



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
05.03.2014 Bulletin 2014/10

(51) Int Cl.:
F01K 25/10 (2006.01)

(21) Application number: **12182561.6**

(22) Date of filing: **31.08.2012**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(72) Inventors:
• **Sormunen, Risto**
00940 Helsinki (FI)
• **Raiko, Markku**
05800 Hyvinkää (FI)

(71) Applicant: **Fortum OYJ**
02150 Espoo (FI)

(74) Representative: **Papula Oy**
Mechelininkatu 1 a
00180 Helsinki (FI)

(54) **Method and system for energy storing and short-term power generation**

(57) In a method for energy storing and short-term power generation, an intermediate storage of a CCS system is used to store the working fluid of a CO₂ based Rankine process. Liquid CO₂ is stored in an underground reservoir (10) arranged to continually receive liquid CO₂ at a first temperature from one or more CO₂ capture sites and to discharge liquid CO₂ to be transported to a final storage. The underground reservoir (10) is kept at a pressure of 8 - 10 bar. When short-term power generation is needed, liquid CO₂ is withdrawn from the underground

reservoir (10), pressurized to about 40 - 50 bar, evaporated with the help of a low value heat source, and expanded in an expander turbine (13), which is connected to a generator (14). The expanded CO₂ is then condensed and returned to the underground reservoir (10) at a second temperature which is higher than the first temperature. When short-term power generation is no more needed, liquid CO₂ from the underground reservoir (10) is circulated through a heat pump (23) to cool the CO₂ until its temperature reaches the first temperature.

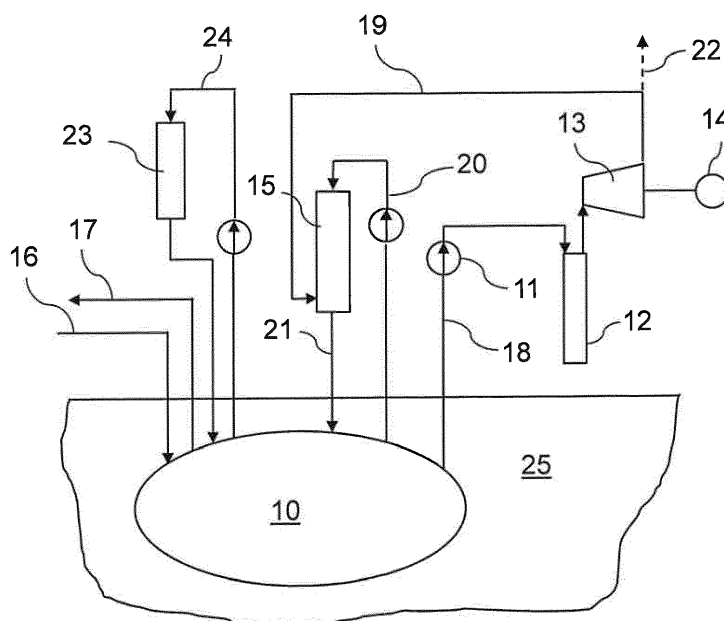


FIG. 1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method and a system for energy storing and short-term power generation. Quick short-term high capacity power generation is usually needed for back-up or peak load power supply.

BACKGROUND OF THE INVENTION

[0002] The ambitious target of the European Renewable Directive is that by 2020 20% of energy is produced from renewable sources. This means renewable power capacity of about 220 GW. About 80% of this capacity is estimated to be coming from variable and less predictable sources, such as onshore and offshore wind power or solar systems. In longer term this trend is expected to continue. This means that the total energy generation will be highly variable, leading to increased price volatility of electricity. The system will be strongly dependent on weather conditions, particularly in the Central and Northern Europe, where cloudy and windless weather conditions often dominate during winter. Without proper energy storages this will lead to a situation where the European electricity system needs substantially more than 100 GW quick short-term and longer-term back-up power available all the time. Old coal-fired power plants can be taken into service after certain period of time, in practice within several hours. Thus, quick-term back-up power has to be ready for use from hydroelectric power, which is not always available, or peaking reserve power, such as gas turbines or diesel engines. Anyway, huge investments for back-up capacity are expected. Obviously, there is an increasing need for more cost efficient solutions in the energy market.

[0003] At the same time it seems now to be evident that to prevent or at least delay global warming and other problems due to the still growing worldwide CO₂ emissions Carbon Capture and Storage (CCS) solutions have to be implemented extensively. The future of CCS storages at onshore sites seems to be out of the question especially in Europe because of the public resistance. Thus, offshore storages will finally be the only probable solution for CCS, leading to shipping-based transportation of liquefied CO₂. Intermediate storages of CO₂ must then be founded near such harbors where to liquid CO₂ can be pumped via pipeline network from the CO₂ capture sites - power plants and industrial plants - before shipping to the final offshore storages.

[0004] To be as cost efficient as possible in a total CCS system, the transportation network has to collect liquid CO₂ from various sources to an intermediate storage before shipping. According to several studies, the intermediate storage must be of quite a large volume, whereby in most cases steel tanks and other on-the-ground solutions tend to become highly expensive. One of the best alternatives is then to base the storage in the bedrock at

a depth where hydrostatic pressure will minimize the energy needed for keeping the storage conditions at a suitable pressure and temperature.

[0005] US 2012/0001429 A1 discloses a carbon dioxide-based geothermal energy generation system comprising a reservoir located below a caprock, one or more injection wells for feeding cold CO₂ into the reservoir, and one or more production wells for discharging heated CO₂ from the reservoir. An energy converting apparatus is connected to each injection well and to each production well so that thermal energy contained in the heated CO₂ can be converted to electricity, heat, or combinations thereof. Compressed CO₂ at a pressure of 30 - 70 bar and a temperature below 30°C is injected to the underground reservoir, and heated CO₂ with a temperature greater than 30°C is drawn off the reservoir. The system is quite complicated and high pressure is needed in the underground reservoir. The system cannot be considered feasible for peak load operation because of its high nominal investment cost. Also the operational risks are high because of high medium pressure and uncontrolled evaporation of CO₂ in the underground reservoir.

[0006] EP 277777 A2 discloses a system for storing electrical energy in the form of triple-point CO₂ and then using such stored energy plus heat to generate electrical power. A reservoir for liquid CO₂ at about the triple point is created in an insulated vessel. Liquid CO₂ is withdrawn and pumped to a high pressure, which high pressure CO₂ is then heated and expanded to create rotary power which generates electrical power. The discharge stream from the expander is cooled and returned to the vessel where CO₂ vapor is condensed by melting solid CO₂. A fuel-fired gas turbine connected to an electrical power generator is used to heat the high pressure CO₂. The size of an overground CO₂ reservoir is limited. The investment cost is high. Certain operational risks prevail when acting with a triple point medium.

[0007] US 4995234 discloses a method for generating power from liquefied natural gas (LNG) and storing energy. Cold LNG is pressurized, vaporized by removing heat from CO₂ at about triple point temperature, further heated, and finally expanded to create rotary power. A reservoir of CO₂ at about its triple point is created in an insulated vessel to store energy in the form of refrigeration recovered from the evaporated LNG. During peak electrical power periods, liquid CO₂ is withdrawn from the reservoir, pumped to a high pressure, vaporized, further heated, and expanded to create rotary power which generates additional electrical power. During off-peak periods, CO₂ vapor is withdrawn from the reservoir and condensed to liquid by vaporizing LNG. The size of an overground CO₂ reservoir is limited. A fuel-fired gas turbine is needed in the system. The investment cost is high. Certain operational risks prevail when acting with a triple point medium.

PURPOSE OF THE INVENTION

[0008] The object of the present invention is to eliminate the problems of the prior art and to provide an improved method and system for energy storing and short-term power generation.

[0009] Another object is to improve the feasibility of carbon capture and storage (CCS) solutions.

[0010] A further object is to create a system that enables the use of low value heat sources and reduces the use of fossil fuels.

SUMMARY

[0011] The invention employs an intermediate storage of a CCS system as storage for working fluid used in short-term power generation system that uses CO₂ based Rankine cycle and heat pump in turns.

[0012] The invention provides a method for energy storing and short-term power generation, comprising the steps of:

a) storing liquid CO₂ in an underground reservoir arranged to continually receive liquid CO₂ at a first temperature from one or more CO₂ capture sites and to discharge liquid CO₂ for shipping to a final offshore storage, the underground reservoir being maintained at a pressure of 8 - 10 bar;

b) when short-term power generation is needed, carrying out the following steps:

- withdrawing liquid CO₂ from the underground reservoir and increasing the pressure of the liquid CO₂ to about 40 - 50 bar;
- evaporating the pressurized CO₂ with the help of a low value heat source;
- expanding the evaporated CO₂ to a pressure of 8 - 10 bar, whereby rotary power is produced which is used for generation of electrical power;
- condensing the expanded CO₂ and returning the condensed CO₂ to the underground reservoir at a second temperature which is higher than the first temperature;

c) when short-term power generation is no more needed, circulating liquid CO₂ of the underground reservoir through a heat pump to cool the liquid CO₂ until its temperature reaches the first temperature.

[0013] The first temperature, i.e., the temperature of fresh CO₂ supplied to the underground reservoir, can be -45°C ... -55°C, preferably about -50°C. The second temperature, i.e. the temperature of CO₂ returning from the Rankine cycle, can be -15°C ... -25°C, preferably about -20°C.

[0014] Advantageously, the underground reservoir is located in the bedrock at a depth of 200 - 300 m. The volume of the underground reservoir is preferably over

50 000 m³, for instance in the range of 50 000 - 150 000 m³.

[0015] The term "underground reservoir" as used herein refers to geological formations beneath the surface of the earth, irrespective of whether they are underground or undersea.

[0016] The pressurized liquid CO₂ can be evaporated with the help of sea water, atmospheric air, industrial waste heat, etc.

[0017] The invention also provides a system for energy storing and short-term power generation, comprising:

- an underground reservoir arranged to continually receive liquid CO₂ at a first temperature from one or more CO₂ capture sites and to continually discharge liquid CO₂ for shipping to a final offshore storage, the underground reservoir being maintained at a pressure of 8 - 10 bar;
- a pump for withdrawing liquid CO₂ from the underground reservoir and for pressurizing the liquid CO₂ to a pressure of about 40 - 50 bar;
- a heat exchanger for evaporating the pressurized CO₂ with the help of a low value heat source;
- an expander turbine for expanding the evaporated CO₂ to a pressure of 8 - 10 bar, thereby producing rotary power, and a generator connected to the turbine for generating electrical power from the rotary power;
- a condenser for condensing the expanded CO₂;
- means for feeding the condensed CO₂ back to the underground reservoir at a temperature which is higher than the temperature of liquid CO₂ withdrawn from the underground reservoir;
- means for circulating liquid CO₂ of the underground reservoir through a heat pump to cool the liquid CO₂ until its temperature reaches the first temperature.

[0018] The system can also comprise means for releasing expanded CO₂ to the atmosphere when extreme short-term power generation is needed.

[0019] The invention improves the overall economy of Carbon Capture and Storage solutions. Today, CCS is just an expense for power generation systems, which delays the implementation of CCS throughout Europe.

[0020] For a storage of 50 000 m³, the capacity of the new system is estimated to be about 200 MW during 4 hours. If instead of sea water excess heat from a CHP system can be used for the evaporation, the capacity of the system is estimated to be up to 300 MW during 4 hours. The total storage efficiency is in both cases 70 - 80%, or even more.

[0021] The additional cost of the proposed CO₂ based Rankine cycle and heat pump system comprises the cost of additional components, such as an evaporator, an expander turbine and a condenser. These costs are minor compared to the costs of many other back-up power devices, such as gas turbines or diesel generators. Furthermore, the relative size of the components of the new sys-

tem is definitely smaller than the size of components in hydroelectric systems, or even gas turbines. The use of carbon dioxide as the working fluid in a Rankine cycle enables the use of low temperature solutions, which leads into smaller component sizes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The accompanying drawing illustrates an embodiment of the invention and together with the description helps to explain the principles of the invention.

[0023] Fig. 1 is a diagrammatic illustration of a short-term power generation system according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Figure 1 schematically illustrates a system according to the invention. A short-term high capacity power generation cycle employing Rankine cycle comprises an underground reservoir 10 for storage of liquid CO₂, a pump 11 for pressurizing liquid CO₂ withdrawn from the underground reservoir 10, an evaporator 12 for evaporating the pressurized CO₂, an expander turbine 13 for expanding the evaporated CO₂, a generator 14 for converting rotary power to electricity, and a condenser 15 for condensing the expanded CO₂ before it is returned back to the underground reservoir 10.

[0025] Intermediate storage of liquid CO₂ in a CCS system is usually carried out in geological formations, which are located in a bedrock underground or undersea. Such an underground reservoir is arranged to continuously or repeatedly receive liquefied CO₂ from CO₂ capture sites. At the same time, liquid CO₂ is continuously or repeatedly discharged from the intermediate storage to a final storage, which may be offshore or onshore. The intermediate storage is intended for short-term storing only and the content of the storage is changing continually.

[0026] The underground reservoir 10 is located in the bedrock 25 at a depth of 200 - 300 m, and the volume of the underground reservoir 10 is preferably in the range of 50 000 - 150 000 m³. Liquefied CO₂ is continually supplied from one or more industrial sources to the underground reservoir 10 via an inlet pipe 16. The temperature of CO₂ supplied via the inlet pipe 16 is about -50°C. Liquid CO₂ is maintained in the intermediate storage 10 under a pressure of about 8 - 10 bar. Liquid CO₂ is continually discharged from the intermediate storage 10 via an outlet pipe 17 to be transported to a final storage (not shown).

[0027] The evaporator 12 is connected to the underground reservoir 10 via a pipeline 18 and a pump 11 arranged in the pipeline 18. When short-term power generation is needed, liquid CO₂ is withdrawn from the intermediate storage 10 and compressed with the pump 11 to a pressure of about 40 - 50 bar. Pressurized CO₂ is passed to the evaporator 12, which vaporizes the pressurized CO₂ with the help of heat from a suitable low value heat source. This heat source may comprise, for instance, sea water at a temperature of 5°C - 15°C, waste

heat from a district heating system at a temperature of up to 90°C, or atmospheric air. Other possible low value heat sources comprise e.g. water from a river or a lake, geothermal heat, ambient air, and waste heat of an industrial plant or power generation.

[0028] The pressurized CO₂ is typically evaporated at a temperature between +5°C and +20°C. From the evaporator 12 the vaporized CO₂ is fed to the expander turbine 13, where the vaporized CO₂ expands to a pressure of about 8 - 10 bar, thereby creating rotary power which is transferred to the generator 14 that converts mechanical energy to electrical power.

[0029] From the expander turbine 13 the expanded CO₂ is transferred via a pipeline 19 to the condenser 15, where the expanded CO₂ is condensed with the help of liquid CO₂ pumped from the underground reservoir 10 via a pipeline 20. Condensed CO₂ is then returned back to the underground reservoir 10 via a pipeline 21.

[0030] Liquid CO₂ fed to the underground reservoir 10 via the pipeline 21 has a higher temperature than the liquid CO₂ leaving the underground reservoir 10 via the pipeline 18. As a consequence, the temperature of the intermediate storage 10 can gradually rise from about -50°C to about -20°C during a short-term power generation period.

[0031] At a point of time when back-up or peak load power is no more needed, the underground reservoir 10 may be "recharged" by chilling the liquid CO₂ back to a temperature of about -50°C. This can be done by circulating liquid CO₂ through a pipeline 24 and a heat pump 23 to cool the liquid CO₂ until the temperature in the underground reservoir 10 has reached the desired level.

[0032] The system also comprises an option to exceptionally release a part of the expanded CO₂ to the atmosphere via a pipeline 22 to increase the power generation capacity of the system.

[0033] It is obvious to a person skilled in the art that with the advancement of technology, the basic idea of the invention may be implemented in various ways. The invention and its embodiments are thus not limited to the examples described above; instead they may vary within the scope of the claims.

Claims

1. A method for energy storing and short-term power generation, comprising the steps of:

- a) storing liquid CO₂ in an underground reservoir (10) arranged to continually receive liquid CO₂ at a first temperature from one or more CO₂ capture sites and to discharge liquid CO₂ to be transported to a final storage, the underground reservoir (10) being maintained at a pressure of 8 - 10 bar;
- b) when short-term power generation is needed, carrying out the following steps:

- withdrawing liquid CO₂ from the underground reservoir (10) and increasing the pressure of the liquid CO₂ to about 40 - 50 bar;
 - evaporating the pressurized CO₂ with the help of a low value heat source;
 - expanding the evaporated CO₂ to a pressure of 8 - 10 bar, whereby rotary power is produced which is used for generation of electrical power;
 - condensing the expanded CO₂ and returning the condensed CO₂ to the underground reservoir (10) at a second temperature which is higher than the first temperature;
- c) when short-term power generation is no more needed, circulating liquid CO₂ from the underground reservoir (10) through a heat pump (23) to cool the liquid CO₂ until its temperature reaches the first temperature.
2. A method according to claim 1, wherein the first temperature is -45°C ... -55°C, preferably about -50°C, and the second temperature is -15°C ... -25°C, preferably about -20°C.
 3. A method according to claim 1, wherein the underground reservoir (10) is located in the bedrock (25) at a depth of 200 - 300 m, and the volume of the underground reservoir (10) is over 50 000 m³, for instance in the range of 50 000 - 150 000 m³.
 4. A method according to any one of claims 1 to 3, wherein the pressurized liquid CO₂ is evaporated with the help of a low value heat source, such as for instance sea water, atmospheric air, industrial waste heat, etc.
 5. A system for energy storing and short-term power generation, comprising:
 - an underground reservoir (10) arranged to continually receive liquid CO₂ at a first temperature from one or more CO₂ capture sites and to continually discharge liquid CO₂ to be transported to a final storage, the underground reservoir (10) being maintained at a pressure of 8 - 10 bar;
 - a pump (11) for withdrawing liquid CO₂ from the underground reservoir (10) and for pressurizing the liquid CO₂ to a pressure of 40 - 50 bar;
 - a heat exchanger (12) for evaporating the pressurized CO₂ with the help of a low value heat source;
 - a turbine (13) for expanding the evaporated CO₂ to a pressure of 8 - 10 bar, thereby producing rotary power, and a generator (14) connected to the turbine (13) for generating electrical power from the rotary power;
 - a condenser (15) for condensing the expanded CO₂;
 - means (21) for feeding the condensed CO₂ back to the underground reservoir (10) at a higher temperature than the temperature of liquid CO₂ withdrawn from the underground reservoir (10);
 - means (24) for circulating liquid CO₂ withdrawn from the underground reservoir (10) via a heat pump (23) to cool the liquid CO₂ back to the first temperature during periods when short-term power generation is not needed.
 6. A system according to claim 5, wherein the underground reservoir (10) is located in the bedrock (25) at the depth of 200 - 300 m, and the volume of the underground reservoir (10) is over 50 000 m³, for instance in the range of 50 000 - 150 000 m³.
 7. A system according to claim 5 or 6, further comprising means (22) for releasing expanded CO₂ to the atmosphere when extreme short-term power generation is needed.
 8. A system according to any one of claims 5 to 7, wherein the heat exchanger (12) is arranged to utilize low value heat sources, such as sea water, atmospheric air, industrial waste heat, etc.

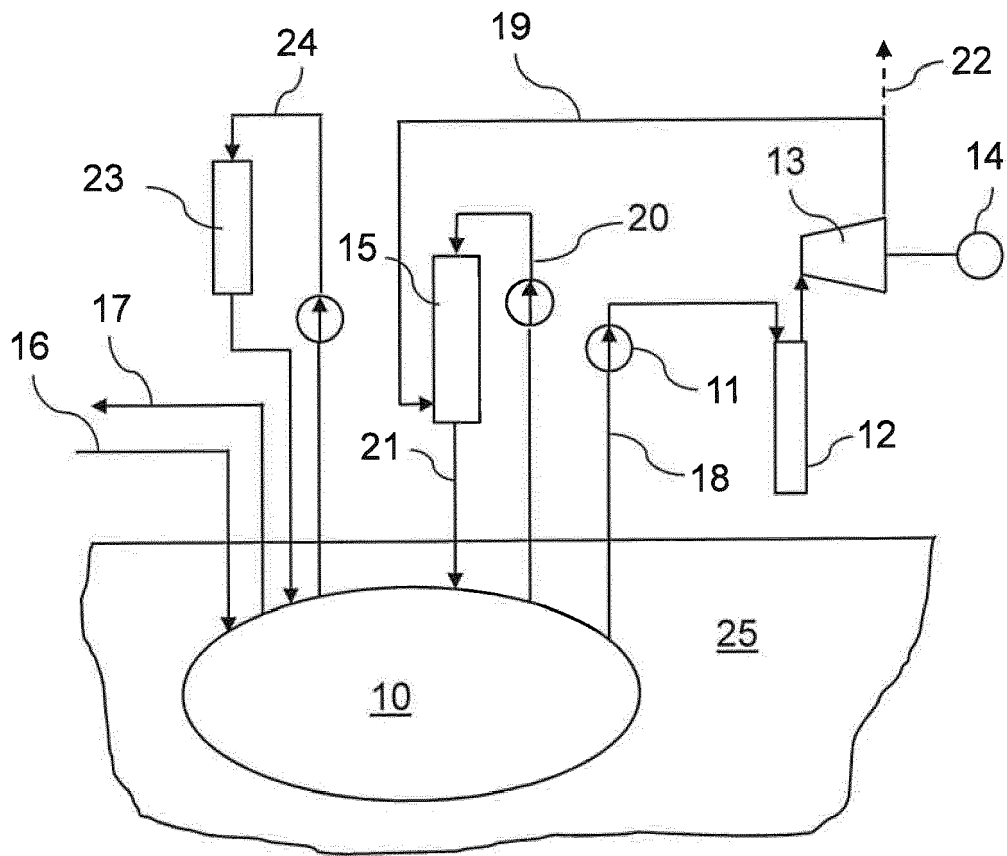


FIG. 1



EUROPEAN SEARCH REPORT

Application Number
EP 12 18 2561

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 4 995 234 A (KOOY RICHARD J [US] ET AL) 26 February 1991 (1991-02-26) * figure 1 *	1,5	INV. F01K25/10
A	EP 0 277 777 A2 (CBI RES CORP [US]) 10 August 1988 (1988-08-10) * figure *	1,5	
A	US 2012/001429 A1 (SAAR MARTIN O [US] ET AL) 5 January 2012 (2012-01-05) * figure 1 *	1,5	
			TECHNICAL FIELDS SEARCHED (IPC)
			F01K
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 8 March 2013	Examiner Coquau, Stéphane
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

1
EPO FORM 1503 03/82 (F04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 12 18 2561

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

08-03-2013

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4995234	A	26-02-1991	AT 126861 T	15-09-1995
			AU 6606990 A	28-04-1991
			DE 69021859 D1	28-09-1995
			EP 0446342 A1	18-09-1991
			ES 2076376 T3	01-11-1995
			JP 2898092 B2	31-05-1999
			JP H04502196 A	16-04-1992
			US 4995234 A	26-02-1991
			WO 9105145 A1	18-04-1991

EP 0277777	A2	10-08-1988	AU 595421 B2	29-03-1990
			AU 1125188 A	11-08-1988
			CA 1284177 C	14-05-1991
			DE 3871538 D1	09-07-1992
			DE 3871538 T2	03-12-1992
			EP 0277777 A2	10-08-1988
			ES 2032541 T3	16-02-1993
			JP 2858750 B2	17-02-1999
			JP 63239302 A	05-10-1988
			US 4765143 A	23-08-1988

US 2012001429	A1	05-01-2012	AU 2010223059 A1	22-09-2011
			CA 2753393 A1	16-09-2010
			EP 2406562 A2	18-01-2012
			US 2012001429 A1	05-01-2012
			WO 2010104599 A2	16-09-2010

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 20120001429 A1 [0005]
- EP 277777 A2 [0006]
- US 4995234 A [0007]