GM}$$

NOTE B: FEED HEATING INPUT =

$$\text{ENTHALPY INCREASE FROM POINT 2 TO POINT 3} \\ = 99.3 \text{ CAL/GM} - 90.3 \text{ CAL/GM} = 9.0 \text{ CAL/GM}$$

NOTE C: BOILING HEAT INPUT =

$$\text{ENTHALPY INCREASE FROM POINT 3 TO POINT 4} \\ = 156.0 \text{ CAL/GM} - 99.3 \text{ CAL/GM} = 56.7 \text{ CAL/GM}$$

NOTE D: SUPERHEAT INPUT =

$$\text{ENTHALPY INCREASE FROM POINT 4 TO POINT 5} \\ = 168.0 \text{ CAL/GM} - 156.0 \text{ CAL/GM} = 12.0 \text{ CAL/GM}$$

NOTE E: USEFUL WORK OUTPUT: (a) IF ISENTROPIC, WORK OUTPUT
= ENTHALPY DECREASE FROM POINT 5 TO POINT 6
= 168.0 CAL/GM - 162.0 CAL/GM = 6.0 CAL/GM

(b) AT 90% ISENTROPIC EFFICIENCY,

$$\text{WORK OUTPUT} \\ = \text{ENTHALPY DECREASE FROM POINT 5 TO POINT 6} \\ = 6.0 \times 90\% = 5.4 \text{ CAL/GM}$$

NOTE F: EXPANDER MUST EXPAND THE CO₂ FROM A SPECIFIC VOLUME OF 14.5 ML/GM TO A SPECIFIC VOLUME OF 22 ML/GM. THE EXPANDER MUST THEREFORE HAVE AN EXPANSION RATIO OF $\frac{22}{14.5} = 1.52$



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FIG. 4.-DESERT REGION EMBODIMENT

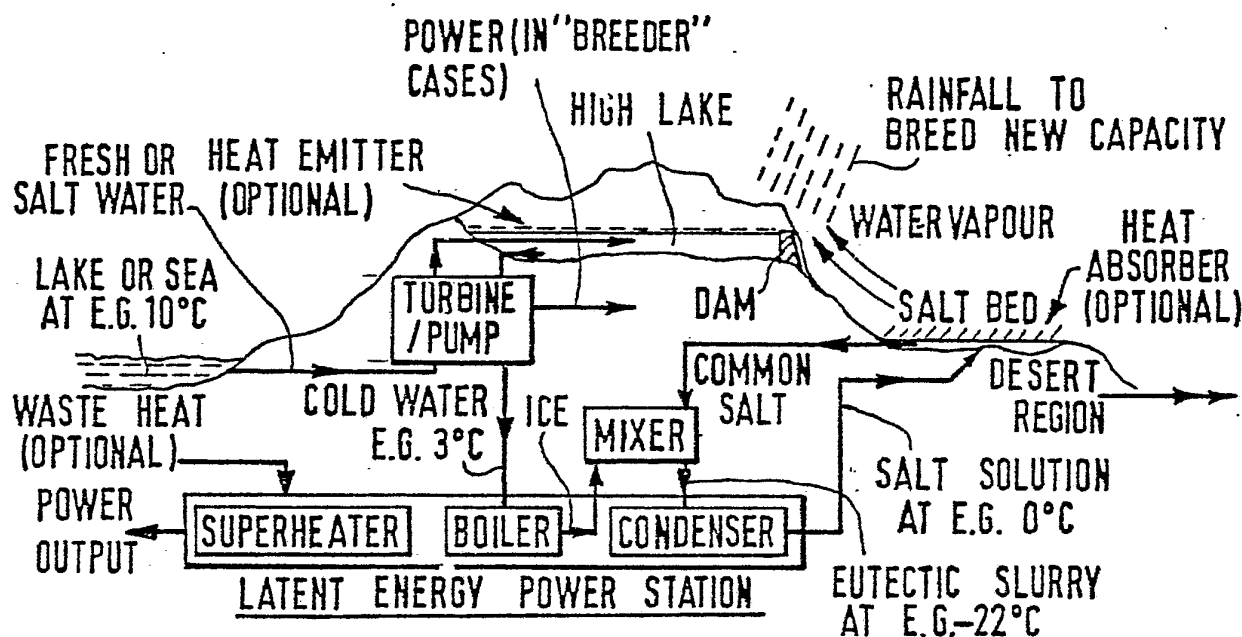
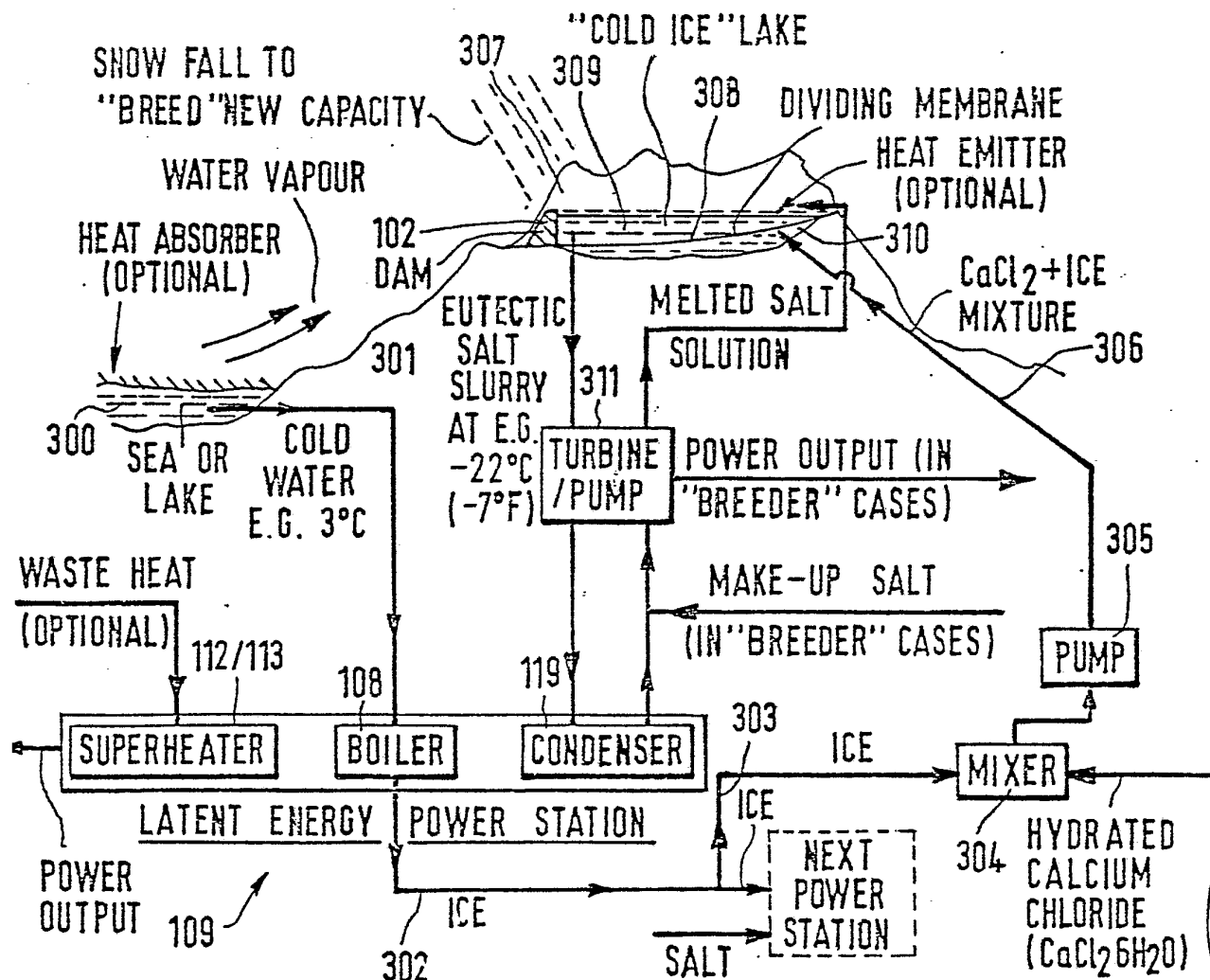


FIG. 5.-SUB ARCTIC OR MOUNTAIN REGION EMBODIMENT



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FIG. 7.

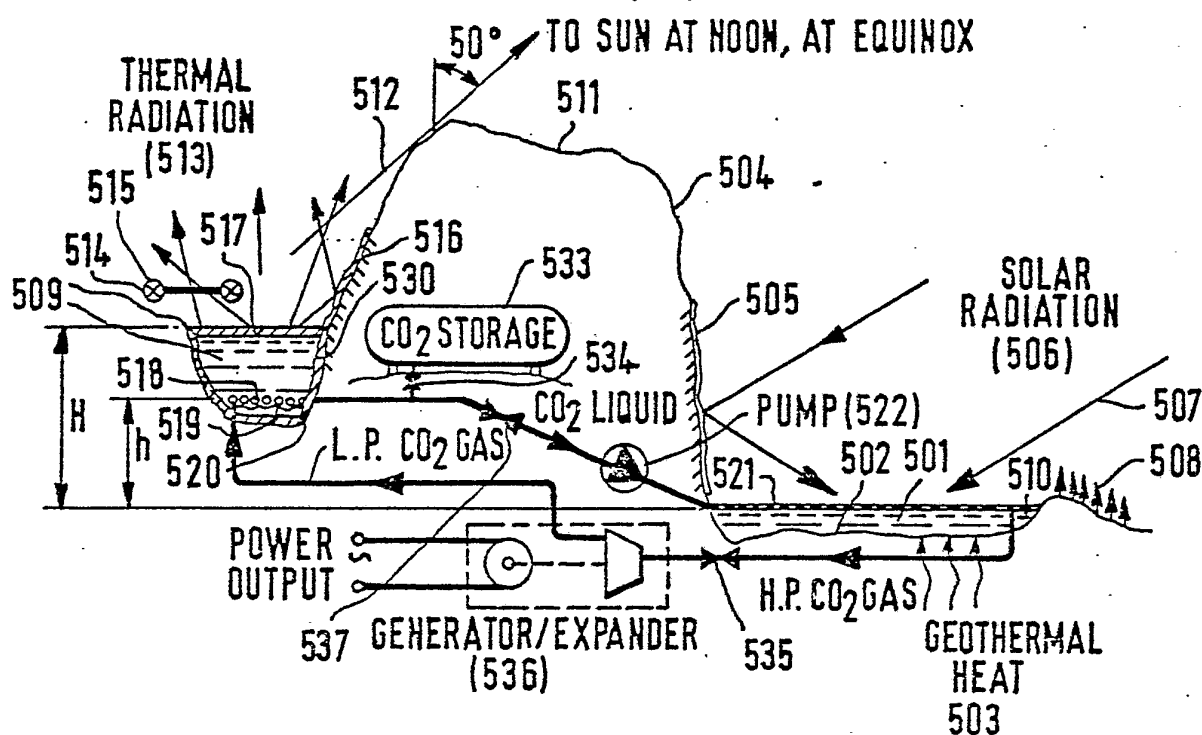
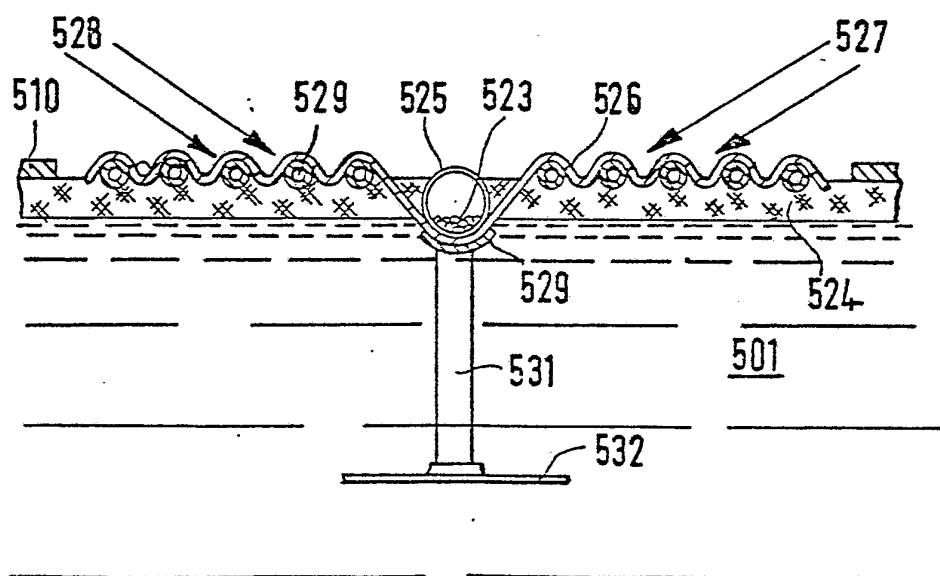
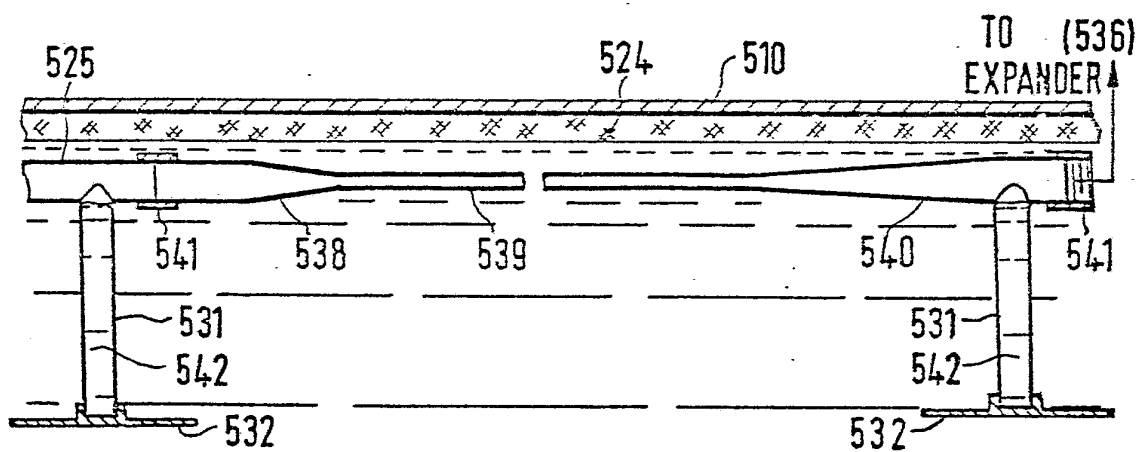


FIG. 8.



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FIG. 9.



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 79/00024

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) * According to International Patent Classification (IPC) or to both National Classification and IPC		
F 03 G 7/04; F 01 K 25/10; F 24 J 3/02; F 22 G 1/00		
II. FIELDS SEARCHED		
Minimum Documentation Searched 4		
Classification System	Classification Symbols	
Int.Cl. ²	F 03 G; F 01 K; F 24 J	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 5		
III. DOCUMENTS CONSIDERED TO BE RELEVANT 14		
Category *	Citation of Document, 16 with indication, where appropriate, of the relevant passages 17	Relevant to Claim No. 13
A	US, A, 4104883, published 8th August 1978, see column 2, lines 33-68; columns 3,4; column 5, lines 1-19; colonne 6, lines 55-68; colonne 7, lines 1-4; figures, NAEF	1,2,5,25,26, 27,28,29,30
	DE, A, 2819946, published 7th December 1978, see page 9, lines 17-28; page 10, lines 1-5; figures, Jackson	1,2,5,25,26, 27
	US, A, 3953971, published 4th May 1976, see column 2, lines 44-68; column 3, lines 1-15; column 4, lines 33-39; column 5, lines 31-36; figures, Parker	1,2,3,4,5, 7,23,35
	CH, A, 339432, published 15th August 1959, see page 1, lines 43-60; page 2, lines 97-101; figures, Rüegg	1,2,3,4,5,7, 35
	DE, A, 2650236, published 3rd May 1978, Crede	1,2,28,29,31
	FR, A, 2383329, published 6th October 1978, Cicero	1
* Special categories of cited documents: 15 "A" document defining the general state of the art "E" earlier document but published on or after the international filing date "L" document cited for special reason other than those referred to in the other categories "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but on or after the priority date claimed "T" later document published on or 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		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search *	Date of Mailing of this International Search Report *	
5th October 1979	16th October 1979	
International Searching Authority 1	Signature of Authorized Officer 20	
European Patent Office	G.L.M. Kruidenberg	