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Electronic supplementary materials

Quantification of Technological Progress in Greenhouse Gas (GHG) Capture and Mitigation using Patent Data

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Electronic Supplementary Material

The present document is prepared to complement the result section of the original manuscript and has two parts. The first part provides additional information regarding the patents with the highest Search Path Node Pair (SPNP) measures in various subdomains. The second part provides a sensitivity analysis of the results with respect to the shared bodies of knowledge and age of central patents.

1. The most central patents with the highest SPNPs

Tables S1-S13 report the patents with the highest Search Path Node Pair (SPNP), corresponding to the technological domains reported in Table 1 of the original manuscript. It should be noted that the source of the information applied in the analyses was the patentsview.org website. The complete set of patents can be retrieved from this website using the corresponding CPC classifications, mentioned in Table 1 of the original manuscript.

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Table S1. The patents with highest SPNP values in the “CO2 capture and storage” domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
4333744	1981	0.996	Union Carbide Corporation	Two-feed pressure swing adsorption process	One portion comprising about 30-80% of a hydrogen-containing feed gas having a relatively high carbon dioxide content is preheated to remove a substantial portion of said carbon dioxide therefrom. The thus - preheated stream is passed to a pressure swing adsorption bed from which a purified hydrogen stream is withdrawn. Upon completion of this step, the unpretreated portion of the feed gas is passed to the feed end of the bed, with purified hydrogen continuing to be withdrawn from the bed. In cyclic pressure swing adsorption operations employing such a two-feed process, the recovery of purified hydrogen is enhanced as compared with operations in which none of the feed gas is pretreated for carbon dioxide removal or in which all of the feed gas is so treated for removal of carbon dioxide therefrom.
6389814	2000	0.996	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid phase or super critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
4130403	1977	0.994	individual(s)	Removal of H.sub.2 S and/or CO.sub.2 from a light hydrocarbon stream by use of gas permeable membrane	A method for removing H.sub.2 S and CO.sub.2 from a natural gas stream involves the employment of a dried cellulose ester membrane having a permeability for H.sub.2 S and CO.sub.2 of at least 10.sup.-8. A gas permeation process may also be used to produce a CO.sub.2 rich stream from gas in gas reservoirs which contain a large amount of CO.sub.2. The produced rich CO.sub.2 stream may then be used in flooding processes for enhanced oil recovery.
4671069	1985	0.994	Hitachi, Ltd.	Combustor for gas turbine	A premixture of compressed air and gaseous fuel is supplied and combusted into a head combustion chamber of a combustor for gas turbine and main combustion of lean, low flame temperature is carried out in a rear combustion chamber following the heat combustion chamber to prevent the formation of high flame temperature which tends to promote NOx generation.

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4256469	1978	0.985	individual(s)	Repressurization technique for pressure swing adsorption	In a pressure swing adsorption process, the adsorbent being for example a carbon molecular sieve, the usual initial surge of an undesired component, e.g., O.sub.2 in a nitrogen stream, from the outlet of a freshly repressurized adsorber, is reduced or eliminated by conducting repressurization in a stage-wise manner with the final part of the repressurization being conducted substantially more slowly than the initial stage of repressurization.
4854249	1988	0.984	Institute of Gas Technology	Two stage combustion	A process for combusting sulfur and nitrogen containing carbonaceous materials in a two stage combustion process wherein sulfur and nitrogen containing carbonaceous materials and sulfur fixation agent particulates are introduced into a first combustion stage single fluidized bed having a density/size selective solids withdrawal conduit. The carbonaceous materials are combusted in the fluidized bed under substoichiometric oxygen conditions at temperatures of about 1600.degree. to about 2000.degree. F. producing ash and reducing gases forming a reducing region in a major portion of the single fluidized bed, the reducing gases comprising gaseous sulfur compounds. In a reducing region of the fluidized bed, the gaseous sulfur compounds are reacted with oxides of the sulfur fixation agent forming an intermediate solid metallic sulfur compound and nitrogen contained in the carbonaceous materials is converted to molecular nitrogen. The intermediate sulfur compound is reacted in an oxidizing region maintained at a base portion of the fluidized bed to form a stable, solid, environmentally acceptable sulfur containing compound which is withdrawn through the selective solids withdrawal conduit with agglomerated ash.
4270466	1979	0.977	Klockner-Humboldt-Deutz AG	Method and apparatus for rendering an ignitable fuel-oxygen mixture inert	Method and apparatus for operating a process in which combustible solid particles are mixed during processing with air and circulated through a plurality of stages, thereby tending to build up an oxygen enriched combustible mixture during shutdown, the invention involving adding additional fuel to the oxygen enriched combustible mixture during such shutdown in a closed burner system, burning the resulting mixture in the closed burner system, and recirculating the flue gas from such combustion back into the plurality of stages to thereby function as an inert gas to prevent accidental combustion or explosion.
7138007	2005	0.977	Chevron U.S.A. Inc.	Gas separation using molecular sieve SSZ-73	The present invention relates to new crystalline, essentially all silicon oxide molecular sieve SSZ-73 prepared using a 3-ethyl-1,3,8,8-tetramethyl-3-azoniabicyclo[3.2.1]octane cation as a structure-directing agent, and its use in gas separations.
5850833	1995	0.976	individual(s)	Apparatus for hypoxic training and therapy	An apparatus is provided for hypoxic training or therapy. The apparatus provides a user air having a lower oxygen content than the ambient atmosphere. The apparatus reduces the oxygen content of the air by passing the ambient air through a membrane separator which extracts the oxygen therefrom by a vacuum pump attached to the permeate outlet of the separator. Alternatively, the oxygen content can be reduced by adsorption of oxygen from the ambient air or by adding a low oxygen gas to air taken from the environment. This low oxygen gas may be stored nitrogen or stored gas which is low in oxygen, or it may be derived from the exhaled air from the user. If the exhaled air from the user used, carbon dioxide and water are extracted by a membrane separator or by physical or chemical process which adsorbs carbon dioxide from the gas.

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6170264	1998	0.975	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid phase or super critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
4934148	1989	0.974	Union Carbide Corporation	Dry, high purity nitrogen production process and system	Feed air to a prepurifier adsorption system/cryogenic air separation system for dry, high purity nitrogen and/or oxygen production is dried in a membrane dryer preferably characterized by a countercurrent flow path. Drying is enhanced by the use of purge gas on the permeate side of the membrane dryer, which adsorption system or cryogenic air separation system product or waste gas, dried feed air or ambient air being used as purge gas.
4544384	1983	0.972	individual(s)	Adsorber for two-component recovery and method of operating same	An adsorber for the cleaning of air or natural gas by the removal of water as a first component and carbon dioxide and/or a hydrocarbon as a second component from the gas stream to be treated utilizes two distinct adsorber beds traversed in succession by the gas stream, at least one of these beds being vertically oriented so that the gas stream and the regenerating gas pass horizontally through it.
4723966	1986	0.972	Union Carbide Corporation	Gas separation by pressure swing adsorption	A pressure swing adsorption process is disclosed wherein binary gas purification is effected from a single adsorbent bed. An adsorbent bed is charged under pressure with a gas mixture having some components that are more adsorbable than others. The process causes the bed to be polarized with one end of the bed containing the more adsorbable components and the other end containing the less adsorbable components. Once charged, the bed is depressurized simultaneously from both ends, thus removing the separated components from their respective ends.
4077779	1976	0.965	Air Products and Chemicals, Inc.	Hydrogen purification by selective adsorption	Hydrogen-containing gas mixtures are subjected to selective adsorption in a pressure swing cyclic system to remove carbon dioxide and/or hydrocarbon gases, obtaining high recovery of hydrogen at high purity. The system can also be employed for separation of methane from admixture with CO.sub.2.

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6247316	2000	0.964	Clean Energy Systems, Inc.	Clean air engines for transportation and other power applications	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining air is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen containing fuel, such as hydrogen or methane. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control a temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is discharged into the surrounding environment and the remainder is routed back to the gas generator.
5972080	1997	0.961	Dainippon Ink and Chemicals, Inc.	Separation membrane	Separation membranes excellent in strength, durability, heat resistance and solvent resistance as well as in balance between substance separation properties and substance permeability are disclosed, which are formed from polyhydrazidoimide resins, and preferably comprises a non-porous dense layer formed from a polyhydrazidoimide resin obtained from the reaction of an aromatic tetracarboxylic dianhydride such as 4,4'-(hexafluoroisopropylidene)diphthalic anhydride and an aromatic dihydrazide such as isophthalic dihydrazide as essential components.
4850194	1987	0.956	BBC Brown Boveri AG	Burner system	The present invention relates to a burner system, in particular for a gas turbine, with a main supply channel (2), debouching into a combustion chamber (1), for a fuel/air mixture having a swirler (5) and a burner lance (3) which passes through the swirler (5). To improve the transverse ignition properties between several such burner systems, optionally disposed on the burner chamber (1), and also to increase the flame stability, the burner lance (3) has, on the combustion chamber side with respect to the swirler (5) exit openings (12, 16) for fuel supplied to its interior or for a fuel-rich fuel/air mixture supplied to, or formed in, its interior.
4863371	1988	0.954	Union Carbide Corporation	Low NO.sub.x high efficiency combustion process	A process to combust fuel and oxidant at high efficiency and with low NO.sub.x generation even when the fuel has non-uniform characteristics and the oxidant is pure oxygen, wherein fuel and oxidant are first combusted within a high velocity oxidant-rich jet, fuel is mixed with combustion products in a recirculation zone and the mixture is aspirated into the oxidant-rich jet and combusted in a diffuse secondary flame at the periphery of the oxidant-rich jet.
4946382	1989	0.951	Union Carbide Corporation	Method for combusting fuel containing bound nitrogen	A method for combusting fuel containing bound nitrogen to achieve reduced NO.sub.x emissions wherein the oxidant and fuel are injected separately into a combustion zone through a burner and the oxidant is injected with a momentum equal to at least three times the fuel stream momentum and at an angle equal to or greater than the sum of the angles of the fuel stream periphery and oxidant stream periphery with their respective centerlines.

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6139604	1998	0.951	Praxair Technology, Inc.	Thermally powered oxygen/nitrogen plant incorporating an oxygen selective ion transport membrane	A low energy cost process for the co-production of oxygen and nitrogen employing a fuel tube extending into the first oxygen selective ion transport membrane whereby fuel is introduced adjacent to the closed end and flows cocurrently with oxygen containing gas in the annulus and an oxygen selective ion transport membrane having a separator section and a reactor section. An oxygen-containing feedstock, typically air, is compressed and then contacts the cathode side of the separator section where a portion of the oxygen contained within the feedstock is transported to the anode side of the separator section and recovered as an oxygen product gas. Substantially the remainder of the oxygen contained within the feedstock is transported from the cathode side of the reactor section to the anode side and exothermically reacted with a fuel. Following the exothermic reaction, hot nitrogen rich product gas is expanded in a turbine to generate the power necessary to compress the feedstock. Expanded nitrogen rich product gas may then be recovered from the turbine exhaust.
4171206	1978	0.948	Air Products and Chemicals, Inc.	Separation of multicomponent gas mixtures	Multicomponent gas mixtures containing: (1) hydrogen as primary component, (2) a secondary key component that is more strongly sorbed by the adsorbent than hydrogen, and (3) a minor quantity of one or more dilute components less strongly sorbed than the secondary key component, are subject to selective adsorption in an adiabatic pressure swing cyclic system for the separate recovery of high purity hydrogen and of the secondary component. A given example is the treatment of a shift converter effluent gas from a hydrocarbon reformer plant, wherein hydrogen and carbon dioxide are separately recovered as key components substantially freed of minor dilute components such as methane, carbon monoxide and nitrogen.
6190160	1999	0.947	L'Air Liquide, Societe Anonyme pour pour l'Etude et l'Exploitation des	Process for combustion of a fuel with an oxygen-rich oxidant	The invention relates to a process for combustion of a fuel with an oxygen-rich oxidant, in a combustion chamber (3), in which, cyclically: at least one principal variable representing the combustion in the said combustion chamber (3) is measured, and, as a function of the result of the measurement of the at least one principal variable, a control instruction for regulating the flowrates of fuel and oxidant to be injected into the combustion chamber (3) is determined. Then the regulating control instruction is applied in order to make the fuel burn with the oxidant in the chamber (3). Additionally at least one secondary variable associated with an operational constraint of the combustion chamber (3) or with a perturbation in the operation of the latter is measured, and for the determination of regulating control instruction, the measurement result of the at least one secondary variable is also taken into account. The invention is useful in glass furnaces, rotary furnaces, and incineration furnaces.
4417449	1982	0.945	Air Products and Chemicals, Inc.	Process for separating carbon dioxide and acid gases from a carbonaceous off-gas	A process is described for the separation of carbon dioxide and sulfide gases from oil shale retorting off-gases, coal gasification off-gases, oxygen fireflooding off-gases or carbon dioxide miscible flood enhanced oil recovery off-gases for recycle to a retort, gasifier, petroleum reservoir or to further sulfide processing prior to export. The process separates the off-gases into an essentially sulfur-free light BTU fuel gas, a heavy hydrocarbon stream and a carbon dioxide acid gas stream wherein the off-gas is compressed if necessary and cooled to separate the various streams. The carbon dioxide acid gas stream is expanded in an auto-refrigeration step to provide the necessary process refrigeration. In the oil shale retort and coal gasification applications the sulfur constituents are sorbed on spent oil shale particles or coal ash.

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6360524	2001	0.944	Praxair Technology, Inc.	Oxygen separator designed to be integrated with a gas turbine and method of separating oxygen	An oxygen separator and method for separating oxygen from a heated oxygen containing gas that employs oxygen-selective ceramic membranes of elongated, tubular configuration within a duct for separation of oxygen from a heated gas. The duct can be attached between the exhaust of a gas turbine and a power generator driven by the exhaust or can be connected to one or more burners of a gas turbine. Supplementary compressed feed air may be added at a flow rate at least equal to that of the permeated oxygen for cooling and flow balancing purposes. A purge stream can also be introduced. Additionally, combustor tubes fabricated from an oxygen-selective ceramic membrane material may also be provided to produce combustion products that in turn can be used as a purge for downstream oxygen-selective ceramic membranes.
5409525	1993	0.943	Agency of Industrial Science & Technology	Hydrous gel membranes for gas separation	This invention relates to hydrous gel membranes for gas separation which comprise support membranes formed by solvent-soluble polymeric materials containing in their repeating unit a bulky structural part and hydrophilic functional groups represented by the following general formula (1) ##STR1## (R.sub.1, R.sub.2, R.sub.3, and R.sub.4 designate hydrogen, alkyl group, and halogen and R.sub.5 and R.sub.6 designate any one of --H, --SO.sub.3 H, --COOH, and --OH) and water or an aqueous solution of substances with affinity for CO.sub.2 substantially uniformly retained in the support membranes. The membranes show not only high CO.sub.2 permeation and CO.sub.2 selectivity but also long-term stable membrane performance and ease of fabricability into membranes and are capable of recovering a large volume of CO.sub.2 generated at stationary sites efficiently at low cost.
6128919	1998	0.942	Messer Griesheim Industries, Inc.	Process for separating natural gas and carbon dioxide	A process for separating natural gas and carbon dioxide from a raw feed stream, such as in carbon dioxide for EOR processes. Separation is by membrane separation at low pressures. By utilizing low pressure separation, highly selective membranes can be used and recycling becomes practical.
4430306	1981	0.939	Mitsubishi Denki Kabushiki Kaisha	Oxygen recycle type ozonizing apparatus	An ozonized oxygen fed from an ozonizer is passed to a reaction tower to treat an object material. In recovering non-reacted oxygen from the reaction tower to reuse in the ozonizer, zeolite is used as an adsorbent to remove impurities contained in the recovered oxygen, such as water, volatile organic materials and CO.sub.2 gas so that a raw material oxygen without containing any impurity is fed to the ozonizer to increase the ozonizing efficiency.
4627367	1984	0.937	Coal Industry (Patents) Limited	Hot gas generation	In a hot gas generating apparatus coal is fed to a first gasifying fluidized bed wherein it is partially gasified to generate a combustible gas and char. The char is circulated to a second combustion fluidized bed for burning in the presence of excess air. The combustible gas is mixed with the oxygen rich gases from the second bed and burnt to give a hot gas product.
4813980	1987	0.937	Air Products and Chemicals, Inc.	Recovery of nitrogen, hydrogen and carbon dioxide from hydrocarbon reformate	Multi-column pressure swing adsorption process for simultaneous production of ammonia synthesis gas and carbon dioxide from a reformer off gas having hydrogen, nitrogen and carbon dioxide as major components accompanied by minor quantities of methane, carbon monoxide and argon as impurities. The PSA system features two groups of adsorbent columns in which CO.sub.2 is adsorbed in adsorbers of the first group, the essentially CO.sub.2 -freed effluent being charged to an adsorber of the second group for removal of minor impurities while discharging an effluent gas having an H.sub.2 /N.sub.2 content stoichiometric for NH.sub.3 synthesis. The CO.sub.2 recovered from the first group of adsorbers is available at a high purity for reaction with the ammonia product for production of urea.

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5618332	1995	0.936	L'Air Liquide S.A.	Process for enhancing the selectivity of mixed gas separations	Gas separation membranes having enhanced selectivity for a mixture of gases is disclosed. The membranes may be asymmetric or multicomponent. The membranes surprisingly provide selectivity for gases in a mixture that approaches the relative selectivity of the single gas components. Preferably the membrane provides selectivity for a mixture of gases which is at least 65%, preferably 80%, of the relative selectivity of the corresponding single gases. A process for making improved gas separation membranes is also disclosed.

Table S2. The patents with highest SPNP values in the “non-CO2 GHG capture and disposal” domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
7168243	2005	0.993	Caterpillar Inc.	NOx adsorber and method of regenerating same	New technologies, such as NOx adsorber catalytic converters, are being used to meet increasingly stringent regulations on undesirable emissions, including NOx emissions. NOx adsorbers must be periodically regenerated, which requires an increased fuel consumption. The present disclosure includes a method of regenerating a NOx adsorber within a NOx adsorber catalytic converter. At least one sensor positioned downstream from the NOx adsorber senses, in the downstream exhaust, at least one of NOx, nitrous oxide and ammonia concentrations a plurality of times during a regeneration phase. The sensor is in communication with an electronic control module that includes a regeneration monitoring algorithm operable to end the regeneration phase when a time rate of change of the at least one of NOx, nitrous oxide and ammonia concentrations is after an expected plateau region begins.
4006066	1975	0.98	Vereinigte Aluminum-Werke Aktiendesellschaft	Method of and apparatus for the treatment of exhaust-gases in the electrolytic production of aluminum	Hydrogen-fluoride-containing gases from the electrolytic production of aluminum are subjected to electrostatic precipitation to remove dust particles containing substances which are deleterious to aluminum production before the gases are treated in an expanded bed with alumina on which the hydrogen fluoride is adsorbed. Following the dry adsorption in the expanded bed, the gases entraining the adsorbent particles are subjected to electrostatic precipitation in which the particles are separated from the gas thus freed from hydrogen fluoride. The particles are recycled to the electrolytic aluminum production apparatus, the particles being free from the deleterious substances which have previously been removed.
6508057	1999	0.98	Institut Francais du Petrole	Process and device intended for nitrogen oxides elimination in an exhaust line of an internal-combustion engine	A device for eliminating nitrogen oxides in an exhaust line of a lean-burn internal-combustion engine (1) a NOx trap (3) for trapping the nitrogen oxides, a system for regenerating the nitrogen oxides when the NOx trap is saturated, a hydrocarbon treating catalyst (2) placed upstream from the NOx trap (3), a hydrocarbon injector (4) placed upstream from hydrocarbon treating catalyst (2), a probe (7) for measuring the gas mixture strength. The hydrocarbon treating catalyst (2) is a partial (or controlled) hydrocarbon oxidation catalyst that cooperates with the NOx trap (3) for trapping the nitrogen oxides and that allows to obtain, at the outlet thereof, gases with a low oxygen (O2) concentration and with high carbon monoxide (CO) and hydrogen (H2) concentrations. A control unit is furthermore provided for recording and processing data coming from various detectors and/or stored in order to carry out effective regeneration of the NOx trap (3) without disrupting the smooth running of the engine.

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7051520	2004	0.98	Isuzu Motors Limited	Sulfur purge control method and exhaust gas purifying system	In an exhaust gas purifying system (1) for removing NOx by a NOx occlusion reduction type catalyst (11) for exhaust gas of an internal combustion engine, the air-fuel ratio in the exhaust gas is controlled by setting the target air-fuel ratio at a predetermined first air-fuel ratio which is a rich air-fuel ratio by a sulfur purge control means (C24) after the start of sulfur purge, and thereafter, the air-fuel ratio in the exhaust gas is controlled by changing the target air-fuel ratio to the predetermined second air-fuel ratio which is a stoichiometric air-fuel ratio, when the oxygen concentration (Od) in the downstream of the NOx occlusion reduction type catalyst (11) measured by an oxygen concentration detection means (C12) becomes lower than a predetermined threshold. Thereby, sulfur component accumulated in the NOx occlusion reduction type catalyst (11) can be purged efficiently, while preventing carbon monoxide from being discharged into the atmospheric air.
5229089	1991	0.975	The BOC Group, Inc.	Recovery of flammable materials from gas streams	A process for separating methane from an oxygen-containing gas mixture which contains methane at a concentration greater than the upper explosive gas mixture limit by pressure swing adsorption without producing an explosive gas mixture. The process includes the steps of feeding the gas mixture into an adsorber which contains an adsorbent which preferentially adsorbs methane until the desired production pressure is attained in the adsorber and then stopping the flow of feed gas into the adsorber and charging methane product gas at the production pressure cocurrently into the adsorber while simultaneously withdrawing nonadsorbed product gas from the nonadsorbed product end of the adsorber. The desorbed product stream is enriched in methane relative to the feed stream and the concentration of methane in the nonadsorbed product stream is less than the minimum flammable mixture concentration.
4544384	1983	0.972	individual(s)	Adsorber for two-component recovery and method of operating same	An adsorber for the cleaning of air or natural gas by the removal of water as a first component and carbon dioxide and/or a hydrocarbon as a second component from the gas stream to be treated utilizes two distinct adsorber beds traversed in succession by the gas stream, at least one of these beds being vertically oriented so that the gas stream and the regenerating gas pass horizontally through it.
4723966	1986	0.972	Union Carbide Corporation	Gas separation by pressure swing adsorption	A pressure swing adsorption process is disclosed wherein binary gas purification is effected from a single adsorbent bed. An adsorbent bed is charged under pressure with a gas mixture having some components that are more adsorbable than others. The process causes the bed to be polarized with one end of the bed containing the more adsorbable components and the other end containing the less adsorbable components. Once charged, the bed is depressurized simultaneously from both ends, thus removing the separated components from their respective ends.
8516800	2010	0.967	Caterpillar Inc.	System and method for introducing a reductant agent	A system and method controls injection of a reductant agent in a selective catalytic reduction system. The system and method include an injector injecting the reductant agent to an exhaust system directing exhaust from a power system. A coolant system circulates coolant proximate to the injector. A coolant temperature sensor monitors a coolant temperature of the coolant. A controller adjusts the injection timing of the injector based at least in part on the coolant temperature.

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5771686	1996	0.966	Mercedes-Benz AG	Method and apparatus for operating a diesel engine	A method and an apparatus are provided for operating a diesel engine with an exhaust feedback device located between the exhaust line and the intake air line, with an adjusting element that can be operated by an adjusting drive actuated by an auxiliary force to operate the exhaust feedback device as a function of signals from an electronic control device. An engine regulator permits rich/lean regulation of the diesel engine as a function of its operating parameters. A storage catalyst is located in the exhaust line, in which catalyst oxides of nitrogen (NO.sub.x) can be adsorbed, desorbed, and reduced. A sensor is located downstream from the storage catalyst for detecting the NO.sub.x concentration in the exhaust stream in such fashion that when an NO.sub.x storage threshold value is reached that varies in terms of its characteristics as a function of the rpm and the load, a switch is made from operation with a lambda value of larger than 1 to operation with a lambda value of less than 1.
4077779	1976	0.965	Air Products and Chemicals, Inc.	Hydrogen purification by selective adsorption	Hydrogen-containing gas mixtures are subjected to selective adsorption in a pressure swing cyclic system to remove carbon dioxide and/or hydrocarbon gases, obtaining high recovery of hydrogen at high purity. The system can also be employed for separation of methane from admixture with CO.sub.2.
5785741	1996	0.965	L'Air Liquide Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude	Process and system for separation and recovery of perfluorocompound gases	Processes and systems to recover at least one perfluorocompound gas from a gas mixture are provided. In one embodiment the inventive process comprises the steps of a) providing a gas mixture comprising at least one perfluorocompound gas and at least one carrier gas, the gas mixture being at a predetermined pressure; b) providing at least one glassy polymer membrane having a feed side and a permeate side; c) contacting the feed side of the at least one membrane with the gas mixture; d) withdrawing from the feed side of the membrane as a non-permeate stream at a pressure which is substantially equal to the predetermined pressure a concentrated gas mixture comprising essentially the at least one perfluorocompound gas; and e) withdrawing from the permeate side of the membrane as a permeate stream a depleted gas mixture comprising essentially the at least one carrier gas.
6546720	2001	0.963	Ford Global Technologies, LLC	Method and apparatus for controlling the amount of reactant to be added to a substance using a sensor which is responsive to both the reactant and the substance	A method wherein a reactant is added to a substance to react with such substance. The product of such reaction along with un-reacted portions of the substance and un-reacted portions of the reactant are directed to a sensor. The sensor produces an output signal in response to detection of both the un-reacted portions of the substance and the un-reacted portions of the reactant. The method includes changing the amount of reactant added to the substance. A measurement is made to determine whether the change in the amount of reactant and the change the output signal are in the same direction or in opposite directions. A processor is provided for controlling the addition of a reactant to a substance to react with such substance. The product of such reaction along with un-reacted portions of the substance and un-reacted portions of the reactant are directed to a sensor. The sensor produces an output signal in response to detection of both the un-reacted portions of the substance and the un-reacted portions of the reactant. The processor changes the amount of reactant added to the substance; such processor being programmed to: determine whether the change in the amount of reactant and the change the output signal are in the same direction or in opposite directions. With such arrangement, the processor uses the product of the change in reactant and output signal to correct the nominal urea:NOx ratio.

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6521550	2001	0.958	Hitachi, Ltd.	Process for manufacturing semiconductor integrated circuit device including treatment of gas used in the process	In a gas-phase treating process of a semiconductor wafer using hydrogen, there is provided a technique for safely eliminating the hydrogen in an exhaust gas discharged from a gas-phase treating apparatus. The profile at the end portions of the side walls of gate electrodes of a poly-metal structure is improved by forming the gate electrodes over a semiconductor wafer IA having a gate oxide film and then by supplying the semiconductor wafer 1A with a hydrogen gas containing a low concentration of water, as generated from hydrogen and oxygen by catalytic action, to oxidize the principal face of the semiconductor wafer 1A selectively. After this, the hydrogen in the exhaust gas, as discharged from an oxidizing furnace, is completely converted into water by causing it to react with oxygen by a catalytic method.
6723665	2003	0.957	Renesas Technology Corp.	Process for manufacturing semiconductor integrated circuit device including treatment of gas used in the process	In a gas-phase treating process of a semiconductor wafer using hydrogen, there is provided a technique for safely eliminating the hydrogen in an exhaust gas discharged from a gas-phase treating apparatus. The profile at the end portions of the side walls of gate electrodes of a poly-metal structure is improved by forming the gate electrodes over a semiconductor wafer IA having a gate oxide film and then by supplying the semiconductor wafer 1A with a hydrogen gas containing a low concentration of water, as generated from hydrogen and oxygen by catalytic action, to oxidize the principal face of the semiconductor wafer 1A selectively. After this, the hydrogen in the exhaust gas, as discharged from an oxidizing furnace, is completely converted into water by causing it to react with oxygen by a catalytic method.
6826906	2001	0.956	Engelhard Corporation	Exhaust system for enhanced reduction of nitrogen oxides and particulates from diesel engines	A diesel engine aftertreatment exhaust system uses catalyzed soot filters for particulate matter reduction and urea SCR catalysts for NOx reduction on diesel engines in a combined system to lower particulate matter and NOx at the same time. With this integral emission control system, diesel engines are able to meet ultra low emission standards.
4773339	1987	0.955	Foster Wheeler Energy Corporation	Process for removing nitrous oxides from a gas	A process for removing nitrous oxides from a gas, comprising the step of passing air through a bed of particulate material including a carbonaceous material to fluidize the material and promote combustion of the fuel and adding additional carbonaceous material to the bed. Additional air above the area of introduction of the air passes through the bed and passes the gas through the bed so that carbonaceous material scavenges the oxygen in the nitrous oxides.
5740669	1995	0.953	Toyota Jidosha Kabushiki Kaisha	Exhaust gas purification device for an engine	In the present invention, a NO.sub.x absorbent is used for removing the NO.sub.x in the exhaust gas. The NO.sub.x absorbent absorbs NO.sub.x in the exhaust gas when the air-fuel ratio of the exhaust gas is lean, and releases the absorbed NO.sub.x and reduces it to nitrogen when the air-fuel ratio of the exhaust gas is rich or stoichiometric. To prevent the NO.sub.x absorbent from being saturated with the absorbed NO.sub.x, the NO.sub.x absorbent must be regenerated periodically by causing the NO.sub.x in the absorbent to be released and reduced. However, it is found that when the regenerating process by supplying a rich air-fuel ratio exhaust gas to the NO.sub.x absorbent is carried out at high NO.sub.x absorbent temperature, a part of NO.sub.x flows out from the NO.sub.x absorbent at the beginning of the regenerating process without being reduced. In the present invention, this outflow of NO.sub.x is suppressed by, for example, carrying out the regenerating process only when the temperature of the NO.sub.x absorbent is lowered to a predetermined temperature. This predetermined temperature is set low enough to ensure that the amount of the outflow of NO.sub.x is minimized.

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6602808	2001	0.952	Hitachi, Ltd.	Process for manufacturing semiconductor integrated circuit device including treatment of gas used in the process	In a gas-phase treating process of a semiconductor wafer using hydrogen, there is provided a technique for safely eliminating the hydrogen in an exhaust gas discharged from a gas-phase treating apparatus. The profile at the end portions of the side walls of gate electrodes of a poly-metal structure is improved by forming the gate electrodes over a semiconductor wafer IA having a gate oxide film and then by supplying the semiconductor wafer 1A with a hydrogen gas containing a low concentration of water, as generated from hydrogen and oxygen by catalytic action, to oxidize the principal face of the semiconductor wafer 1A selectively. After this, the hydrogen in the exhaust gas, as discharged from an oxidizing furnace, is completely converted into water by causing it to react with oxygen by a catalytic method.
4121539	1977	0.949	individual(s)	Animal enclosure system with waste treatment means	An animal-supporting platform receives solid waste excreted by the animals. A mixture of the waste and a carrier liquid are treated in airtight holding tanks where ammonia gas is produced at ambient temperatures. The material is then fed to an airtight chamber provided with liquid overflow means and a liquid outlet passage which leads downwardly from the overflow means and then upwardly to a discharge point located outside the chamber. Combustible methane gas generated by decomposition of the waste material is discharged through a gas outlet opening located in an upper portion of the chamber, and undigested solids are moved through the chamber and then removed from the chamber by a conveyor means leading through a submerged chamber outlet opening.
4171206	1978	0.948	Air Products and Chemicals, Inc.	Separation of multicomponent gas mixtures	Multicomponent gas mixtures containing: (1) hydrogen as primary component, (2) a secondary key component that is more strongly sorbed by the adsorbent than hydrogen, and (3) a minor quantity of one or more dilute components less strongly sorbed than the secondary key component, are subject to selective adsorption in an adiabatic pressure swing cyclic system for the separate recovery of high purity hydrogen and of the secondary component. A given example is the treatment of a shift converter effluent gas from a hydrocarbon reformer plant, wherein hydrogen and carbon dioxide are separately recovered as key components substantially freed of minor dilute components such as methane, carbon monoxide and nitrogen.
6891138	2003	0.94	individual(s)	Electromagnetic susceptors with coatings for artificial dielectric systems and devices	A coated susceptor of electromagnetic energy for chemical processing made of a matrix material that surrounds a non-matrix material that is made from a material that is different from the matrix material, in which the matrix material is constructed of material having lower dielectric losses compared to the non-matrix material, the non-matrix material initially absorbs electromagnetic energy applied to the electromagnetic susceptor to a greater extent than the matrix material, the non-matrix material produces subsequent heat in the matrix material, and the surface of the susceptor is coated with a material that interacts with applied electromagnetic energy of at least one frequency and initially absorbs electromagnetic energy and produces heat.
6886573	2002	0.939	Air Products and Chemicals, Inc.	Plasma cleaning gas with lower global warming potential than SF6	A process for cleaning a deposit from an interior surface of a processing chamber includes generating a plasma from a cleaning gas including SO₂F₂and contacting the interior surface with the plasma for a time sufficient to convert the deposit into a volatile product, thereby cleaning the deposit from the interior surface, in which the process is conducted in the absence of SF₆. The deposits, which may be removed by the process of the invention, include silicone, silicone oxide, silicone nitride, tungsten, copper and aluminum.

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4813980	1987	0.937	Air Products and Chemicals, Inc.	Recovery of nitrogen, hydrogen and carbon dioxide from hydrocarbon reformate	Multi-column pressure swing adsorption process for simultaneous production of ammonia synthesis gas and carbon dioxide from a reformer off gas having hydrogen, nitrogen and carbon dioxide as major components accompanied by minor quantities of methane, carbon monoxide and argon as impurities. The PSA system features two groups of adsorbent columns in which CO.sub.2 is adsorbed in adsorbers of the first group, the essentially CO.sub.2 -freed effluent being charged to an adsorber of the second group for removal of minor impurities while discharging an effluent gas having an H.sub.2 /N.sub.2 content stoichiometric for NH.sub.3 synthesis. The CO.sub.2 recovered from the first group of adsorbers is available at a high purity for reaction with the ammonia product for production of urea.
5417934	1993	0.933	Boc Limited	Dry exhaust gas conditioning	A gas treatment method and apparatus for use in connection with processes of etching semiconductor devices or of plasma enhanced chemical vapor deposition onto semiconductor materials. In accordance with the method and apparatus, the exhaust gases are introduced into first and second stages while heating the first and second stages. The stages can be contained within a heated cartridge. The first stage contains silicon or a silicon-rich alloy or a silicon-rich substance in a particulate form and a partial coating of copper or a copper rich substance in intimate contact with the silicon, the silicon-rich alloy or the silicon-rich substance. The second stage contains calcium oxide, a calcium oxide containing material, or a soda lime containing medium.
7036304	2003	0.933	NISSAN MOTOR CO., LTD.	Exhaust gas purifying apparatus and method for internal combustion engine	Removal of poisoning substance (sulfur oxidant) is controlled based upon estimating an amount of the poisoning substance deposited in an exhaust gas purification catalyst disposed in an exhaust pipe for an internal combustion engine, a lower limit is set corresponding to a possible removal amount of the poisoning substance varying with a state of a catalyst, and the removal control of the poisoning substance is ended when the estimated amount is less than the lower limit. The estimated amount can be accurately calculated, thereby ending the removal control at a proper timing. Fuel economy and exhaust gas purification performance improves.
6066508	1998	0.931	Hitachi, Ltd.	Process for manufacturing semiconductor integrated circuit device including treatment of gas used in the process	In a gas-phase treating process of a semiconductor wafer using hydrogen, there is provided a technique for safely eliminating the hydrogen in an exhaust gas discharged from a gas-phase treating apparatus. The profile at the end portions of the side walls of gate electrodes of a poly-metal structure is improved by forming the gate electrodes over a semiconductor wafer IA having a gate oxide film and then by supplying the semiconductor wafer 1A with a hydrogen gas containing a low concentration of water, as generated from hydrogen and oxygen by catalytic action, to oxidize the principal face of the semiconductor wafer 1A selectively. After this, the hydrogen in the exhaust gas, as discharged from an oxidizing furnace, is completely converted into water by causing it to react with oxygen by a catalytic method.
4475929	1983	0.929	Union Carbide Corporation	Selective adsorption process	In pressure swing adsorption processing including higher pressure adsorption, cocurrent depressurization to intermediate pressure, countercurrent depressurization and/or lower pressure purge and repressurization, a cocurrent purge step is employed at adsorption pressure prior to cocurrent depressurization. Methane or natural gas is advantageously employed as the cocurrent purge gas. The cocurrent purge step reduces the storage of product gas, such as hydrogen, in the bed, enhances product recovery and correspondingly reduces the amount of desired product gas discharged with the waste gas discharged the countercurrent depressurization and/or purge steps used for bed regeneration. The value of the waste gas as a fuel is likewise enhanced by the presence of said methane or natural gas therein.

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6032484	1998	0.929	Air Products and Chemicals, Inc.	Recovery of perfluorinated compounds from the exhaust of semiconductor fabs with recycle of vacuum pump diluent	A method for the separation and recovery of fluorochemicals from a gas stream containing a diluent gas and fluorochemicals by first contacting the gas stream with a membrane system in one or more stages where the membrane(s) is selectively more permeable to the diluent gas than the fluorochemicals to result in a permeate stream rich in diluent gas and retentate rich in fluorochemicals, thereafter subjecting retentate the gas stream to a purification by distillation or adsorption resulting in a product stream enriched in fluorochemicals and a purified diluent stream. The purified diluent stream is used as a purge stream and/or a recycle stream together with the permeate stream to a vacuum pump upstream of the membrane separation step. A product stream can be produced from a similar gas stream containing diluent gas and fluorochemical by an adsorption step combined with a subsequent distillation step where the purified diluent from the adsorption step is used as a purge stream and/or wholly or partial combined with a purified diluent stream from the distillation step as a recycle stream introduced into the process upstream of the adsorption step. Enriched fluorochemical and an enriched diluent streams can be produced from a stream containing diluent gas and fluorochemicals by cryogenic distillation with the enriched diluent stream recycled to the process upstream of the distillation step.
6723155	2002	0.922	Air Products and Chemicals, Inc.	Purification of gas streams	A method for removing a first and a second minor component from a gas mixture comprising the first and second minor components and one or more major components. The method comprises providing a first adsorbent zone containing a first adsorbent material and a second adsorbent zone containing a second adsorbent material wherein the selectivity of the first adsorbent material for the first minor component relative to the second minor component is greater than the selectivity of the second adsorbent material for the first minor component relative to the second minor component. The average particle diameter of the first adsorbent material and the average particle diameter of the second adsorbent material preferably are substantially the same. The gas mixture is passed through the first adsorbent zone and subsequently through the second adsorbent zone. A purified gas containing the one or more major components and depleted in the first and second minor component is withdrawn from the second adsorbent zone.
6347627	1998	0.915	Pioneer Inventions, Inc.	Nitrous oxide based oxygen supply system	A self-contained system which converts nitrous oxide to a breathable gas mixture of nitrogen and oxygen. In the preferred embodiment of the present invention, a portable system is disclosed wherein liquefied nitrous oxide is converted to a breathable gas mixture of nitrogen and oxygen. The decomposition occurs over a catalyst bed which is all contained in a small reactor. The invention is useful for underwater, fire fighting and outer space applications.

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Table S3. The patents with highest SPNP values in the "Combined combustion with potential for GHG mitigation" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
6389814	2000	0.996	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid phase or super critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
4519995	1983	0.994	Osterreichische Draukraftwerke AG	Method of desulfurizing flue gases of coal firings	In a method for desulfurizing flue gas generated in coal combusting plants, the coal is burned in the presence of a dry additive material, such as CaCO optionally in presence of recycled cold flue gas whereby additive material which has not reacted is discharged together with the flue gas from the firing space and is separated together with the ashes in dust filters. The relative moisture of the flue gas is increased before entering the dust filter so that the sulfur compounds in the flue gas react to a greater extent with the additive material in the dust filters. The device for practicing this method comprises a heat exchanger and/or an injection cooler arranged streamup of the flue gas filtering installation.
4671069	1985	0.994	Hitachi, Ltd.	Combustor for gas turbine	A premixture of compressed air and gaseous fuel is supplied and conbusted into a head combustion chamber of a combustor for gas turbine and main combustion of lean, low flame temperature is carried out in a rear combustion chamber following the heat combustion chamber to prevent the formation of high flame temperature which tends to promote NOx generation.
4411204	1981	0.99	Combustion Engineering, Inc.	Method of firing a pulverized fuel-fired steam generator	A method of firing a pulverized fuel-fired steam generator furnace wherein a mixture of recirculated cleaned flue gas and air is supplied to the mill for drying the pulverized fuel in the mill and transporting the pulverized fuel to the furnace. The volume flow rate of the gaseous mixture of recirculated flue gas and air is controlled in response to the feed rate of fuel to the mill to maintain a mixture to fuel ratio in the transport stream of about but not less than 1.5. The volume flow rate of recirculated flue gas with respect to the volume flow rate of air is controlled to maintain the oxygen content of the gaseous mixture at a level of at least 12% by volume and preferably in the range of 12 to 15% by volume.

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4854249	1988	0.984	Institute of Gas Technology	Two stage combustion	A process for combusting sulfur and nitrogen containing carbonaceous materials in a two stage combustion process wherein sulfur and nitrogen containing carbonaceous materials and sulfur fixation agent particulates are introduced into a first combustion stage single fluidized bed having a density/size selective solids withdrawal conduit. The carbonaceous materials are combusted in the fluidized bed under substoichiometric oxygen conditions at temperatures of about 1600.degree. to about 2000.degree. F. producing ash and reducing gases forming a reducing region in a major portion of the single fluidized bed, the reducing gases comprising gaseous sulfur compounds. In a reducing region of the fluidized bed, the gaseous sulfur compounds are reacted with oxides of the sulfur fixation agent forming an intermediate solid metallic sulfur compound and nitrogen contained in the carbonaceous materials is converted to molecular nitrogen. The intermediate sulfur compound is reacted in an oxidizing region maintained at a base portion of the fluidized bed to form a stable, solid, environmentally acceptable sulfur containing compound which is withdrawn through the selective solids withdrawal conduit with agglomerated ash.
4223640	1978	0.978	The Babcock & Wilcox Company	Fuel firing	An apparatus and method to permit the burning of high and varying moisture content fuels without requiring supplemental fuel (oil or gas) firing. The invention provides in-situ drying of the high and varying moisture content fuels by modulating the temperature of the combustion air entering the furnace (11) of the vapor generator (10). The variable flow paths taken by the air and flue gas are functions of the moisture content of the fuel being fired. The flue gas may be selectively by-passed around an economizer (20) for direct introduction into a first air heater (30). The gas is then passed through a precipitator (34) and a second air heater (40). Combustion air is passed through the second air heater (40) and may be then apportioned between the first air heater (30) and a by-pass (60) around the air heater (40) before introduction into the furnace (11).
4270466	1979	0.977	Klockner-Humboldt-Deutz AG	Method and apparatus for rendering an ignitable fuel-oxygen mixture inert	Method and apparatus for operating a process in which combustible solid particles are mixed during processing with air and circulated through a plurality of stages, thereby tending to build up an oxygen enriched combustible mixture during shutdown, the invention involving adding additional fuel to the oxygen enriched combustible mixture during such shutdown in a closed burner system, burning the resulting mixture in the closed burner system, and recirculating the flue gas from such combustion back into the plurality of stages to thereby function as an inert gas to prevent accidental combustion or explosion.
6170264	1998	0.975	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid

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					phase or super critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
6247316	2000	0.964	Clean Energy Systems, Inc.	Clean air engines for transportation and other power applications	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining air is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen containing fuel, such as hydrogen or methane. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control a temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is discharged into the surrounding environment and the remainder is routed back to the gas generator.
4850194	1987	0.956	BBC Brown Boveri AG	Burner system	The present invention relates to a burner system, in particular for a gas turbine, with a main supply channel (2), debouching into a combustion chamber (1), for a fuel/air mixture having a swirler (5) and a burner lance (3) which passes through the swirler (5). To improve the transverse ignition properties between several such burner systems, optionally disposed on the burner chamber (1), and also to increase the flame stability, the burner lance (3) has, on the combustion chamber side with respect to the swirler (5) exit openings (12, 16) for fuel supplied to its interior or for a fuel-rich fuel/air mixture supplied to, or formed in, its interior.
4863371	1988	0.954	Union Carbide Corporation	Low NO.sub.x high efficiency combustion process	A process to combust fuel and oxidant at high efficiency and with low NO.sub.x generation even when the fuel has non-uniform characteristics and the oxidant is pure oxygen, wherein fuel and oxidant are first combusted within a high velocity oxidant-rich jet, fuel is mixed with combustion products in a recirculation zone and the mixture is aspirated into the oxidant-rich jet and combusted in a diffuse secondary flame at the periphery of the oxidant-rich jet.
5263471	1992	0.954	individual(s)	Solid fuel clean burning zero clearance fireplace	A high efficiency clean burning fireplace for burning solid fuels at pyrolytic temperatures is provided with refractory walls maintained about 1100.degree. Fahrenheit at different burning rates. A top wall of the combustion chamber includes an exhaust stack and a primary air heat exchanger having an exhaust manifold for discharging primary preheated combustion air down and across the inside surface of glass panels in the doors of the fireplace. A secondary air heat exchanger is mounted below the primary air heat exchanger and separated therefrom by a top refractory panel in the combustion chamber. The secondary air heat exchanger exhaust manifold is in the combustion chamber and discharges secondary combustion air across the top of the combustion chamber and into the primary combustion air creating a high turbulence and complete burning of the secondary production of combustion while heating the refractory walls above a pyrolytic temperature at different burning rates.

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4946382	1989	0.951	Union Carbide Corporation	Method for combusting fuel containing bound nitrogen	A method for combusting fuel containing bound nitrogen to achieve reduced NO.sub.x emissions wherein the oxidant and fuel are injected separately into a combustion zone through a burner and the oxidant is injected with a momentum equal to at least three times the fuel stream momentum and at an angle equal to or greater than the sum of the angles of the fuel stream periphery and oxidant stream periphery with their respective centerlines.
6190160	1999	0.947	L'Air Liquide, Societe Anonyme pour pour l'Etude et l'Exploitation des	Process for combustion of a fuel with an oxygen-rich oxidant	The invention relates to a process for combustion of a fuel with an oxygen-rich oxidant, in a combustion chamber (3), in which, cyclically: at least one principal variable representing the combustion in the said combustion chamber (3) is measured, and, as a function of the result of the measurement of the at least one principal variable, a control instruction for regulating the flowrates of fuel and oxidant to be injected into the combustion chamber (3) is determined. Then the regulating control instruction is applied in order to make the fuel burn with the oxidant in the chamber (3). Additionally at least one secondary variable associated with an operational constraint of the combustion chamber (3) or with a perturbation in the operation of the latter is measured, and for the determination of regulating control instruction, the measurement result of the at least one secondary variable is also taken into account. The invention is useful in glass furnaces, rotary furnaces, and incineration furnaces.
6360524	2001	0.944	Praxair Technology, Inc.	Oxygen separator designed to be integrated with a gas turbine and method of separating oxygen	An oxygen separator and method for separating oxygen from a heated oxygen containing gas that employs oxygen-selective ceramic membranes of elongated, tubular configuration within a duct for separation of oxygen from a heated gas. The duct can be attached between the exhaust of a gas turbine and a power generator driven by the exhaust or can be connected to one or more burners of a gas turbine. Supplementary compressed feed air may be added at a flow rate at least equal to that of the permeated oxygen for cooling and flow balancing purposes. A purge stream can also be introduced. Additionally, combustor tubes fabricated from an oxygen-selective ceramic membrane material may also be provided to produce combustion products that in turn can be used as a purge for downstream oxygen-selective ceramic membranes.
5040972	1990	0.941	Systech Environmental Corporation	Pyrolyzer-kiln system	A pyrolyzer-kiln system for generating combustible fume from waste material and supplementing the fuel used to provide heat energy to a clinker kiln. The system includes a pyrolyzer for generating a combustible pyrolytic fume, a kiln for burning the fume as part of a cement-forming process, a conduit for conveying the fume from the pyrolyzer to the kiln, and a closed-loop feedback component for monitoring the heating value of the fume and varying the operational parameters of the pyrolyzer to maintain the heating value of the fume generated within a predetermined range. The closed-loop feedback component includes a calorimeter which continuously samples and burns fume from the conduit. The heating value of the fume is determined by measuring the amount of auxiliary fuel and air required to be mixed with the fume to maintain a predetermined temperature when the combustion is burned within the calorimeter. Controllers monitor the amount of auxiliary fuel and air supplied to the calorimeter and vary the temperature within the pyrolyzer to effect an increase or decrease in the heating value of the fume. The system also includes a burner pipe for injecting the fume into the kiln which has a variable orifice to maintain a constant pressure differential across the orifice and thereby maintain a predetermined flame shape as the fume is burned in the kiln.

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4627367	1984	0.937	Coal Industry (Patents) Limited	Hot gas generation	In a hot gas generating apparatus coal is fed to a first gasifying fluidized bed wherein it is partially gasified to generate a combustible gas and char. The char is circulated to a second combustion fluidized bed for burning in the presence of excess air. The combustible gas is mixed with the oxygen rich gases from the second bed and burnt to give a hot gas product.
4800825	1988	0.934	TRW Inc.	Slagging-combustor sulfur removal process and apparatus	In the operation of a slagging combustor, including an apertured baffle defining part of a cylindrical combustion chamber having a head end which includes a nozzle for injection of sulfur-containing particulate carbonaceous material to be combusted in a whirling oxidant flow field, there is injected a particulate sulfur sorbent at the aperture of the baffle towards the nozzle to react with released sulfur. The sulfur sorbent is injected into the combustion zone from a location near the exit end thereof. Fuel is injected near the center of the head end. A relatively fuel-rich recirculation zone is established and maintained along the longitudinal axis of the combustion chamber surrounded by a relatively oxygen-rich annular region. Sorbent mixes intimately with, and flows co-currently with, recirculating gases, generally toward the head end of the combustion zone, whereby the mixture of sorbent and gaseous products of combustion are maintained at temperatures and stoichiometric conditions favoring conversion of sulfur to compounds that dissolve in the molten slag.
4471702	1983	0.931	individual(s)	Apparatus for burning waste material	Apparatus for burning material and utilizing the heat of burning has a primary combustion chamber with an upper portion vented to the atmosphere, the material being fed into the primary combustion chamber. A secondary combustion chamber is in communication with a lower portion of the primary combustion chamber, and air is supplied into the secondary combustion chamber. A fan draws air from the atmosphere into the upper portion of the primary combustion chamber and draws combustion gases downwardly through burning waste material in the primary combustion chamber to cause further combustion of the combustion gases in the secondary combustion chamber. Combustion gases from the primary combustion chamber are vented to the atmosphere from the upper portion of the primary combustion chamber when the fan is not operating.
4579067	1984	0.923	Ecochem Research, Inc.	Combustion reactor	A combustion reactor which includes a reactor housing having an interior chamber, an inlet port at a top end of the housing and an outlet port at a bottom end thereof. The interior chamber has a circular cross-section, the diameter of which continuously increases from the inlet port to an intermediate level and then continuously decreases to the outlet port. A gas inlet conduit opens into the interior chamber adjacent to the inlet port at a location and in a direction tangent to a notional circle whose center lies on the axis of the interior chamber. By directing a high velocity flow of gas containing oxygen into the chamber tangent to the interior surface thereof and initially a combustible gas, upon ignition of the combustible gas and feeding into the inlet port combustible material, combustion of the fuel material takes place as the latter progresses from the inlet to the outlet.

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5065680	1990	0.917	Phoenix Environmental, Inc.	Method and apparatus for making solid waste material environmentally safe using heat	Harmful constituents are removed from non-combustible solid waste, such as incinerator ash, by continuously feeding a mixture of the solid waste and a combustible excitation material into a reaction chamber, igniting the mix in said chamber and causing it to react in the presence of oxygen until the heat of the reaction causes the solid waste material to become a molten slag and the temperature within the chamber above the molten slag is high enough to destroy substantially all of the harmful constituents in the gaseous effluent released by the formation of the molten slag. The excess molten slag is conducted from the reaction chamber. The effluent is conducted from the reaction chamber into a second chamber where it is rapidly cooled to cause particulate material to precipitate out of the effluent. The effluent is thereafter treated to remove substantially all of the remaining particulate and harmful gases to achieve acceptable environmental quality. The thus treated effluent is released into the atmosphere.
5123364	1990	0.916	American Combustion, Inc.	Method and apparatus for co-processing hazardous wastes	A method of thermal decontamination of organic wastes in which the waste is treated in a primary incinerator by a heat source such that solid residue is collected from the incinerator and exhaust fumes then participate in an industrial thermal process by being directed to an industrial containment by combusting the exhaust gases together with fuel and an oxidizer with oxygen concentration in excess of air to decontaminate the exhaust gases and using the heat produced in the industrial process.
5500194	1994	0.916	Petrocon Technologies, Inc.	Hybrid low NO.sub.x process for destruction of bound nitrogen compounds	A process for treating an exhaust stream which includes high levels of noxious compounds containing chemically bound nitrogen, to produce an effluent stream that is extremely low in oxides of nitrogen and environmentally safe for discharge into the atmosphere. A source of oxygen and fuel is added to the exhaust stream to create a fuel-rich mixture, the quantity of fuel being sufficient to react with the available oxygen. The fuel-enriched stream is provided to a thermal reactor and reacted to provide a heated oxygen-depleted stream which includes quantities of by-product NO.sub.x, which stream is then cooled to 800.degree. to 1000.degree. F. Conversion oxygen is added to the cooled stream which is then passed over a first catalyst bed under overall reducing conditions, the quantity of conversion oxygen added being in stoichiometric excess of the amount of NO.sub.x in the stream, but less than the amount of combustibles, whereby the NO.sub.x is first oxidized to NO.sub.2, and then the NO.sub.2 is reduced by the excess combustibles. The stream is cooled to a temperature of about 450.degree. to 550.degree. F., and air is added to produce a further cooled stream at a temperature of about 400.degree. to 500.degree. F., and having a stoichiometric excess of oxygen. This is passed over an oxidizing catalyst bed to oxidize remaining excess combustibles, and provide an effluent stream having environmentally safe characteristics.
7384452	2005	0.916	Praxair Technology, Inc.	Fluid heating method	A method of heating a fluid utilizing a process heater having one or more first combustion zones and one or more second combustion zones. The combustion of a fuel is divided between the first and second combustion zones. The oxygen is provided for combustion within the first combustion zone by one or more oxygen transport membranes that contribute between about 50 and 99 percent of the stoichiometric amount of oxygen required for complete combustion of the fuel passing through the process heater. A supplemental or secondary oxidant is introduced into second combustion zone to complete combustion of the fuel and thereby produce a flue gas stream containing between about 1 and 3 percent oxygen to ensure complete combustion of the fuel. In this manner, the surface area of the oxygen transport membranes may be reduced below the surface area that otherwise would be required if 100 percent of the oxygen were contributed by the oxygen transport membranes.

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4363623	1981	0.915	individual(s)	Casings for heat exchangers and burner/recuperator assemblies incorporating such casings	The invention provides a protective casing for a cube-shaped modular ceramic heat exchanger core, in which the core can easily be installed without danger of leakage between the fluid paths of the core, either while the device is new as its temperature changes, and subsequently as it is in use subjected to drastically altering operating temperature. Moreover, the core can easily be replaced by a core of different heat transfer ability without diminishing the ability to prevent such leakage. To this end the core rests in the casing with the edges of one face engaged with a suitable ceramic fibre composition gasket; the opposite face of the same flow path as engaged by another such gasket and the gasket is in turn engaged by a gasket compression member. The compression member is urged into this engagement by strong springs which thereby hold the gaskets in the necessary sealing engagement. Preferably the body of the protective casing is of refractory material, and may be enclosed by a supplementary outer metal casing. The exchanger may be used as a heat reclaimer receiving through one path the outlet flue gas of a high temperature furnace, and through the other path the combustion air for the furnace hot air burner. Preferably the gasket compression member is located at the inlet for the combustion air, which is the coolest location. The invention also permits the production of an integral burner/recuperator assembly without the need for heavily insulated connections as in the prior art.
4205630	1978	0.913	Combustion Engineering, Inc.	Steam air preheater for maintaining the flue gas temperature entering dust collection equipment	In a pulverized fuel-fired steam generator, a steam air heater is disposed in the air inlet duct to the main air heater. Steam from an auxiliary in-plant source or from the boiler itself is passed through the steam air heater thereby increasing the temperature of the air entering the main air heater. The flow rate of steam passed through the steam air heater is regulated to maintain the flue gas temperature entering dust collection equipment located in the flue gas stream downstream of the main air heater above the dew point of water vapor and the condensation point of sulfuric acid during start-up and low load operations.
4773847	1987	0.913	Tecogen, Inc.	Thermoelectric field burner	A liquid-fueled thermoelectric field burner operable in two modes, a start-up mode and a steady-state mode. A rechargeable battery backed up by a manually operated generator permits cold start-up of a preheat burner followed by operation of a main burner which provides heat to thermoelectric converters which operate to provide necessary power for steady-state operation. Cold start-up is facilitated by atomizing the liquid fuel for combustion in the preheat burner, and steady-state blue flame operation is enhanced by mixing vaporized fuel and preheated air for combustion in a main burner. The thermoelectric converters are cooled by air from a cooling blower.
4168946	1977	0.91	Comstock & Wescott, Inc.	Catalytic fuel combustion apparatus and method	A flameless catalytic combustion apparatus includes a combustion chamber with a hydrogenous fuel inlet and a mass of catalyst in the chamber between the inlet and an outlet. Preferably the catalyst mass comprises porous pellet bodies supporting varying high and low concentrations of platinum family metals dispersed therein. For spontaneous starting of combustion the fuel is one of the lower alcohols and the high catalyst concentration is at the fuel inlet. The fuel may be in a container pressurized by air, or a lower ether or lower hydrocarbon which is also a fuel. Preferably separate, valved conduits from the fuel container first supply either atomized fuel droplets or air and fuel vapor to the high catalyst concentration for spontaneous ignition of combustion and vaporized fuel for continued combustion throughout the catalyst mass. The catalytic combustion apparatus may include a heat exchanger for fluids such as air, water or personal care foams and creams, or may be used in heating and cooking apparatus.

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3945942	1972	0.9	Texaco Development Corporation	Fuel burner and process for gas manufacture	A partial oxidation burner and process for the manufacture of synthesis gas, reducing gas and other gas mixtures substantially comprising H.sub.2 and CO. A hydrocarbon, oxygen-rich gas and, optionally, H.sub.2 O or some other temperature moderator are introduced into the reaction zone of a synthesis gas generator in which, by partial oxidation at an autogenous temperature in the range of about 1700.degree. to 3500.degree.F. and a pressure in the range of about 1 to 250 atmospheres, said synthesis, fuel, or reducing gas is produced. For example, a hydrocarbon is introduced into the reaction zone by way of the inner assembly of a novel multitube burner, and a mixture of oxygen-rich gas and steam is passed through a coaxial conduit disposed about the outside of said inner assembly. Said inner assembly comprises a central conduit of circular cross-section, having a plurality of parallel open-ended tubes extending downstream from the exit end of said central conduit and in communication therewith. The tubes terminate in a surrounding nozzle, which is the exit end of the coaxial outer conduit.
6293084	2000	0.9	Praxair Technology, Inc.	Oxygen separator designed to be integrated with a gas turbine and method of separating oxygen	An oxygen separator and method for separating oxygen from a heated oxygen containing gas that employs oxygen-selective ceramic membranes of elongated, tubular configuration within a duct for separation of oxygen from a heated gas. The duct can be attached between the exhaust of a gas turbine and a power generator driven by the exhaust or can be connected to one or more burners of a gas turbine. Supplementary compressed feed air may be added at a flow rate at least equal to that of the permeated oxygen for cooling and flow balancing purposes. A purge stream can also be introduced. Additionally, combustor tubes fabricated from an oxygen-selective ceramic membrane material may also be provided to produce combustion products that in turn can be used as a purge for downstream oxygen-selective ceramic membranes.

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Table S4. The patents with highest SPNP values in the "More efficient combustion or heat usage" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
4041906	1976	0.992	individual(s)	Energy system producing electricity, hot water and steam from combustible refuse	An energy system which burns refuse inside a steam chamber to drive a steam turbine and an electrical generator. In addition to the electrical energy produced, hot water and steam are delivered as by-products.
5482402	1993	0.984	Hrubetz Environmental Services, Inc.	Method and apparatus for heating subsurface soil for decontamination	A technique for in situ decontamination of an earth formation. High gas temperatures can be achieved at subsurface formations by supplying a fuel at a subsurface location, such as at the bottom of a wellbore. Pressurized air or gas preheated to a temperature of about 700.degree. F.-1200.degree. F. is supplied to the wellbore to ignite the fuel. The combustion heat produced by the fuel further heats the preheated gas to temperatures in the range of 1200.degree. F.-4500.degree., which heated gases are forced out of the borehole into the contaminated formation. Contaminants are thereby volatilized or oxidized and removed from the formation to the surface.
4092825	1976	0.982	Chevron Research Company	Process for base-load and peak-load power generation	Disclosed is an integrated process for the generation of base-load and peak-load power, particularly electrical power, from a solid carbonaceous material. A solid carbonaceous material is gasified to produce a combustible synthesis gas. A portion of this synthesis gas is contacted with a Fischer-Tropsch catalyst to produce condensable hydrocarbons. Preferably, a second portion of the synthesis gas is combusted and utilized to generate a base-load power output and the condensable hydrocarbons are utilized as a fuel as needed for peak-load power production.
5072675	1991	0.982	individual(s)	Apparatus and method for the destruction of waste	A process for the destruction of waste including the steps of passing an organic waste into a chamber, pumping an inert gas into the chamber until the pressure within the chamber is at least 10,000 p.s.i., heating the chamber to a temperature in excess of 300.degree. F., dissociating the organic waste into its gaseous constituents, and passing the gaseous constituents from the chamber. The chamber is filled with an inert gas so as to displace oxygen from the chamber. The pressurized gaseous constituents are delivered to a turbine so as to actuate the turbine and to generate electricity therefrom. The gaseous constituents pass from the turbine into a boiler. An oxygen-containing gas is mixed with the gaseous constituents within the boiler so as to produce pressurized steam. This pressurized steam is passed to a turbine so as to produce electricity. The inert gas is argon.
4158948	1978	0.981	Texaco Inc.	Conversion of solid fuels into fluid fuels	Solid carbonaceous fuels are converted into gaseous fuels by a process comprising liquefying at least a portion of the solid fuel, subjecting a portion of the high boiling product to gasification with substantially pure oxygen to provide hydrogen for the liquefaction, subjecting the balance of the high boiling product to gasification with air to provide a gaseous product used as the stripping medium to remove lighter boiling materials from the liquefaction product and recovering fuel gas from the stripping zone overhead.

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5011329	1990	0.973	Hrubetz Exploration Company	In situ soil decontamination method and apparatus	Disclosed is in situ decontamination methods and apparatus for injecting a hot gas into boreholes formed in a contaminated soil area to vaporize the soil moisture and contaminants, and for collecting the vaporized contaminants at the surface of the soil. A burner heats pressurized gases and mixes the same with combustion gases for injection into the contaminated zone. A central collection system recovers the vaporized contaminants and couples such vapors to an on-site incinerator for disposal. Controlled heating of the injection gas is effective to sequentially remove different types of contaminants, as well as to provide in situ oxidation of other contaminants, while minimizing recondensation of the soil vapors. Wellbore casings are especially adapted for injecting the gas in predetermined patterns. In addition, a heater and incinerator assembly utilizes a single burner for both heating the dry gas and for incinerating the vapor contaminants.
8673220	2012	0.968	McAlister Technologies, LLC	Reactors for conducting thermochemical processes with solar heat input, and associated systems and methods	Reactors for conducting thermochemical processes with solar heat input, and associated systems and methods. A representative system includes a reactor having a reaction zone, a reactant source coupled in fluid in communication with the reactant zone, and a solar concentrator having at least one concentrator surface positionable to direct solar energy to a focal area. The system can further include an actuator coupled to the solar concentrator to move the solar concentrator relative to the sun, and a controller operatively coupled to the actuator. The controller can be programmed with instructions that direct the actuator to position the solar concentrator to focus the solar energy on the reaction zone when the solar energy is above a threshold level, and point to a location in the sky having relatively little radiant energy to cool an object when the solar energy is below the threshold level.
4101294	1977	0.963	General Electric Company	Production of hot, saturated fuel gas	A clean, cool stream of low BTU gas is heated and saturated with water vapor by means of a hot liquid stream containing water. Contamination of the gas stream by droplets, particulate matter and salt content of the liquid stream is obviated by maintaining separation between the gas and liquid phases by means of a microporous barrier. The barrier is made of a material selected from the group consisting of hydrophobic polymer material and hydrophilic polymer material having a gel structure.
4338788	1980	0.961	UOP Inc.	Cogeneration process linking FCC regenerator and power plant turbine	An air supply system for the catalyst regeneration zone of a fluidized catalytic cracking unit also supplies a pressurized air stream to the turbine of an electrical generating plant. The compressor which produces the pressurized air stream is driven by passing the flue gas of the regeneration zone through a power recovery expander. Preferably, the pressurized air stream is first heated by heat exchange against the turbine effluent and then admixed with hot gas from separate turbin-type gas generators prior to being passed into the turbine. This provides a very practical and relatively low-cost cogeneration process.
4827723	1988	0.961	A. Ahlstrom Corporation	Integrated gas turbine power generation system and process	The system includes a circulating fluidized bed combustor coupled at its outlet to a separator. A vertical return channel is provided for conveying separated solid particles from the separator back to the combustion chamber. A gas turbine cycle is provided, including a gas compressor, a heat transfer means directed to a first duct to the compressor for heating the compressed oxidizing gas, a gas turbine connected through a second duct to the heat transfer means for power generation and a third duct for conveying expanded oxidizing gas from the turbine to the combustion chamber. The heat transfer means includes tubes disposed inside the vertical return channel for indirect heat transfer between the compressed gas and the dense suspension of separated particles flowing downwardly in the vertical channel.

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5181481	1991	0.958	Foster Wheeler Energy Corporation	Fluidized bed combustion system and method having multiple furnace sections	A combustion system in which a furnace having a fluidized bed disposed therein is divided into multiple sections by one or more partitions. Openings are provided in the lower portion of each partition for permitting the fluidized bed material to flow between the furnace sections, and openings are provided in the upper portion of each partition for equalizing the gas pressure between the furnace sections.
5224334	1992	0.958	RadiSys Corporation	Low NO.sub.x cogeneration process and system	A process and system for low NO.sub.x cogeneration to produce electricity and useful heat. Fuel and oxygen are provided to an internal combustion engine connected to drive an electric generator, to thereby generate electricity. An exhaust stream is recovered from the engine at a temperature of about 500.degree. to 1000.degree. F. which includes from about 6 to 15 percent oxygen. Fuel is added to the exhaust stream to create a fuel-rich mixture, the quantity of fuel being sufficient to react with oxygen and reduce the NO.sub.x in said exhaust stream. The fuel-enriched stream is provided to an afterburner, and the fuel, NO.sub.x and available oxygen are reacted to provide a heated oxygen-depleted stream. The oxygen-depleted stream is cooled in a first heat exchanger. Conversion oxygen is admixed with the cooled stream which is then passed over a catalyst bed under overall reducing conditions. NO is converted to NO.sub.2 at the forward end of the bed, and the NO.sub.2 then reacts on the remainder of the bed with excess combustibles. The stream from the reducing catalyst bed is cooled from a temperature of 750.degree. to 1250.degree. F. to about 450.degree. to 650.degree. F. and air is added to produce a further cooled stream at 400.degree. to 600.degree. F. having a stoichiometric excess of oxygen, and the further cooled stream is passed over an oxidizing catalyst bed to oxidize remaining combustibles. The resultant low NO.sub.x stream can then be provided for venting.
5724807	1997	0.957	Montenay International Corp.	Combined gas turbine-steam cycle waste-to-energy plant	A waste-to-energy plant which is designed and operated to burn municipal waste combines a high pressure steam turbine/generator cycle and a combustion turbine/generator cycle; wherein the exit gas from the combustion turbine is utilized to superheat high pressure steam prior to entering the steam turbine. The combination of the combustion turbine/generator cycle with the steam turbine/generator cycle enables operation of the waste-to-energy plant at high pressure and high temperature resulting in greatly increased thermal cycle efficiency while eliminating superheater surfaces from the waste heat recovery boiler, thereby greatly reducing corrosion problems associated with waste heat recovery boilers.
7882646	2007	0.953	EarthRenew, Inc.	Process and system for drying and heat treating materials	This invention discloses systems and methods for conversion of high moisture waste materials to dry or low moisture products for recycle or reuse. The equipment systems comprise a gas turbine generator unit (preferred heat source), a dryer vessel and a processing unit, wherein the connection between the gas turbine and the dryer vessel directs substantially all the gas turbine exhaust into the dryer vessel and substantially precludes the introduction of air into the dryer vessel and wherein the processing unit forms the dried material from the dryer vessel into granules, pellets or other desired form for the final product. Optionally, the systems and methods further provide for processing ventilation air from manufacturing facilities to reduce emissions therefrom.
8544633	2011	0.951	General Electric Company	Segmented solid feed pump	A system is provided with a segmented solid feed pump having a plurality of pump segments disposed along a closed-loop path. The plurality of pump segments are coupled together in series along the closed-loop path, and the plurality of pump segments move along the closed-loop path. Furthermore, each pump segment includes a holding receptacle.

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5261765	1991	0.948	Hrubetz Environmental Services, Inc.	Method and apparatus for heating subsurface soil for decontamination	A technique for in situ decontamination of an earth formation. High gas temperatures can be achieved at subsurface formations by supplying a fuel at a subsurface location, such as at the bottom of a wellbore. Pressurized air or gas preheated to a temperature of about 700.degree. F.-1200.degree. F. is supplied to the wellbore to ignite the fuel. The combustion heat produced by the fuel further heats the preheated gas to temperatures in the range of 1200.degree. F.-4500.degree., which heated gases are forced out of the borehole into the contaminated formation. Contaminants are thereby volatilized or oxidized and removed from the formation to the surface.
5040972	1990	0.941	Systech Environmental Corporation	Pyrolyzer-kiln system	A pyrolyzer-kiln system for generating combustible fume from waste material and supplementing the fuel used to provide heat energy to a clinker kiln. The system includes a pyrolyzer for generating a combustible pyrolytic fume, a kiln for burning the fume as part of a cement-forming process, a conduit for conveying the fume from the pyrolyzer to the kiln, and a closed-loop feedback component for monitoring the heating value of the fume and varying the operational parameters of the pyrolyzer to maintain the heating value of the fume generated within a predetermined range. The closed-loop feedback component includes a calorimeter which continuously samples and burns fume from the conduit. The heating value of the fume is determined by measuring the amount of auxiliary fuel and air required to be mixed with the fume to maintain a predetermined temperature when the combustion is burned within the calorimeter. Controllers monitor the amount of auxiliary fuel and air supplied to the calorimeter and vary the temperature within the pyrolyzer to effect an increase or decrease in the heating value of the fume. The system also includes a burner pipe for injecting the fume into the kiln which has a variable orifice to maintain a constant pressure differential across the orifice and thereby maintain a predetermined flame shape as the fume is burned in the kiln.
5632148	1993	0.937	Ormat Industries Ltd.	Power augmentation of a gas turbine by inlet air chilling	In order to augment the power produced by a gas turbine system of a type having an air compressor for producing compressed air, a combustor for heating the compressed air, and a gas turbine responsive to the heated air for driving the air compressor and the load, cooling air is supplied to the compressor by indirectly contacting the air with water that is chilled by flashing some of the water into a vapor.
4473536	1982	0.933	General Electric Co	Catalytic pollution control system for gas turbine exhaust	A steam and gas turbine (STAG) plant employs a catalyst in a heat recovery steam generator to react injected ammonia with NOx from the combustor of the gas turbine to reduce atmospheric emission of NOx from the system. Rapid control of ammonia injection is achieved using a prediction of the NOx being generated in dependence upon the operating conditions of the combustor. A trimming signal from a measurement of NOx being emitted from the heat recovery steam generator downstream of the catalyst is employed to complete the NOx control loop.
4473537	1982	0.933	General Electric Co	Ammonia control system for NOx emission control for gas turbine exhaust	A steam and gas turbine combined cycle plant STAG* employs a catalyst in a heat recovery steam generator to react injected ammonia with NOx from the combustor of the gas turbine to reduce atmospheric emission of NOx from the system. Rapid control of ammonia injection is achieved using a prediction of the NOx being generated in dependence upon the operating conditions of the combustor. A trimming signal from a measurement of NOx being emitted from the heat recovery steam generator downstream of the catalyst is employed to complete the NOx control loop. Compensation is provided to relate the measured NOx downstream of the catalyst with the NOx in the output of the gas turbine taking into account the catalyst efficiency.

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4683715	1985	0.933	Hitachi, Ltd.	Method of starting gas turbine plant	A method of starting a gas turbine plant, which plant has at least one combustor including a primary combustion chamber into which primary fuel nozzles open and a secondary combustion chamber into which secondary fuel nozzles open, a compressor for supplying the combustor with compressed combustion air, and a gas turbine driven by the combustion gas generated in the combustor and adapted to drive a load such as an electric power generator. When the gas turbine is being accelerated to a rated speed or while the load is still below a normal load range, a fuel is supplied only to the primary fuel nozzle, whereas, in other loaded operation range, the fuel is supplied to both the primary and secondary fuel nozzles. Before the fuel supply to the secondary fuel nozzles is commenced, a part of the compressed air is bled through at least one air bleed pipe leading from the compressor and having an air bleed valve. The air bleed valve is controlled in such a manner that the opening degree thereof is maximized when the fuel supply to the secondary fuel nozzles is commenced and is progressively decreased in accordance with the increase of the load such as to become substantially zero when the load has been increased to the normal load range.
5321944	1993	0.933	Orad, Inc.	Power augmentation of a gas turbine by inlet air chilling	In order to augment the power produced by a gas turbine system of a type having an air compressor for producing compressed air, a combustor for heating the compressed air, and a gas turbine responsive to the heated air for driving the air compressor and the load, cooling air is supplied to the compressor by indirectly contacting the air with water that is chilled by flashing some of the water into a vapor.
5865878	1997	0.929	Praxair Technology, Inc.	Method for producing oxidized product and generating power using a solid electrolyte membrane integrated with a gas turbine	A process for producing an oxidized product in conjunction with a turbine for generating power. This process comprises contacting a compressed and heated oxygen-containing gas stream with at least one solid electrolyte oxygen selective ion transport membrane in a membrane reactor. A reactant is passed into the reactor to generate an oxidized product therefrom. Oxygen-depleted retentate stream from the reactor is added to a gas turbine combustor and expanded in a gas turbine to generate power.
4686378	1985	0.925	ETA Thermal Systems Corporation	Apparatus for generating heat and electricity	An apparatus is disclosed for generating thermal and electrical energy outputs in response to thermal and electrical load requirements imposed thereon. The apparatus includes a variable speed power source and a mechanism for transferring thermal energy from the power source a coolant fluid. A generator is also provided and is driven by the power source to produce electrical energy for the electrical load. The output frequency of the generator is independent of the speed of the power source. A mechanism is also provided for extracting thermal energy from the coolant fluid and directing the thermal energy to the thermal load. Finally, a device is included for monitoring the loads and controlling the thermal and electrical outputs in response to the loads by independently varying the speed of the power source and the output frequency of the generator to provided desired thermal and electrical energy outputs.

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4353206	1980	0.924	Westinghouse Electric Company LLC	Apparatus for removing NOx and for providing better plant efficiency in combined cycle plants	In a combined cycle power plant having one or more combustion turbines and a steam turbine, a dry catalytic NOx removal module is disposed in each of the turbine exhaust stacks. A waste heat exchanger system includes an economizer coil and a pair of high pressure evaporator coils on upstream and downstream sides of the NOx removal module to generate steam for injection into the turbine combustors and for delivery to a superheater coil upstream from the upstream evaporator coil. A bypass stack across the upstream evaporator coil is damper controlled to regulate the exhaust gas temperature at the entry to the NOx removal module. A downstream low pressure evaporator coil generates steam for induction into the low pressure section of the steam turbine. Superheated steam is supplied to the high pressure section of the steam turbine. The compressor inlet guide vanes are closed to increase exhaust gas temperature as required after the upstream evaporator bypass flow reaches zero and no longer controls gas temperature. If the inlet guide vanes reach the fully closed position, reductant injection flow is shut off to terminate the NOx removal process under low exhaust gas temperature conditions. A plant afterburner is operated to add heat to the exhaust gas if gas temperature is too low.
5069685	1990	0.915	The United States of America as represented by the Secretary of the Air	Two-stage coal gasification and desulfurization apparatus	The present invention is directed to a system which effectively integrates a two-stage, fixed-bed coal gasification arrangement with hot fuel gas desulfurization of a first stream of fuel gas from a lower stage of the two-stage gasifier and the removal of sulfur from the sulfur sorbent regeneration gas utilized in the fuel-gas desulfurization process by burning a second stream of fuel gas from the upper stage of the gasifier in a combustion device in the presence of calcium-containing material. The second stream of fuel gas is taken from above the fixed bed in the coal gasifier and is laden with ammonia, tar and sulfur values. This second stream of fuel gas is burned in the presence of excess air to provide heat energy sufficient to effect a calcium-sulfur compound forming reaction between the calcium-containing material and sulfur values carried by the regeneration gas and the second stream of fuel gas. Any ammonia values present in the fuel gas are decomposed during the combustion of the fuel gas in the combustion chamber. The substantially sulfur-free products of combustion may then be combined with the desulfurized fuel gas for providing a combustible fluid utilized for driving a prime mover.
6786050	2002	0.913	JNC Corporation	System and method for oil fuel burning integrated combined cycle power generation	A light portion is extracted from feed oil by a separation system. The light portion is then subject to a hydrotreatment to obtain impurity-removed fuel oil which is stored in an intermediate tank. A residue of the feed oil after extraction of the light portion is gasified to obtain syngas (H2 gas+CO gas) which is used as basic fuel for power generation in a power generation system. The fuel oil is fed to the power generation system as auxiliary fuel for supplementing the power generation based on the syngas. The power generation system includes a plurality of gas turbines and generators. The number of the gas turbines to be driven by the fuel oil is controlled to adjust the power generation amount depending on demand.
8114663	2009	0.912	The Governement of the United States of America as represented by the Secretary of the Air Force	Method for consolidated waste management and resource recovery	A waste management and resource recovery system that uses the different waste streams from typical waste sources as fuel or feedstock for its subsystems that, in turn, produce fuel, feedstock or energy for other subsystems such that all the different waste streams are effectively managed. The subsystems include a gas burner for solid and fuel wastes that supplies heat to a hydrothermal processor for saccharification of paper and cardboard. The resulting saccharification broth, along with kitchen wastes and blackwater, are supplied to a bioreactor using dark fermentation to produce hydrogen and volatile fatty acids. The hydrogen and volatile fatty acids are supplied to hydrogen and microbial fuel cells to produce electrical energy for operating the system and potable water. A steam accumulator is added to provide sufficient temperatures and pressures to reach the necessary thermodynamic states for the

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					saccharification process. An enzymatic saccharification processor may also improve the saccharification process.
4069675	1976	0.91	Measurex Corporation	Method of optimizing the performance of a multi-unit power	A method of optimizing the performance of a multi-unit power plant which produces both electrical and steam energy by determining the incremental efficiency of power boilers with various fuel inputs and thereafter determining the index of performance by taking into account cost factors and reallocating in the most optimum manner.
4214451	1978	0.909	Systems Control, Inc.	Energy cogeneration system	An energy cogeneration system of the type employed in industrial plants, such as paper mills, is described. The system utilizes the energy of steam to generate electricity, as well as to operate various industrial processes in the plant. The requirements of the processes for steam are continuously monitored, and if the requirements at any given time are significantly less than the steam being delivered thereto, the delivered steam pressure and/or temperature is reduced to make more steam energy available for other purposes.

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Table S5. The patents with highest SPNP values in the "Capture by biological separation" domain

Patent number	Filing year	Centrality measure	Organization	title	abstract
4936996	1989	0.824	Biodynamic Systems Inc.	Method of processing biodegradable organic material	An improved method and apparatus for treating a biodegradable organic material in an aqueous medium to produce methane gas is disclosed. The method involves flowing the aqueous medium under pressure through a hydrolytic-redox, immobilized microbe bioreactor to form a reaction product and then continuing the flow of the reaction product through an anaerobic, immobilized microbe bioreactor whereby methane gas is evolved. The aqueous medium is flowed in a downward direction counter to the flow of the gaseous carbon dioxide given off during the reaction and the aqueous medium may be recycled.
7521217	2006	0.617	CO2 Solution, Inc.	Carbonic anhydrase having increased stability under high temperature conditions	The present invention relates to polynucleotide and polypeptide sequences of carbonic anhydrase variants having increased stability under high temperature conditions compared to native carbonic anhydrase.
6524843	1999	0.562	CO2 Solution, Inc.	Process and apparatus for the treatment of carbon dioxide with carbonic anhydrase	A process is disclosed for the extraction, production and purification of carbon dioxide gas. The process may also be employed for the production of aqueous and/or organic solutions of bicarbonate ions using a precursor feed stream of gas containing carbon dioxide. The process consists of the countercurrent flushing of a packed tower-type bioreactor with gas containing carbon dioxide and a liquid solvent. The bioreactor contains carbonic anhydrase covalently bound to an inert inorganic support. The carbon dioxide of the gaseous phase diffuses into the liquid phase. The immobilized carbonic anhydrase catalyses the hydration of the carbon dioxide which forms hydrogen and bicarbonate ions. The solution of ions may be employed directly or, alternatively, subjected to an ion-exchange resin to immobilize the bicarbonate ions. The aqueous solution of hydrogen and bicarbonate ions may also be recirculated into a second identical bioreactor, wherein they are catalytically converted to water and carbon dioxide.
6945925	2004	0.534	individual(s)	Biosequestration and organic assimilation of greenhouse gases	Provided herein are methods for the biosequestration and organic assimilation of a gas that contributes to the greenhouse effect. In these methods, a gas that contributes to the greenhouse effect is introduced into a peat bog where it is thereafter sequestered and organically assimilated. A capture method may be employed in conjunction with the present invention to enable transport of the gas from an industrial site to a processing facility located at or near a peat bog. Once transported to a relevant processing facility, the captured gas may be regenerated and thereafter introduced into the peat bog for its biosequestration and organic assimilation. In the context of the present invention, the gas may be a greenhouse gas (GHG), sulfur oxide (SO_x) gas, and/or volatile organic compound (VOC).

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7820432	2009	0.426	CO2 Solution, Inc.	Triphasic bioreactor and process for gas effluent treatment	A triphasic bioreactor for physico-chemically treating a gas is disclosed. The triphasic bioreactor comprises a reaction chamber with a liquid and biocatalysts in suspension in the liquid, for catalyzing a reaction between the gas and the liquid to obtain a treated gas and a solution containing a reaction product. A gas bubbling means is provided in the reaction chamber for bubbling the gas to be treated into the liquid thereby dissolving the gas into the liquid and increasing a pressure inside the reaction chamber. The bioreactor further comprises a liquid inlet in fluid communication with the reaction chamber for receiving the liquid and filling the reaction chamber, a liquid outlet in fluid communication with the reaction chamber for releasing the solution and a gas outlet in fluid communication with the reaction chamber to release the treated gas. The bioreactor further comprises a retention device to retain the biocatalysts in the reaction chamber. The invention also concerns a process using the triphasic bioreactor. The triphasic bioreactor may advantageously be used for removing carbonic dioxide from a CO₂-containing gas.
7579185	2006	0.246	CO2 Solution, Inc.	Triphasic process for gas effluent treatment	A triphasic bioreactor for physico-chemically treating a gas is disclosed. The triphasic bioreactor comprises a reaction chamber with a liquid and biocatalysts in suspension in the liquid, for catalyzing a reaction between the gas and the liquid to obtain a treated gas and a solution containing a reaction product. A gas bubbling means is provided in the reaction chamber for bubbling the gas to be treated into the liquid thereby dissolving the gas into the liquid and increasing a pressure inside the reaction chamber. The bioreactor further comprises a liquid inlet in fluid communication with the reaction chamber for receiving the liquid and filling the reaction chamber, a liquid outlet in fluid communication with the reaction chamber for releasing the solution and a gas outlet in fluid communication with the reaction chamber to release the treated gas. The bioreactor further comprises a retention device to retain the biocatalysts in the reaction chamber. The invention also concerns a process using the triphasic bioreactor. The triphasic bioreactor may advantageously be used for removing carbonic dioxide from a CO₂-containing gas.
8507264	2011	0.242	Algae Systems, LLC	Photobioreactor systems and methods for treating CO₂-enriched gas and producing biomass	Certain embodiments and aspects of the invention relate to a photobioreactor including covered photobioreactor units through which a liquid medium stream and a gas stream flow. The liquid medium comprises at least one species of phototrophic organism therein. Certain methods of using the photobioreactor system as part of fuel generation system and/or a gas-treatment process or system at least partially remove certain undesirable pollutants from a gas stream. In certain embodiments, a portion of the liquid medium is diverted from a photobioreactor unit and reintroduced upstream of the diversion position. In certain embodiments, the disclosed photobioreactor system, methods of using such systems, and/or gas treatment apparatus and methods provided herein can be used as part of an integrated combustion method and system, wherein photosynthetic organisms used within the photobioreactor are harvested from the photobioreactor, processed, and used as a fuel source for a combustion system like an electric power plant.
7803575	2008	0.23	Novozymes A/S	Heat-stable carbonic anhydrases and their use	The present invention relates to use of heat-stable carbonic anhydrase in CO₂extraction, e.g., from flue gas, natural gas or biogas. Furthermore, the invention relates to isolated polypeptides having carbonic anhydrase activity at elevated temperatures and isolated polynucleotides encoding the polypeptides. The invention also relates to nucleic acid constructs, vectors, and host cells comprising the polynucleotides.

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8110395	2006	0.192	Algae Systems, LLC	Photobioreactor systems and methods for treating CO₂-enriched gas and producing biomass	Certain embodiments and aspects of the present invention relate to a photobioreactor including covered photobioreactor units through which a liquid medium stream and a gas stream flow. The liquid medium comprises at least one species of phototrophic organism therein. Certain methods of using the photobioreactor system as part of fuel generation system and/or a gas-treatment process or system at least partially remove certain undesirable pollutants from a gas stream. In certain embodiments, a portion of the liquid medium is diverted from a photobioreactor unit and reintroduced upstream of the diversion position. In certain embodiments, the disclosed photobioreactor system, methods of using such systems, and/or gas treatment apparatus and methods provided herein can be used as part of an integrated combustion method and system, wherein photosynthetic organisms used within the photobioreactor are harvested from the photobioreactor, processed, and used as a fuel source for a combustion system such as an electric power plant.
8277769	2011	0.174	CO2 Solutions Inc.	Process for treating carbon dioxide containing gas	A process is disclosed for recycling carbon dioxide emissions from a fossil-fuel power plant into useful carbonated species The process primarily comprises the steps of: a) burning the fossil fuel, thereby generating heat and a hot exhaust gas containing CO₂; and b) converting the heat into energy. The process is characterized in that it further comprises the steps of: c) cooling the exhaust gas; and d) biologically transforming the CO₂contained in the cooled exhaust gas into carbonated species, thereby obtaining a low CO₂exhaust gas and producing useful carbonated species. The low CO₂exhaust gas obtained in step d) can be released in the atmosphere without increasing the problem of greenhouse effect.
7862788	2008	0.173	ALSTOM Technology Ltd.	Promoter enhanced chilled ammonia based system and method for removal of CO₂from flue gas stream	A chilled ammonia based CO₂capture system and method is provided. A promoter is used to help accelerate certain capture reactions that occur substantially coincident to and/or as a result of contacting a chilled ammonia based ionic solution with a gas stream that contains CO₂.
8435479	2012	0.162	CO2 Solutions Inc.	Process for treating carbon dioxide containing gas	A process is disclosed for recycling carbon dioxide emissions from a fossil-fuel power plant into useful carbonated species The process primarily comprises the steps of: a) burning the fossil fuel, thereby generating heat and a hot exhaust gas containing CO₂; and b) converting the heat into energy. The process is characterized in that it further comprises the steps of: c) cooling the exhaust gas; and d) biologically transforming the CO₂contained in the cooled exhaust gas into carbonated species, thereby obtaining a low CO₂exhaust gas and producing useful carbonated species. The low CO₂exhaust gas obtained in step d) can be released in the atmosphere without increasing the problem of greenhouse effect.

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8329458	2010	0.153	CO2 Solutions Inc.	Carbonic anhydrase bioreactor and process for CO₂containing gas effluent treatment	A triphasic bioreactor for physico-chemically treating a gas is disclosed. The triphasic bioreactor comprises a reaction chamber with a liquid and biocatalysts in suspension in the liquid, for catalyzing a reaction between the gas and the liquid to obtain a treated gas and a solution containing a reaction product. A gas bubbling means is provided in the reaction chamber for bubbling the gas to be treated into the liquid thereby dissolving the gas into the liquid and increasing a pressure inside the reaction chamber. The bioreactor further comprises a liquid inlet in fluid communication with the reaction chamber for receiving the liquid and filling the reaction chamber, a liquid outlet in fluid communication with the reaction chamber for releasing the solution and a gas outlet in fluid communication with the reaction chamber to release the treated gas. The bioreactor further comprises a retention device to retain the biocatalysts in the reaction chamber. The invention also concerns a process using the triphasic bioreactor. The triphasic bioreactor may advantageously be used for removing carbonic dioxide from a CO₂-containing gas.
7514056	2006	0.126	CO2 Solution, Inc.	Process and installation for the fractionation of air into specific gases	In order to reduce incoming atmospheric carbon dioxide levels in compressed air prior to cryogenic distillation, a water spray cooling tower equipped with biocatalytic packing, or fed with absorptive reagents, is used to convert gaseous carbon dioxide into bicarbonate ions which dissolve in the cooling water. The hydration reaction and refrigeration occur synergistically. The bicarbonate ions are subsequently removed from the solution using the heat from the compressed air in a regenerator re-boiler unit, and then fed to a percolation cooling tower for releasing CO₂and cooling.
8329459	2010	0.083	CO2 Solutions Inc.	Carbonic anhydrase system and process for CO₂containing gas effluent treatment	A triphasic bioreactor for physico-chemically treating a gas is disclosed. The triphasic bioreactor comprises a reaction chamber with a liquid and biocatalysts in suspension in the liquid, for catalyzing a reaction between the gas and the liquid to obtain a treated gas and a solution containing a reaction product. A gas bubbling means is provided in the reaction chamber for bubbling the gas to be treated into the liquid thereby dissolving the gas into the liquid and increasing a pressure inside the reaction chamber. The bioreactor further comprises a liquid inlet in fluid communication with the reaction chamber for receiving the liquid and filling the reaction chamber, a liquid outlet in fluid communication with the reaction chamber for releasing the solution and a gas outlet in fluid communication with the reaction chamber to release the treated gas. The bioreactor further comprises a retention device to retain the biocatalysts in the reaction chamber. The invention also concerns a process using the triphasic bioreactor. The triphasic bioreactor may advantageously be used for removing carbonic dioxide from a CO₂-containing gas.
8066965	2009	0.078	CO2 Solution, Inc.	Process for recycling carbon dioxide emissions from power plants into carbonated species	A process is disclosed for recycling carbon dioxide emissions from a fossil-fuel power plant into useful carbonated species The process primarily comprises the steps of: a) burning the fossil fuel, thereby generating heat and a hot exhaust gas containing CO₂; and b) converting the heat into energy. The process is characterized in that it further comprises the steps of: c) cooling the exhaust gas; and d) biologically transforming the CO₂contained in the cooled exhaust gas into carbonated species, thereby obtaining a low CO₂exhaust gas and producing useful carbonated species. The low CO₂exhaust gas obtained in step d) can be released in the atmosphere without increasing the problem of greenhouse effect.

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8329460	2011	0.072	CO2 Solutions Inc.	Carbonic anhydrase bioreactor and process	A triphasic bioreactor for physico-chemically treating a gas is disclosed. The triphasic bioreactor comprises a reaction chamber with a liquid and biocatalysts in suspension in the liquid, for catalyzing a reaction between the gas and the liquid to obtain a treated gas and a solution containing a reaction product. A gas bubbling means is provided in the reaction chamber for bubbling the gas to be treated into the liquid thereby dissolving the gas into the liquid and increasing a pressure inside the reaction chamber. The bioreactor further comprises a liquid inlet in fluid communication with the reaction chamber for receiving the liquid and filling the reaction chamber, a liquid outlet in fluid communication with the reaction chamber for releasing the solution and a gas outlet in fluid communication with the reaction chamber to release the treated gas. The bioreactor further comprises a retention device to retain the biocatalysts in the reaction chamber. The invention also concerns a process using the triphasic bioreactor. The triphasic bioreactor may advantageously be used for removing carbonic dioxide from a CO₂-containing gas.
7998714	2009	0.067	Akermin, Inc.	Process for accelerated capture of carbon dioxide	The present invention generally relates to the removal of carbon dioxide from a gas stream, particularly a flue gas, hydrogen gas from a reformer, natural gas, or gas from a cement kiln. Immobilized enzymes for use in carbon capture and other systems are also disclosed.
8178332	2011	0.063	Akermin, Inc.	Process for accelerated capture of carbon dioxide	The present invention generally relates to the removal of carbon dioxide from a gas stream, particularly a flue gas, hydrogen gas from a reformer, natural gas, or gas from a cement kiln. Immobilized enzymes for use in carbon capture and other systems are also disclosed.
8168149	2010	0.02	ALSTOM Technology Ltd.	Promoter enhanced chilled ammonia based system and method for removal of CO₂from flue gas stream	A method and system for CO₂capture from flue gas uses an absorber vessel in which a flue gas stream containing CO₂is contacted with an ammoniated solution to remove CO₂from the flue gas, and a regenerator vessel in which CO₂is released from the ammoniated solution. Parasitic energy consumption of the system can be reduced by adding to the ammoniated solution a promoter effective to enhance the formation of ammonium bicarbonate within the ammoniated solution. The amount of ammoniated solution recycled from the regenerator vessel to the absorber vessel is less than that which would be required using the ammoniated solution without the promoter for removal of the same amount of CO₂from the flue gas.

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Table S6. The patents with highest SPNP values in the "Capture by absorption" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
8354086	2011	0.923	individual(s)	Captured CO₂from atmospheric, industrial and vehicle combustion waste	A CO₂control device and method for capturing CO₂from fluid flow, including: a flow-through apparatus and an CO₂absorbing filter treated with an alkaline material which is housed within the flow-through apparatus. The flow-through apparatus receives fluid flow and the CO₂from the fluid flow is absorbed by the CO₂absorbing filter. The absorbed CO₂is converted into CaCO₃which is combined with volcanic ash to form a useful cement material.
4830838	1988	0.904	The Dow Chemical Company	Removal of hydrogen sulfide from fluid streams with minimum production of solids	Fluid streams containing hydrogen sulfide from a steam turbine or from a sour gas stream are contacted with an aqueous solution of a polyvalent metal chelate and a bisulfite whereby the hydrogen sulfide is converted to free sulfur and then to soluble sulfur compounds. The metal chelate is reduced to a lower oxidation state metal chelate and reduced metal chelate is subsequently oxidized with air back to the higher oxidation state and reused. The bisulfite is formed by combustion of a portion of the fluid stream and subsequent absorption of the sulfur dioxide formed thereby in a two-stage countercurrent scrubber operating at conditions favorable for high bisulfite and low sulfite formation and selective away from carbon dioxide absorption.
6228145	1999	0.893	Kvaerner ASA	Method for removing carbon dioxide from gases	A method for removing and preventing discharge into the atmosphere of carbon dioxide from combustion gases and natural gas from installations for production of oil and/or gas, wherein the combustion gas is passed to an absorber containing a solvent, where carbon dioxide is absorbed in the solvent, and the thereby purified combustion gas, largely free of carbon dioxide, is released into the atmosphere, where the CO.sub.2 rich solvent is passed to a desorber where CO.sub.2 is removed from the solvent, and the thereby largely CO.sub.2 -free solvent is recycled to the absorber, and the separated CO.sub.2 gas is passed to a compression stage for compression and utilization and/or disposal in a suitable manner, where membrane gas/liquid contactors are employed in both the absorber and the desorber, and that an external stripping steam is supplied to the desorber.

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4112052	1977	0.886	Exxon Research & Engineering Co.	Process for removing carbon dioxide containing acidic gases from gaseous mixtures using aqueous amine scrubbing solutions	Carbon dioxide containing acidic gases are substantially removed from a normally gaseous mixture by a process comprising contacting the normally gaseous mixture with an aqueous amine solution, wherein at least one of the amines is a sterically hindered amine. The process is operated at a thermodynamic cyclic capacity (as determined from the vapor liquid equilibrium isotherm of the vapor-liquid system) which is greater than in an aqueous amine CO.sub.2 scrubbing process wherein monoethanolamine is the only amine utilized under similar conditions of gaseous feed composition, scrubbing solution composition, temperatures and pressures. A particularly preferred sterically hindered amine is 2-amino-2-methyl-1-propanol.
4654062	1986	0.886	Air Products and Chemicals, Inc.	Hydrocarbon recovery from carbon dioxide-rich gases	A process is set forth for the separation of carbon dioxide from propane and higher alkanes using a carbon dioxide-loaded lean oil solvent and higher solvent flows and heat utilizations rather than mechanical energy utilization. A high pressure carbon dioxide product is produced, making the invention valuable in carbon dioxide miscible flood enhanced petroleum recovery operations.
4112051	1977	0.872	Exxon Research & Engineering Co.	Process and amine-solvent absorbent for removing acidic gases from gaseous mixtures	Acidic gases are substantially removed from a normally gaseous mixture by a process comprising contacting the normally gaseous mixture with an amine-solvent liquid absorbent comprising (i) an amine comprised of at least about 50 mol % of a sterically hindered amine, and (ii) a solvent for said amine mixture which is also a physical absorbent for said acidic gases. The liquid absorbent may also include up to about 35 weight percent water.
4475347	1982	0.866	Air Products and Chemicals, Inc.	Process for separating carbon dioxide and sulfur-containing gases from a synthetic fuel production process off-gas	A process is described for the separation of an off-gas from a synthetic fuels production process, such as oil shale retorting, coal gasification, oxygen fireflooding or carbon dioxide miscible flood enhanced oil recovery, into an essentially sulfur-free, light fuel gas and a sulfur containing carbon dioxide gas. The off-gas is contacted with methanol to remove the sulfur containing gases and is then cooled to separate out a light fuel gas from a predominantly carbon dioxide gas. The carbon dioxide gas is again contacted with the same methanol to scrub the latter of sulfur-containing gas and reabsorb the sulfur onto the carbon dioxide gas. The carbon dioxide gas can then be recycled to the synthetic fuels production process with deposition of the sulfur therein or the gas can be delivered for export with downstream sulfur treatment.

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5749941	1996	0.866	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk Onderzoek TNO	Method for gas absorption across a membrane	The invention relates to a method for the absorption of one or more gaseous components from a gas phase, in that the gas phase with the component(s) to be absorbed present therein is brought into contact with a liquid phase, wherein the gas phase and the liquid phase are separated by a hydrophobic membrane of a material other than polytetrafluoroethene, wherein the liquid phase comprises water and a water-miscible and/or water-soluble absorbent, and wherein the liquid phase does not give rise to any leakage from the membrane or is effective in preventing or counteracting leakage from the membrane. According to a first preferred aspect, the liquid phase comprises waterand a water-miscible and/or water-soluble organic absorbent, wherein the surface tension at 20.degree. C. has been brought to at least 60.times.10.sup.-3 N/m by adding a water-soluble salt. According to a second preferred aspect, the liquid phase comprises an aqueous solution of a water-soluble amino acid or a salt thereof, such as taurine and derivatives. According to a third preferred aspect, the liquid phase comprises an aqueoussolution of a water-soluble phosphate salt. The membranes are preferably in the form of hollow fibres of, for example, polypropene or polyethene. The method is suitable in particular for the absorption of carbon dioxide.
4112050	1977	0.865	Exxon Research & Engineering Co.	Process for removing carbon dioxide containing acidic gases from gaseous mixtures using a basic salt activated with a hindered amine	Carbon dioxide containing acidic gases are removed from a normally gaseous mixture by a process comprising contacting the normally gaseous mixture with an aqueous solution comprising (a) a basic alkali metal salt or hydroxide and (b) an activator for said basic salt or alkali metal salt or hydroxide comprising at least one sterically hindered amine.
4552572	1983	0.86	Bechtel International Corporation	Process for desulfurization of fuel gas	Apparatus and a method for removal of acid gases from a first gas rich in carbon dioxide and for desulfurizing a second gas lean in carbon dioxide but containing sulfur compounds as impurities. The method includes contacting the first gas with a solvent capable of extracting carbon dioxide and sulfur compounds from the first gas. Then, the solvent containing carbon dioxide is separated from the solvent containing sulfur compounds. The second gas is then contacted with said solvent containing carbon dioxide under conditions sufficient to cause said solvent containing carbon dioxide to extract sulfur compounds from said second gas and to release carbon dioxide. The desulfurized second gas is thereafter separated from the solvent containing sulfur compounds from the second gas.

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4270937	1979	0.858	CNG Research Company	Gas separation process	A process for separating acid gases such as CO.sub.2, H.sub.2 S, and SO.sub.2, other sulfur-containing molecules such as COS, and other relatively high boiling point impurities from lower boiling point components of a gas stream comprises: dehydrating the gas stream and contacting it, at an elevated pressure and at substantially the dew point temperature of carbon dioxide therein, with a liquid carbon dioxide refrigerant-absorbent to absorb such impurities other than CO.sub.2, and separating the liquid carbon dioxide and absorbed impurities; condensing CO.sub.2, and separating the liquid carbon dioxide and absorbed impurities; condensing CO.sub.2 from the residual gas stream at such pressure, preferably by indirect heat exchange; contacting the residual gas stream at such pressure with a second refrigerant-absorbent below the triple point temperature of carbon dioxide, and separating additional carbon dioxide therewith. The second refrigerant-absorbent is preferably a liquid-solid slurry comprising an organic liquid vehicle and carbon dioxide in the solid phase to provide in situ refrigeration by melting of the solid phase. The final, residual gas stream is heat exchanged to recover its refrigeration potential. Further, a crystallization process is disclosed for separating a crystallizable material and an excluded material which is at least partially excluded from the solid phase of the crystallizable material obtained upon freezing a liquid mixture of the materials. The solid phase is formed and melted at spaced locations in a liquid mixture of the materials and, within the liquid mixture, internal solid and liquid flows are maintained in opposite directions to effect separation of the materials. The solid phase is formed by evaporative cooling of the liquid mixture and melted by direct contact with a condensing vapor phase of the materials, each of these operations being performed substantially at the prevailing triple point locus conditions in the respective locations in the liquid mixture.
4430316	1981	0.848	individual(s)	Scrubbing system yielding high concentration of hydrogen sulfide	In a system for the separation of sour gases especially hydrogen sulfide and carbon dioxide from a raw gaseous mixture e.g., hydrogen-containing in order to form a purified gaseous mixture, comprising scrubbing the gaseous mixture in a first scrubbing stage with a physical scrubbing liquid e.g., methanol having a higher absorbability for hydrogen sulfide than for carbon dioxide, withdrawing from the scrubbing stage a first stream of scrubbing liquid loaded with hydrogen sulfide and carbon dioxide, and regenerating the loaded scrubbing liquid to form (a) a gaseous phase containing hydrogen sulfide, and (b) regenerated scrubbing liquid, the improvement of scrubbing said gaseous phase containing hydrogen sulfide in a second scrubbing stage with a stream of scrubbing liquid capable of absorbing additional H.sub.2 S, e.g., a CO.sub.2 -depleted stream from an H.sub.2 S enrichment column; and subjecting resultant second stream of scrubbing liquid loaded with hydrogen sulfide to a separation stage, preferably rectification, to form a bottoms of regenerated scrubbing liquid and an overhead of a gaseous phase rich in hydrogen sulfide irrespective of whether the raw gaseous mixture has a very low H.sub.2 S concentration.

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4477419	1983	0.847	individual(s)	Process for the recovery of CO2 from flue gases	A method is disclosed for recovering carbon dioxide from gases containing the same as well as oxygen and/or sulfur compounds employing aqueous 5 to 80% alkanolamine solutions. Corrosion of the metals of construction and solvent degradation are minimized by the use of copper ion maintained in solution and continuous removal of ionic iron and solvent degradation products by treating the solvent or a portion of the solvent with a carbon bed, mechanical filter and/or a anion exchange resin.
7753618	2009	0.833	Calera Corporation	Rocks and aggregate, and methods of making and using the same	Compositions comprising synthetic rock, e.g., aggregate, and methods of producing and using them are provided. The rock, e.g., aggregate, contains CO₂and/or other components of an industrial waste stream. The CO₂may be in the form of divalent cation carbonates, e.g., magnesium and calcium carbonates. Aspects of the invention include contacting a CO₂containing gaseous stream with a water to dissolve CO₂, and placing the water under precipitation conditions sufficient to produce a carbonate containing precipitate product, e.g., a divalent cation carbonate.
4242108	1979	0.831	Air Products and Chemicals, Inc.	Hydrogen sulfide concentrator for acid gas removal systems	A novel method is disclosed for treating a contaminated gas such as a contaminated natural gas or a synthesis product gas from the partial oxidation of petroleum or coal to concentrate and remove hydrogen sulfide at a reduced energy and capital requirement. Hydrogen sulfide in the contaminated stream is absorbed to form a hydrogen sulfide rich solvent which includes co-absorbed carbon dioxide, which is then removed to prevent dilution of the concentrated hydrogen sulfide formed when the solvent is regenerated. The solvent leaving the hydrogen sulfide absorber is heated before entering a high pressure stripper column wherein the co-absorbed carbon dioxide is stripped from the solvent, preferably by stripping with nitrogen or a portion of the product gas, and the carbon dioxide is recycled to the hydrogen sulfide absorber. The CO.sub.2 stripper is operated at a pressure not substantially below the pressure of the hydrogen sulfide absorber, eliminating the need for large compressors required in conventional methods to recycle the carbon dioxide.
7754169	2009	0.825	Calera Corporation	Methods and systems for utilizing waste sources of metal oxides	Methods are provided for producing a composition comprising carbonates, wherein the methods comprise utilizing waste sources of metal oxides. An aqueous solution of divalent cations, some or all of which are derived from a waste source of metal oxides, may be contacted with CO2 and subjected to precipitation conditions to provide compositions comprising carbonates. In some embodiments, a combustion ash is the waste source of metal oxides for the aqueous solution containing divalent cations. In some embodiments, a combustion ash is used to provide a source of proton-removing agents, divalent cations, silica, metal oxides, or other desired constituents or a combination thereof.

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4609389	1984	0.824	individual(s)	Process for scrubbing gaseous components out of gaseous mixtures	Gaseous components are scrubbed from gaseous mixtures with a physical solvent; the latter, after absorption of the scrubbed-out gaseous components, is regenerated by expansion and stripping, wherein the gaseous fraction being released is discharged and the regenerated solvent is recycled into the scrubbing step. To reduce the content of solvent vapors in the gases to be exhausted into the atmosphere, the released gaseous fraction is cooled in heat exchange with non-thermally degasified solvent in order to condense out entrained solvent vapors from the gaseous fraction.
8377401	2010	0.822	Air Liquide Process & Construction, Inc.	Process and apparatus for the separation of a gaseous mixture	A process for separating carbon dioxide from a fluid containing carbon dioxide, NO₂, and at least one of oxygen, argon, and nitrogen comprises the steps of separating at least part of the fluid into a carbon dioxide enriched stream, a carbon dioxide depleted stream comprising CO₂and at least one of oxygen, argon, and nitrogen and a NO₂enriched stream and recycling said NO₂enriched stream upstream of the separation step.
7951355	2007	0.82	Shell Oil Company	Process for producing a purified synthesis gas stream	A process for producing a purified synthesis gas stream from a contaminated feed synthesis gas stream is disclosed. A part of the feed synthesis gas stream is subjected to a water gas shift step. The water gas shift step is used in combination with bulk contaminant removal followed by polishing to thereby remove the contaminants from the synthesis gas stream so as to provide the purified synthesis gas stream having a desired low level of contaminants.
4714597	1986	0.814	Hylsa, S.A.	Corrosion inhibitor for CO.sub.2 absorption process using alkanolamines	Brass, bronze and other mixture of copper and zinc use used to treat alkanolamine solutions used in systems for separating CO.sub.2 from gaseous mixtures to give enhanced protection against ferrous metal corrosion.
7887694	2008	0.804	Calera Corporation	Methods of sequestering CO₂	Methods of sequestering carbon dioxide (CO₂) are provided. Aspects of the methods include precipitating a storage stable carbon dioxide sequestering product from an alkaline-earth-metal-containing water and then disposing of the product, e.g., by placing the product in a disposal location or using the product as a component of a manufactured composition. Also provided are systems for practicing methods of the invention.
4895708	1988	0.793	Mobil Oil Corporation	Removal of mercury from natural gas	Natural gas containing mercury is treated for liquifaction by contacting it with alkali and amine treating units to remove carbon dioxide and hydrogen sulfide. The amine and alkali treating units also contain sulfur in reacted form. This serves to guard downstream equipment against failure of upstream mercury-removing equipment, namely sulfur, on a selected support.

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7208605	2003	0.793	The University of Alabama	Functionalized ionic liquids, and methods of use thereof	One aspect of the present invention relates to ionic liquids comprising a pendant Bronsted-acidic group, e.g., a sulfonic acid group. Another aspect of the present invention relates to the use of an ionic liquid comprising a pendant Bronsted-acidic group to catalyze a Bronsted-acid-catalyzed chemical reaction. A third aspect of the present invention relates to ionic liquids comprising a pendant nucleophilic group, e.g., an amine. Still another aspect of the present invention relates to the use of an ionic liquid comprising a pendant nucleophilic group to catalyze a nucleophile-assisted chemical reaction. A fifth aspect of the present invention relates to the use of an ionic liquid comprising a pendant nucleophilic group to remove a gaseous impurity, e.g., carbon dioxide, from a gas, e.g., sour natural gas.
4332781	1980	0.785	Shell Oil Company	Removal of hydrogen sulfide and carbonyl sulfide from gas-streams	Hydrogen sulfide and carbonyl sulfide are removed from a gas stream in a staged procedure characterized by conversion of the hydrogen sulfide to produce sulfur in aqueous solution, hydrolysis of the carbonyl sulfide remaining in the gas stream to produce hydrogen sulfide and carbon dioxide, and removal of the hydrogen sulfide from the gas stream.
4357801	1980	0.782	Occidental Research Corporation	Removal of carbon dioxide in geothermal power systems	A process for removing carbon dioxide in geothermal power generating processes employing a geothermal fluid such as geothermal brine containing carbon dioxide, to improve the efficiency of geothermal power generation, comprises introducing an aqueous alkaline solution, preferably an aqueous calcium hydroxide solution, into a vapor stream obtained from the brine during power generation, to remove carbon dioxide from the stream. In the case, for example, of power generation by direct contact heat exchange between geothermal brine and a working fluid such as isobutane, where the working fluid is expanded to generate power, aqueous calcium hydroxide can be introduced into a direct contact condenser into contact with the working fluid therein to remove CO.sub.2 present in the working fluid, thereby aiding in reducing loss of working fluid from the system and aiding in reducing pump power. The aqueous alkaline, e.g., calcium hydroxide, solution alternatively can be contacted with the geothermal fluid prior to flashing or prior to direct contact heat exchange with a working fluid, to remove CO.sub.2 from uncondensible gas contained in the fluid.
8196387	2010	0.781	Praxair Technology, Inc.	Electrical power generation apparatus	An apparatus for generating electrical power in which a synthesis gas stream generated in a gasifier is partially oxidized, expanded and thereafter, is combusted in an oxygen transport membrane system of a boiler. The combustion generates heat to raise steam to in turn generate electricity by a generator coupled to a steam turbine. The resultant flue gas can be purified to produce a carbon dioxide product.

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8540954	2010	0.778	Universitetet for Miljo-og Biovitenskap Institutt for Matematiske Realfag og Teknologi	CO₂?capture in molten salts	The present invention concerns carbon dioxide capture from waste gas, where metal oxides dissolved in salt melts are used as absorbents.
8715394	2011	0.756	Lehigh University	Autothermal cycle for CO₂capture	Provided herein are methods and apparatus for capturing or otherwise decreasing the amount of CO₂in an exhaust stream. The separation process for removing CO₂from a waste stream preferably operates substantially at atmospheric pressure and at a preselected temperature, and without the need of thermal swing regeneration. This novel elimination of the heat up and cool down periods allows the inventive cycle herein to be run faster, and more efficiently than in previously known systems. Further, in some examples herein, the heat of adsorption is used to provide the heat of regeneration.
7637984	2006	0.749	UOP LLC	Integrated separation and purification process	Increasing the economic and environmental compatibility in treatment processes in sour gas production. For 25 yr, Mobil Erdgas Erdoel GmbH (MEEG) has been treating considerable amounts of sour gas in N. Germany. In 9 fields with different gas qualities, there are ca 30 producing wells. The main processes of the sour gas production and treatment are described. The gas is dried at the well site and if the reservoir pressure is not sufficient, compressed for transportation to the central processing facility. In most cases the use of sulfur solvents is necessary at the wells. Natural gas scrubbers for the total removal of hydrogen sulfide and Claus units with downstream units to obtain sulfur are utilized. To increase the environmental compatibility and economics, a number of secondary processes have been introduced for emission control; glycol stripping; and the Purisol, Selexol, Sulfinol, and Claus processes.
7914685	2010	0.748	Calera Corporation	Rocks and aggregate, and methods of making and using the same	Compositions comprising synthetic rock, e.g., aggregate, and methods of producing and using them are provided. The rock, e.g., aggregate, contains CO₂and/or other components of an industrial waste stream. The CO₂may be in the form of divalent cation carbonates, e.g., magnesium and calcium carbonates. Aspects of the invention include contacting a CO₂containing gaseous stream with a water to dissolve CO₂, and placing the water under precipitation conditions sufficient to produce a carbonate containing precipitate product, e.g., a divalent cation carbonate.

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Table S7. The patents with highest SPNP values in the "Capture by adsorption" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**Title**	**abstract**
4333744	1981	0.996	Union Carbide Corporation	Two-feed pressure swing adsorption process	One portion comprising about 30-80% of a hydrogen-containing feed gas having a relatively high carbon dioxide content is preheated to remove a substantial portion of said carbon dioxide therefrom. The thus - preheated stream is passed to a pressure swing adsorption bed from which a purified hydrogen stream is withdrawn. Upon completion of this step, the unpretreated portion of the feed gas is passed to the feed end of the bed, with purified hydrogen continuing to be withdrawn from the bed. In cyclic pressure swing adsorption operations employing such a two-feed process, the recovery of purified hydrogen is enhanced as compared with operations in which none of the feed gas is pretreated for carbon dioxide removal or in which all of the feed gas is so treated for removal of carbon dioxide therefrom.
4256469	1978	0.985	individual(s)	Repressurization technique for pressure swing adsorption	In a pressure swing adsorption process, the adsorbent being for example a carbon molecular sieve, the usual initial surge of an undesired component, e.g., O.sub.2 in a nitrogen stream, from the outlet of a freshly repressurized adsorber, is reduced or eliminated by conducting repressurization in a stage-wise manner with the final part of the repressurization being conducted substantially more slowly than the initial stage of repressurization.
7138007	2005	0.977	Chevron U.S.A. Inc.	Gas separation using molecular sieve SSZ-73	The present invention relates to new crystalline, essentially all silicon oxide molecular sieve SSZ-73 prepared using a 3-ethyl-1,3,8,8-tetramethyl-3-azoniabicyclo[3.2.1]octane cation as a structure-directing agent, and its use in gas separations.
5850833	1995	0.976	individual(s)	Apparatus for hypoxic training and therapy	An apparatus is provided for hypoxic training or therapy. The apparatus provides a user air having a lower oxygen content than the ambient atmosphere. The apparatus reduces the oxygen content of the air by passing the ambient air through a membrane separator which extracts the oxygen therefrom by a vacuum pump attached to the permeate outlet of the separator. Alternatively, the oxygen content can be reduced by adsorption of oxygen from the ambient air or by adding a low oxygen gas to air taken from the environment. This low oxygen gas may be stored nitrogen or stored gas which is low in oxygen, or it may be derived from the exhaled air from the user. If the exhaled air from the user used, carbon dioxide and water are extracted by a membrane separator or by physical or chemical process which adsorbs carbon dioxide from the gas.

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4934148	1989	0.974	Union Carbide Corporation	Dry, high purity nitrogen production process and system	Feed air to a prepurifier adsorption system/cryogenic air separation system for dry, high purity nitrogen and/or oxygen production is dried in a membrane dryer preferably characterized by a countercurrent flow path. Drying is enhanced by the use of purge gas on the permeate side of the membrane dryer, which adsorption system or cryogenic air separation system product or waste gas, dried feed air or ambient air being used as purge gas.
4544384	1983	0.972	individual(s)	Adsorber for two-component recovery and method of operating same	An adsorber for the cleaning of air or natural gas by the removal of water as a first component and carbon dioxide and/or a hydrocarbon as a second component from the gas stream to be treated utilizes two distinct adsorber beds traversed in succession by the gas stream, at least one of these beds being vertically oriented so that the gas stream and the regenerating gas pass horizontally through it.
4723966	1986	0.972	Union Carbide Corporation	Gas separation by pressure swing adsorption	A pressure swing adsorption process is disclosed wherein binary gas purification is effected from a single adsorbent bed. An adsorbent bed is charged under pressure with a gas mixture having some components that are more adsorbable than others. The process causes the bed to be polarized with one end of the bed containing the more adsorbable components and the other end containing the less adsorbable components. Once charged, the bed is depressurized simultaneously from both ends, thus removing the separated components from their respective ends.
4077779	1976	0.965	Air Products and Chemicals, Inc.	Hydrogen purification by selective adsorption	Hydrogen-containing gas mixtures are subjected to selective adsorption in a pressure swing cyclic system to remove carbon dioxide and/or hydrocarbon gases, obtaining high recovery of hydrogen at high purity. The system can also be employed for separation of methane from admixture with CO.sub.2.
6139604	1998	0.951	Praxair Technology, Inc.	Thermally powered oxygen/nitrogen plant incorporating an oxygen selective ion transport membrane	A low energy cost process for the co-production of oxygen and nitrogen employing a fuel tube extending into the first oxygen selective ion transport membrane whereby fuel is introduced adjacent to the closed end and flows cocurrently with oxygen containing gas in the annulus and an oxygen selective ion transport membrane having a separator section and a reactor section. An oxygen-containing feedstock, typically air, is compressed and then contacts the cathode side of the separator section where a portion of the oxygen contained within the feedstock is transported to the anode side of the separator section and recovered as an oxygen product gas. Substantially the remainder of the oxygen contained within the feedstock is transported from the cathode side of the reactor section to the anode side and exothermically reacted with a fuel. Following the exothermic reaction, hot nitrogen rich product gas is expanded in a turbine to generate the power necessary to compress the feedstock. Expanded nitrogen rich product gas may then be recovered from the turbine exhaust.

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4171206	1978	0.948	Air Products and Chemicals, Inc.	Separation of multicomponent gas mixtures	Multicomponent gas mixtures containing: (1) hydrogen as primary component, (2) a secondary key component that is more strongly sorbed by the adsorbent than hydrogen, and (3) a minor quantity of one or more dilute components less strongly sorbed than the secondary key component, are subject to selective adsorption in an adiabatic pressure swing cyclic system for the separate recovery of high purity hydrogen and of the secondary component. A given example is the treatment of a shift converter effluent gas from a hydrocarbon reformer plant, wherein hydrogen and carbon dioxide are separately recovered as key components substantially freed of minor dilute components such as methane, carbon monoxide and nitrogen.
4430306	1981	0.939	Mitsubishi Denki Kabushiki Kaisha	Oxygen recycle type ozonizing apparatus	An ozonized oxygen fed from an ozonizer is passed to a reaction tower to treat an object material. In recovering non-reacted oxygen from the reaction tower to reuse in the ozonizer, zeolite is used as an adsorbent to remove impurities contained in the recovered oxygen, such as water, volatile organic materials and CO.sub.2 gas so that a raw material oxygen without containing any impurity is fed to the ozonizer to increase the ozonizing efficiency.
4813980	1987	0.937	Air Products and Chemicals, Inc.	Recovery of nitrogen, hydrogen and carbon dioxide from hydrocarbon reformate	Multi-column pressure swing adsorption process for simultaneous production of ammonia synthesis gas and carbon dioxide from a reformer off gas having hydrogen, nitrogen and carbon dioxide as major components accompanied by minor quantities of methane, carbon monoxide and argon as impurities. The PSA system features two groups of adsorbent columns in which CO.sub.2 is adsorbed in adsorbers of the first group, the essentially CO.sub.2 -freed effluent being charged to an adsorber of the second group for removal of minor impurities while discharging an effluent gas having an H.sub.2 /N.sub.2 content stoichiometric for NH.sub.3 synthesis. The CO.sub.2 recovered from the first group of adsorbers is available at a high purity for reaction with the ammonia product for production of urea.
4475929	1983	0.929	Union Carbide Corporation	Selective adsorption process	In pressure swing adsorption processing including higher pressure adsorption, cocurrent depressurization to intermediate pressure, countercurrent depressurization and/or lower pressure purge and repressurization, a cocurrent purge step is employed at adsorption pressure prior to cocurrent depressurization. Methane or natural gas is advantageously employed as the cocurrent purge gas. The cocurrent purge step reduces the storage of product gas, such as hydrogen, in the bed, enhances product recovery and correspondingly reduces the amount of desired product gas discharged with the waste gas discharged the countercurrent depressurization and/or purge steps used for bed regeneration. The value of the waste gas as a fuel is likewise enhanced by the presence of said methane or natural gas therein.

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4340398	1981	0.927	Union Carbide Corporation	Pressure swing adsorption recovery	Void space gas is released from an adsorbent bed at a higher adsorption pressure by cocurrent depressurization of the bed. The released gas is passed to another bed of a pressure swing adsorption system to equalize the pressure therebetween, the other bed being initially at a lower pressure. A portion of the product effluent withdrawn from yet another bed of the system is not passed to the bed undergoing repressurization, as in conventional practice, but is passed to an external repressurization storage tank during said pressure equalization step. Upon completion of this step, the product effluent is withdrawn from the repressurization tank and passed to said bed undergoing repressurization.
6616732	2002	0.927	CECA S.A.	Zeolite adsorbents, method for obtaining them and their use for removing carbonates from a gas stream	The present invention relates to a novel family of zeolite adsorbents comprising a mixture of zeolite X and zeolite LSX, these adsorbents being predominantly exchanged with sodium or with strontium. These adsorbents are particularly suited to the decarbonatation of gas flows contaminated by CO2.
6176897	1997	0.925	Questor Industries Inc.	High frequency pressure swing adsorption	Pressure swing adsorption separation of a feed gas mixture, to obtain a purified product gas of the less strongly adsorbed fraction of the feed gas mixture, is performed in a plurality of preferably an even number of adsorbent beds, with each adsorbent bed communicating at its product end directly to a variable volume expansion chamber, and at its feed end by directional valves to a feed compressor and an exhaust vacuum pump. For high frequency operation of the pressure swing adsorption cycle, a high surface area layered support is used for the adsorbent. The compressor and vacuum pump pistons may be integrated with the cycle, reciprocating at twice the cycle frequency. Alternative configurations of the layered adsorbent beds are disclosed.
4952223	1989	0.924	The BOC Group, Inc.	Method and apparatus of producing carbon dioxide in high yields from low concentration carbon dioxide feeds	A process for producing substantially pure liquid carbon dioxide from a carbon dioxide feed containing about 35 to about 98% by volume of carbon dioxide wherein a waste stream containing carbon dioxide is separated from contaminants in a pressure swing adsorption apparatus and then recycled to the carbon dioxide feed, and a system for recovering spent carbon dioxide from a refrigeration system using liquid carbon dioxide as a freezing agent.
4468238	1983	0.923	Osaka Oxygen Industries, Ltd.	Process for removing a nitrogen gas from mixture comprising N.sub.2 and CO or N.sub.2 ' CO.sub.2 and CO	Processes for removing N.sub.2 from a feed gas comprising CO+N.sub.2 or CO, CO.sub.2 +N.sub.2 through PSA by using at least two adsorption columns containing an adsorbent exhibiting selective adsorb property to carbon monoxide which comprises: PA0 (i) a step of pressurizing an adsorption column by the feed gas; PA0 (ii) a step of introducing the feed gas into the adsorption column, in which step (i) was previously completed, so as to adsorb CO, or CO+CO.sub.2 on or in the adsorbent; PA0 (iii) a step of connecting the adsorption column, in which step (ii) was previously completed, to the other adsorption column in which step (v) was previously completed, to reduce the pressure in the former adsorption column to one atmosphere or a pressure close to it; PA0 (iv) a step of purging nitrogen by

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					passing product gas through the adsorption column; PA0 (v) a step of desorbing carbon monoxide adsorbed on or in the adsorbent of the adsorption column, by vacuum pump to recover a product gas; and PA0 (vi) a step of a connecting the adsorption column, in which step (v) was previously completed, to the other adsorption column in which step (ii) was previously completed to increase pressure in the former column, PA0 periodically switching the flow between or among said adsorption columns so as to repeat the above steps in all the adsorption columns.
8354086	2011	0.923	individual(s)	Captured CO₂from atmospheric, industrial and vehicle combustion waste	A CO₂control device and method for capturing CO₂from fluid flow, including: a flow-through apparatus and an CO₂absorbing filter treated with an alkaline material which is housed within the flow-through apparatus. The flow-through apparatus receives fluid flow and the CO₂from the fluid flow is absorbed by the CO₂absorbing filter. The absorbed CO₂is converted into CaCO₃which is combined with volcanic ash to form a useful cement material.
6723155	2002	0.922	Air Products and Chemicals, Inc.	Purification of gas streams	A method for removing a first and a second minor component from a gas mixture comprising the first and second minor components and one or more major components. The method comprises providing a first adsorbent zone containing a first adsorbent material and a second adsorbent zone containing a second adsorbent material wherein the selectivity of the first adsorbent material for the first minor component relative to the second minor component is greater than the selectivity of the second adsorbent material for the first minor component relative to the second minor component. The average particle diameter of the first adsorbent material and the average particle diameter of the second adsorbent material preferably are substantially the same. The gas mixture is passed through the first adsorbent zone and subsequently through the second adsorbent zone. A purified gas containing the one or more major components and depleted in the first and second minor component is withdrawn from the second adsorbent zone.
6824590	2003	0.913	Air Products and Chemicals, Inc.	Use of lithium-containing fau in air separation processes including water and/or carbon dioxide removal	A process for separating a feed gas into at least one product gas includes: (a) providing a gas separation apparatus with at least one adsorption layer including a lithium-exchanged FAU adsorbent having water desorption characteristics, defined by drying curves, similar to those for the corresponding fully sodium-exchanged FAU, a heat of adsorption for carbon dioxide equal to or lower than that for the corresponding fully sodium-exchanged FAU at high loadings of carbon dioxide, and onto which the adsorption layer water and/or carbon dioxide adsorb; (b) feeding into the gas separation apparatus a feed gas including nitrogen, oxygen, and at least one of water and carbon dioxide; and (c) collecting from a product end of the gas separation apparatus at least one product gas containing oxygen.

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4761167	1986	0.905	Air Products and Chemicals, Inc.	Hydrocarbon recovery from fuel gas	High purity methane is recovered from a fuel gas stream containing the same in admixture with mainly nitrogen and carbon dioxide, by first removing the carbon dioxide by selective adsorption in a PSA system and separating the remaining nitrogen from the methane by cryogenic distillation, the rejected nitrogen being employed for purging the CO.sub.2 -laden adsorbent beds of the PSA system. Cyclic regeneration of the sorbent-laden bed may entail nitrogen purge with or without including a carbon dioxide rinse, or the nitrogen purge of the sorbent-laden bed may be used in combination with pressure let-down by gas withdrawal into one or more companion beds.
5084075	1990	0.905	Air Products and Chemicals, Inc.	Vacuum swing adsorption process for production of 95+% N.sub.2 from ambient air	A method is described for recovering nitrogen from air in a three bed vacuum swing adsorption technique in which the beds are not rinsed with nitrogen gas before recovering a nitrogen recycle stream and a nitrogen product.
5582029	1995	0.903	Air Products and Chemicals, Inc.	Use of nitrogen from an air separation plant in carbon dioxide removal from a feed gas to a further process	A cryogenic air separation unit (ASU) provides flows of oxygen and nitrogen. The oxygen is used in a process such as COREX iron making or the partial oxidation of hydrocarbons, or in an oxycoal fuelled blast furnace, producing an off-gas containing useful components (H.sub.2 and CO) and carbon dioxide. The carbon dioxide is removed by pressure swing adsorption using nitrogen from the ASU as a regeneration gas and the purified off-gas becomes a feed gas to a further process such as production of iron by direct reduction of iron ore or the production of a NH.sub.3 making ammonia or is recycled into the first process as a feed gas.
4732578	1986	0.902	individual(s)	Pressure swing adsorption process	A pressure swing adsorption process for the selective adsorption of at least one gaseous component from a gaseous mixture and an apparatus for performing the process wherein the gaseous mixture is conducted in cyclic alternation through at least three adsorbers and each adsorber is subdivided into two serially connected adsorber sections. The feed gas mixture is passed, during an adsorption phase, through respectively two series-connected adsorber sections. After termination of at least one cocurrent expansion phase, the adsorber sections are isolated from each other, and the first adsorber section, i.e., first traversed by the feed gas mixture, is further expanded while the second adsorber section is maintained at a higher pressure. Thereafter, the second adsorber section can be expanded countercurrently and thus-withdrawn countercurrent expansion gas can be utilized for purging the first adsorber section.

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5463869	1994	0.902	Air Products and Chemicals, Inc.	Integrated adsorption/cryogenic distillation process for the separation of an air feed	An integrated adsorption/cryogenic distillation process is set forth for the separation of an air feed. The air feed is passed through a vacuum swing adsorption (VSA) unit to remove impurities comprising water and carbon dioxide which will freeze out at cryogenic temperatures. The VSA sequence includes an adsorbent regeneration step whereby the impurity-saturated adsorbent is purged under vacuum with a purge gas. The resulting impurity-depleted air feed is fed to a cryogenic distillation column for rectification into a gaseous nitrogen overhead and a liquid oxygen bottoms. A waste stream from the distillation column is expanded, warmed against the impurity-depleted air feed to recover its refrigeration and subsequently recycled as the purge gas to the VSA unit. A key to the present invention is that the waste stream is expanded to the required sub-ambient pressure level in the cryogenic portion of the process. This enables one to recover all of the available refrigeration from the cryogenic waste stream prior to using such waste stream as the purge gas for the adsorption portion of the process.
4732580	1986	0.899	The BOC Group, Inc.	Argon and nitrogen coproduction process	Argon and nitrogen are produced in a basic two step process. In a first step, oxygen is removed from a compressed air feed using low temperature PSA (pressure swing adsorption). In the second step, argon and nitrogen mixture is separated by cryogenic distillation. The process yields crude liquid argon and very high purity gaseous nitrogen.
5220797	1992	0.899	The BOC Group, Inc.	Argon recovery from argon-oxygen-decarburization process waste gases	The present invention is directed to a method for recovering argon from a feed mixture comprising argon, carbon monoxide, carbon dioxide, nitrogen, and hydrogen which comprises the steps of (a) purifying the feed mixture to remove contaminants, (b) compressing the purified feed mixture to a separation pressure, and (c) passing the compressed purified feed mixture through a pressure swing adsorption system to separate carbon monoxide, carbon dioxide, and all or most of the nitrogen from the mixture as adsorbed products and to produce an argon-rich fraction as a non-adsorbed product. The argon-rich fraction from step (c) may be further purified by passing the fraction to a cryogenic fractional distillation system to separate hydrogen and any remaining nitrogen from the fraction as a distillate product and to produce a pure argon product. In a second and third embodiment, the invention is directed to a method for recovering argon from a feed mixture comprising argon, carbon monoxide, carbon dioxide, nitrogen, and oxygen, wherein oxygen is removed from the argon-rich fraction exiting the pressure swing adsorption system in step (c) by passing the fraction to a second pressure swing adsorption system before or after further purification of the fraction in a cryogenic fractional distillation system.
4259091	1979	0.898	individual(s)	Adiabatic adsorption method for gas purification or separation	An adiabatic adsorption method for pressure-swing adsorbers, e.g. for gas purification or separation of components of a gas mixture, in which several switchable adsorbers are used in an adsorption phase followed by at least two pressure-relief stages and at least one pressure buildup stage with an intervening purging in the adsorption-desorption/regeneration cycle.

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					According to the invention, at least one of the adsorbers is operated as an auxiliary adsorber by comparison with a main adsorber with a reduced contact time between the adsorption medium and gases in the auxiliary adsorber. This reduced contact time can result from a reduced adsorption-phase period by comparison with that of the main adsorber (reduced residence time) and/or by using a reduced charge of the adsorption medium in the auxiliary adsorber by comparison with that of the main adsorber.
4021210	1975	0.893	individual(s)	Adsorption system	In an adsorption-desorption process for separating gaseous mixtures comprising passing a stream of crude gaseous mixture under superatmospheric pressure through a first adsorber, withdrawing from said first adsorber a stream of product gas depleted in undesired component; switching the stream of crude gaseous mixture to a second adsorber when the impurity concentration at a given location before the exhaust end of the first adsorber exceeds a given value in the gas; after the crude gas stream is switched away from said first adsorber, decompressing said first adsorber in at least one decompression stage to release residual product gas therefrom; and employing said residual product gas to re-pressurize an adsorber, the improvement which comprises conducting said decompressing in at least two separate decompression stages, collecting the residual product gas from each decompression stage in separate storage vessels, withdrawing residual product gas from one storage vessel and purging the decompressed adsorber to desorb undesired impurities therefrom, and withdrawing residual product gas from another of said storage vessels and partially re-pressurizing the purged adsorber therewith.

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Table S8. The patents with highest SPNP values in the "Capture by membranes or diffusion" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
4130403	1977	0.994	individual(s)	Removal of H.sub.2 S and/or CO.sub.2 from a light hydrocarbon stream by use of gas permeable membrane	A method for removing H.sub.2 S and CO.sub.2 from a natural gas stream involves the employment of a dried cellulose ester membrane having a permeability for H.sub.2 S and CO.sub.2 of at least 10.sup.-8. A gas permeation process may also be used to produce a CO.sub.2 rich stream from gas in gas reservoirs which contain a large amount of CO.sub.2. The produced rich CO.sub.2 stream may then be used in flooding processes for enhanced oil recovery.
7138007	2005	0.977	Chevron U.S.A. Inc.	Gas separation using molecular sieve SSZ-73	The present invention relates to new crystalline, essentially all silicon oxide molecular sieve SSZ-73 prepared using a 3-ethyl-1,3,8,8-tetramethyl-3-azoniabicyclo[3.2.1]octane cation as a structure-directing agent, and its use in gas separations.
5972080	1997	0.961	Dainippon Ink and Chemicals, Inc.	Separation membrane	Separation membranes excellent in strength, durability, heat resistance and solvent resistance as well as in balance between substance separation properties and substance permeability are disclosed, which are formed from polyhydrazidoimide resins, and preferably comprises a non-porous dense layer formed from a polyhydrazidoimide resin obtained from the reaction of an aromatic tetracarboxylic dianhydride such as 4,4'-(hexafluoroisopropylidene)diphthalic anhydride and an aromatic dihydrazide such as isophthalic dihydrazide as essential components.
6139604	1998	0.951	Praxair Technology, Inc.	Thermally powered oxygen/nitrogen plant incorporating an oxygen selective ion transport membrane	A low energy cost process for the co-production of oxygen and nitrogen employing a fuel tube extending into the first oxygen selective ion transport membrane whereby fuel is introduced adjacent to the closed end and flows cocurrently with oxygen containing gas in the annulus and an oxygen selective ion transport membrane having a separator section and a reactor section. An oxygen-containing feedstock, typically air, is compressed and then contacts the cathode side of the separator section where a portion of the oxygen contained within the feedstock is transported to the anode side of the separator section and recovered as an oxygen product gas. Substantially the remainder of the oxygen contained within the feedstock is transported from the cathode side of the reactor section to the anode side and exothermically reacted with a fuel. Following the exothermic reaction, hot nitrogen rich product gas is expanded in a turbine to generate the power necessary to compress the feedstock. Expanded nitrogen rich product gas may then be recovered from the turbine exhaust.

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5409525	1993	0.943	Agency of Industrial Science & Technology	Hydrous gel membranes for gas separation	This invention relates to hydrous gel membranes for gas separation which comprise support membranes formed by solvent-soluble polymeric materials containing in their repeating unit a bulky structural part and hydrophilic functional groups represented by the following general formula (1) ##STR1## (R.sub.1, R.sub.2, R.sub.3, and R.sub.4 designate hydrogen, alkyl group, and halogen and R.sub.5 and R.sub.6 designate any one of --H, --SO.sub.3 H, --COOH, and --OH) and water or an aqueous solution of substances with affinity for CO.sub.2 substantially uniformly retained in the support membranes. The membranes show not only high CO.sub.2 permeation and CO.sub.2 selectivity but also long-term stable membrane performance and ease of fabricability into membranes and are capable of recovering a large volume of CO.sub.2 generated at stationary sites efficiently at low cost.
6128919	1998	0.942	Messer Griesheim Industries, Inc.	Process for separating natural gas and carbon dioxide	A process for separating natural gas and carbon dioxide from a raw feed stream, such as in carbon dioxide for EOR processes. Separation is by membrane separation at low pressures. By utilizing low pressure separation, highly selective membranes can be used and recycling becomes practical.
5618332	1995	0.936	L'Air Liquide S.A.	Process for enhancing the selectivity of mixed gas separations	Gas separation membranes having enhanced selectivity for a mixture of gases is disclosed. The membranes may be asymmetric or multicomponent. The membranes surprisingly provide selectivity for gases in a mixture that approaches the relative selectivity of the single gas components. Preferably the membrane provides selectivity for a mixture of gases which is at least 65%, preferably 80%, of the relative selectivity of the corresponding single gases. A process for making improved gas separation membranes is also disclosed.
6299669	1999	0.923	University of Texas System	Process for CO2/natural gas separation	The invention includes a process for separating CO.sub.2 from natural gas including: contacting a mixture of CO.sub.2 and natural gas with a first side of a carbon membrane in a manner to cause a portion of the mixture to pass through the carbon membrane to a permeate side. The resulting mixture on the permeate side becomes enriched in CO.sub.2 over that of the mixture on the first side. The carbon membrane includes an asymmetric hollow filamentary carbon membrane, including a partial carbonization product of an asymmetric hollow filament including an aromatic imide polymer material. The carbon membrane is at least 95 weight percent carbon, and has a dense layer located in the outside surface portion of the hollow filamentary membrane and a porous base layer continued from the dense layer and located in the inside portion of the hollow filamentary membrane. The contacting step occurs at a pressure of at least about 200 psia.

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5709733	1996	0.92	Nitto Denko Corporation	Gas separation method	A method of separating a gas, especially carbon dioxide, from a gas mixture of the gas and nitrogen at a low temperature of -20.degree. C. to 50.degree. C. using a gas separation membrane permeable to the gas, including the step of cooling the gas mixture using at least one cooling medium selected from the group consisting of liquefied petroleum gas and liquefied natural gas. The liquefied petroleum gas comprises at least one selected from the group consisting of propane gas and butane gas in an amount of more than 50 vol. %. The gas separation membrane has a CO.sub.2 permeation rate of 1.times.10.sup.-4 to 5.times.10.sup.-2 N cm.sup.3 /(cm.sup.2 cm Hg sec) at 25.degree. C. and a CO.sub.2 /N.sub.2 separation factor of 10 to 200 at 25.degree. C.
5928409	1997	0.908	New Jersey Institute of Technology	Method and apparatus for gas removal by cyclic flow swing membrane permeation	In one aspect, a method for selectively removing at least one target component from a multicomponent feed fluid using a removal system, the system including a feed chamber having an inlet and an outlet, a permeate chamber, and a membrane for separating the feed and permeate chambers. The membrane is selective for the at least one target component. The method includes: in a first period, introducing the feed fluid into the feed chamber through the inlet, thereby exposing the feed fluid to the membrane, while allowing flow out of the outlet, wherein at least a portion of the at least one target component in the feed chamber is removed, either by absorption or adsorption, by the membrane; in a second period, simultaneously halting flow through the inlet and the outlet of the feed chamber, thereby trapping the feed fluid within the feed chamber; and providing a component-gradient across the membrane in both the first and second periods, thereby continually removing the at least one target component and regenerating the membrane.
4834779	1988	0.899	Liquid Air Corporation	Process for membrane seperation of gas mixtures	A method for the substantial separation of at least one gas component from a gas mixture to generate a residue gas substantially depleted of the gas components to be separated. A semipermeable membrane is provided which has a feed gas side and a sweep gas side. The feed gas side is contacted with a feed gas mixture containing at least one gas to be retained and at least one gas to be separated therefrom. The sweep side is simultaneously contacted with a sweep gas having a pressure lower than that of the feed gas. The partial pressure of certain gas components present on both sides of the membrane are balanced to cause the remaining gas components to diffuse in either direction across the membrane depending upon their differential partial pressures. Apparatus for the gas separation is also provided.

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6649047	2002	0.899	K.V. Aerner Process Systems AS	Protection system to prevent damage to a gas diffusion membrane	A protection system arranged to prevent a large trans-membrane pressure difference over a pressure sensitive membrane (4) fitted in a pressure resistant chamber (3), wherein the membrane forms a physical barrier between a liquid and a gas mixture carried through the chamber (3), the protection system includes two shut-off valves (9, 10) provided in the liquid inlet and outlet lines respectively, a buffer tank (3) provided in the line between one of the shut-off valves (9, 10) and the pressure resistant chamber (3), a pressure equalizing valve (12) provided between the gas inlet line (8) and the buffer tank (2) and a pressure sensing valve (14) for measuring the pressure difference over the membrane (4) and which activates the shut-off valves (9, 10) once this pressure difference exceeds a predetermined value.
6228145	1999	0.893	Kvaerner ASA	Method for removing carbon dioxide from gases	A method for removing and preventing discharge into the atmosphere of carbon dioxide from combustion gases and natural gas from installations for production of oil and/or gas, wherein the combustion gas is passed to an absorber containing a solvent, where carbon dioxide is absorbed in the solvent, and the thereby purified combustion gas, largely free of carbon dioxide, is released into the atmosphere, where the CO.sub.2 rich solvent is passed to a desorber where CO.sub.2 is removed from the solvent, and the thereby largely CO.sub.2 -free solvent is recycled to the absorber, and the separated CO.sub.2 gas is passed to a compression stage for compression and utilization and/or disposal in a suitable manner, where membrane gas/liquid contactors are employed in both the absorber and the desorber, and that an external stripping steam is supplied to the desorber.
4781907	1985	0.869	individual(s)	Production of membrane-derived nitrogen from combustion gases	High-purity nitrogen is recovered from combustion gas such as exhaust stack gases, by utilizing selective gas-permeable membranes to separate by rejection, nitrogen from the other gases present in the gas stream.
8535413	2010	0.869	Chevron U.S.A. Inc.	Integrated mechanical vapor recompression (MVR) and membrane vapor permeation process for ethanol recovery (ethanol dehydration) from fermentation broth	An apparatus and process is taught for the formation of ethanol from a fermentation medium in the absence of an ethanol concentration distillation step.
5749941	1996	0.866	Nederlandse Organisatie voor toegepast-natuurwetenschappelijk Onderzoek TNO	Method for gas absorption across a membrane	The invention relates to a method for the absorption of one or more gaseous components from a gas phase, in that the gas phase with the component(s) to be absorbed present therein is brought into contact with a liquid phase, wherein the gas phase and the liquid phase are separated by a hydrophobic membrane of a material other than polytetrafluoroethene, wherein the liquid phase comprises water and a water-miscible and/or water-soluble absorbent, and wherein the liquid phase does not give rise to any leakage from the membrane or is effective in preventing or counteracting leakage from the membrane. According to a first preferred aspect, the liquid phase comprises water and a water-miscible and/or water-soluble organic absorbent, wherein the surface tension at 20.degree. C. has been brought to at least 60.times.10.sup.-3 N/m by adding a water-soluble salt. According to a second preferred aspect, the liquid phase comprises an aqueous

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					solution of a water-soluble amino acid or a salt thereof, such as taurine and derivatives. According to a third preferred aspect, the liquid phase comprises an aqueoussolution of a water-soluble phosphate salt. The membranes are preferably in the form of hollow fibres of, for example, polypropene or polyethene. The method is suitable in particular for the absorption of carbon dioxide.
6059858	1998	0.854	The BOC Group, Inc.	High temperature adsorption process	Oxygen is removed from gas streams by subjecting the gas stream to a pressure swing adsorption process carried out at temperature in the range of 300 to 1400.degree. C. using as adsorbent a perovskite material having the structural formula A.sub.1-x M.sub.x BO.sub.3-.delta., where A is a rare earth ion, M is Na, Ca, Sr, Ba or mixtures of these, B is Co, Mn, Cr or Fe, x varies from 0.1 to 1 and .delta. is the deviation from stoichiometric composition resulting from the substitution of Sr, Ca and Ba for rare earth ions.
4518399	1984	0.852	Monsanto Co	Process for recovering gases from landfills	A process for treating a landfill for recovering methane therefrom wherein a mixture of methane and carbon dioxide is withdrawn from a central portion of the landfill and the carbon dioxide and methane are separated. The methane is fed to a pipeline and a portion of the carbon dioxide is fed to wells spaced around the periphery of the landfill at a pressure of 7 to 170 kPa to prevent air from entering the landfill around the periphery thereof.
5591250	1995	0.848	Gas Research Institute	Material and process for separating carbon dioxide from methane	A process for separating a first gas from a second gas, having the steps of: (1) contacting one side of a semi-permeable gas separation membrane with a feed gas mixture containing at least the first gas and the second gas, wherein the membrane divides a separation chamber into a high-pressure side into which the feed gas mixture is fed and a low-pressure side; (2) maintaining a pressure differential across the membrane under conditions such that the first gas in the feed gas mixture selectively permeates through the membrane from the high-pressure side to the low-pressure side of the membrane; (3) removing from the low-pressure side of the membrane permeated gas mixture which is enriched in the first gas and depleted in the second gas; and (4) removing from the high-pressure side of the membrane a gas mixture which is enriched in the second gas and depleted in the first gas. The membrane used is made, at least in part, of a thin discriminating layer of polyimide having the repeating formula ##STR1## wherein R is: ##STR2##
6383258	2000	0.847	L'Air Liquide Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude	Copolyimide gas separation membranes	A gas separation membrane is formed from a copolyimide produced by copolymerization of monomers which include o-tolidine sulfone, at least one other hydrophilic diamine and 2,2-bis(3,4-dicarboxyphenyl)hexafluoropropane dianhydride. One or more additional aromatic dianhydrides can optionally be included. The novel membrane exhibits an excellent combination of high selectivity of gases to be separated from a gas mixture, high permeability and strong solvent resistance to hydrocarbon chemicals. The membrane is therefore useful in separating gases from gas mixtures in which vapor or liquid hydrocarbon contaminants are present, for example in the separation of carbon dioxide from methane and/or nitrogen in the purification of natural gas.

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5855647	1997	0.828	American Air Liquide, Inc.	Process for recovering SF6 from a gas	A process for recovering SF.sub.6 from a gas is provided. The process includes the step of contacting a gas stream comprising SF.sub.6 and at least one of N.sub.2, O.sub.2, CO.sub.2, and H.sub.2 O with a membrane in at least one membrane separation unit at conditions effective to obtain a retentate stream rich in SF.sub.6 and a permeate stream rich in at least one of N.sub.2, O.sub.2, CO.sub.2, and H.sub.2 O.
8409325	2009	0.826	Ube Industries, Ltd.	Asymmetric gas separation membrane and process for gas separation	There is disclosed an asymmetric gas separation membrane exhibiting both improved gas separation performance and improved mechanical properties, which is made of a soluble aromatic polyimide comprised of a repeating unit represented by general formula (1): wherein B in general formula (1) B comprises 10 to 70 mol % of tetravalent unit B1 represented by general formula (B1) and 90 to 30 mol % of tetravalent unit B2 represented by general formula (B2), and A in general formula (1) comprises 10 to 50 mol % of bivalent unit A1 represented by general formula (A1a) or the like and 90 to 30 mol % of bivalent unit A2 represented by general formula (A2a) or the like.
5928410	1997	0.825	Texaco Inc.	Supported gas separation membrane, process for its manufacture and use of the membrane in the separation of gases	A supported gas separation membrane for separating a particular component from a mixture of gases, a process for its manufacture and the use of the membrane in the separation of gases are provided in which the supported gas separation membrane comprises (a) a porous polymeric support layer and (b) an asymmetric gas separation membrane layer formed from a polyimide having repeating units of the general formula: ##STR1## wherein R is: ##STR2## and x is an integer.
6248153	1999	0.82	3M Innovative Properties Company	Diffusional gas transfer system and method of using same	A diffusional gas transfer system and method having a membrane disposed between a first gas domain and a second gas domain. The first gas domain includes a first mechanism for directing a first environmental gas flow transversely over and in contact with a first surface of the membrane. The second gas domain includes a second mechanism for directing a second environmental gas flow transversely over and in contact with a second surface of the membrane. The membrane is a diffusional gas transfer medium having a multiplicity of tortuous pathways extending from the first surface of the membrane to the second surface of the membrane. The void volume fraction of the membrane is at least 0.2. The membrane is capable of substantially blocking the transfer of particles from the first gas domain to the second gas domain, while permitting the diffusion of gases between the first and second gas domains, and the first gas domain is maintained at a pressure higher than the second gas domain.

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7931731	2009	0.82	Shell Oil Company	Process for production of elemental iron	A process to prepare elemental iron by contacting an iron ore feed with a reducing gas at a pressure of between 1 and 10 bar to obtain iron and an off-gas includes preparing the reducing gas by performing the following steps: (a) partially oxidizing a mixture comprising a solid or liquid carbonaceous fuel and oxygen at a pressure of between 10 and 80 bar, thereby obtaining a gas comprising H₂and CO; (b) removing CO₂and H₂S from the gas obtained in step (a) to obtain an intermediate gas comprising H₂and CO; (c) supplying the intermediate gas obtained in step (b) to a H₂-selective membrane to obtain a H₂-rich permeate gas and a CO-rich retentate; and (d) heating H₂-rich permeate to obtain a heated H₂-rich permeate as the reducing gas.
5240472	1992	0.816	Air Products and Chemicals, Inc.	Moisture removal from a wet gas	This invention pertains to an improved process for the removal of moisture from a moisture laden gas stream such as air utilizing a membrane dryer unit. The membrane dryer unit is equipped such that it incorporates a selective surface flow adsorbent membrane consisting essentially of an inorganic membrane material selected from the group consisting of alumina and silica gel membranes wherein the membrane has a thickness of approximately 0.5 to 50 microns with a mean pore size of less than about 15 A and preferably within about 4 to 10 A. In the cryogenic separation of air, an air stream contaminated with moisture and carbon dioxide is passed through the membrane dryer unit in countercurrent flow to a dry purge gas, wherein the water is selectively removed from the air stream. The partially dried air stream then is conveyed to an adsorption system operated under thermal swing or pressure swing conditions wherein the residual water and carbon dioxide are removed.
4737166	1986	0.813	Bend Research, Inc.	Acid gas scrubbing by composite solvent-swollen membranes	A composite immobilized liquid membrane suitable for acid gas scrubbing is disclosed. The membrane is a solvent-swollen polymer and a microporous polymeric support, the solvent being selected from a class of highly polar solvents containing at least one atom selected from nitrogen, oxygen, phosphorous and sulfur, and having a boiling point of at least 100.degree. C. and a solubility parameter of from about 7.5 to about 13.5 (cal/cm.sup.3 -atm).sup.1/2. Such solvents are homogeneously distributed through the solvent-swollen polymer from 20% to 95% by weight. Also disclosed are methods of acid gas scrubbing of high- and low-Btu gas effluents with such solvent-swollen membranes.

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7909911	2007	0.789	The Trustees of Columbia University in the City of New York	Carbon dioxide permeable membrane	A carbon dioxide permeable membrane is described. In some embodiments, the membrane includes a body having a first side and an opposite second side; a plurality of first regions formed from a molten carbonate having a temperature of about 400 degrees Celsius to about 1200 degrees Celsius, the plurality of first regions forming a portion of the body and the plurality of first regions extending from the first side of the body to the second side of the body; a plurality of second regions formed from an oxygen conductive solid oxide, the plurality of second regions combining with the plurality of first regions to form the body and the plurality of second regions extending from the first side of the body to the second side of the body; and the body is configured to allow carbon dioxide to pass from the first side to the second side.
5820659	1997	0.786	L'Air Liquide Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude	Multicomponent or asymmetric gas separation membranes	Gas separation membranes having enhanced selectivity for a mixture of gases is disclosed. The membranes may be asymmetric or multicomponent. The membranes surprisingly provide selectivity for gases in a mixture that approaches the relative selectivity of the single gas components. Preferably the membrane provides selectivity for a mixture of gases which is at least 65%, preferably 80%, of the relative selectivity of the corresponding single gases. A process for making improved gas separation membranes is also disclosed.
5954859	1997	0.771	Praxair Technology, Inc.	Solid electrolyte ionic conductor oxygen production with power generation	A process for producing an oxygen-depleted gas stream and a high-pressure gas stream containing oxygen and steam by compressing a feed gas stream containing elemental oxygen, heating the feed gas stream, and separating the heated feed gas stream using one or more ion transport modules into the oxygen-depleted gas stream on a retentate side and an oxygen gas stream on a permeate side of an ion transport membrane. The permeate side is purged using a high-pressure purge gas stream containing steam to produce the high-pressure gas stream containing oxygen and steam, which is directed to a turbine to recover power and produce an expanded, lower-pressure gas stream containing oxygen and steam.

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Table S9. The patents with highest SPNP values in the “Capture by rectification and condensation” domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**Title**	**abstract**
4417449	1982	0.945	Air Products and Chemicals, Inc.	Process for separating carbon dioxide and acid gases from a carbonaceous off-gas	A process is described for the separation of carbon dioxide and sulfide gases from oil shale retorting off-gases, coal gasification off-gases, oxygen fireflooding off-gases or carbon dioxide miscible flood enhanced oil recovery off-gases for recycle to a retort, gasifier, petroleum reservoir or to further sulfide processing prior to export. The process separates the off-gases into an essentially sulfur-free light BTU fuel gas, a heavy hydrocarbon stream and a carbon dioxide acid gas stream wherein the off-gas is compressed if necessary and cooled to separate the various streams. The carbon dioxide acid gas stream is expanded in an auto-refrigeration step to provide the necessary process refrigeration. In the oil shale retort and coal gasification applications the sulfur constituents are sorbed on spent oil shale particles or coal ash.
4602477	1985	0.927	Air Products and Chemicals, Inc.	Membrane-aided distillation for carbon dioxide and hydrocarbon separation	A process is described for separating a carbonaceous off-gas in a low temperature distillative separation to produce a fuel gas stream, a carbon dioxide-sulfur stream and a heavy hydrocarbon stream wherein the carbon dioxide-sulfur stream is reduced in pressure to produce refrigeration to return a portion of the fuel gas stream as reflux to the distillation, and the fuel gas stream, now at relatively higher pressure than the carbon dioxide-sulfur stream, is passed over a semi-permeable membrane selective to carbon dioxide to separate carbon dioxide from the fuel gas to combine the permeate carbon dioxide with the carbon dioxide-sulfur stream.
4952223	1989	0.924	The BOC Group, Inc.	Method and apparatus of producing carbon dioxide in high yields from low concentration carbon dioxide feeds	A process for producing substantially pure liquid carbon dioxide from a carbon dioxide feed containing about 35 to about 98% by volume of carbon dioxide wherein a waste stream containing carbon dioxide is separated from contaminants in a pressure swing adsorption apparatus and then recycled to the carbon dioxide feed, and a system for recovering spent carbon dioxide from a refrigeration system using liquid carbon dioxide as a freezing agent.
4990168	1989	0.924	individual(s)	Recovery of carbon dioxide from a carbon dioxide plant vent gas using membranes	A process for recovering CO.sub.2 from a CO.sub.2 liquifaction plant vent gas, which comprises feeding vent gas from a CO.sub.2 liquifaction plant to a first semi-permeable gas separation membrane through which and at a pressure at which CO.sub.2 is capable of diffusing therethrough, to form a CO.sub.2 -enriched permeate, and then returning the CO.sub.2 -enriched permeate to a feed side of said CO.sub.2 liquifaction plant at a pressure capable of effecting the same.

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4359871	1979	0.917	individual(s)	Method of and apparatus for the cooling of natural gas	A method of cooling natural gas in a system in which the natural gas contains components other than methane which are separable by dewpoint condensation and the natural gas is available from a source, e.g. a well, at an elevated pressure. In accordance with the present invention, the natural gas is initially expanded in a work-producing expansion turbine to cool the natural gas to a temperature below the dew point of the components to be separated and the portion of the natural gas remaining after separating these components is compressed in a compressor which can in part be driven by the turbine so that at least a portion of the work output of the turbine is at least in some cases utilized for compressing the methane-containing portion which can be forced under pressure into a pipeline. In dependence upon the variable pressure difference between the input of the expansion turbine and the output of the compressor, energy is recovered from the turbine or supplied to the set formed by the turbine and compressor and the compression of the expanded methane-containing portion is effected after heat exchange with the natural gas to be expanded and/or is directly carried out at the expansion temperature.
4761167	1986	0.905	Air Products and Chemicals, Inc.	Hydrocarbon recovery from fuel gas	High purity methane is recovered from a fuel gas stream containing the same in admixture with mainly nitrogen and carbon dioxide, by first removing the carbon dioxide by selective adsorption in a PSA system and separating the remaining nitrogen from the methane by cryogenic distillation, the rejected nitrogen being employed for purging the CO.sub.2 -laden adsorbent beds of the PSA system. Cyclic regeneration of the sorbent-laden bed may entail nitrogen purge with or without including a carbon dioxide rinse, or the nitrogen purge of the sorbent-laden bed may be used in combination with pressure let-down by gas withdrawal into one or more companion beds.
4681612	1986	0.887	Koch Process Systems, Inc.	Process for the separation of landfill gas	A recycle process for the separation of landfill gas containing a wide variety of impurities into a carbon dioxide product stream and a fuel-grade-pressurized methane product stream, the process providing for the removal of both the impurities and the carbon dioxide in a cryogenic column as a bottom stream, the separation of the methane from the overhead product stream by a membrane process, and, optionally, the removal of impurities from the carbon dioxide bottom stream in a separate purification column, to recover a high-quality, liquid, carbon dioxide stream.

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7871457	2006	0.875	Praxair Technology, Inc.	Carbon dioxide production method	A method of producing a carbon dioxide product stream from a synthesis gas stream formed within a hydrogen plant having a synthesis gas reactor, a water-gas shift reactor, located downstream of the synthesis gas reactor to form the synthesis gas stream and a hydrogen pressure swing adsorption unit to produce a hydrogen product recovered from the synthesis gas stream. In accordance with the method the carbon dioxide from the synthesis gas stream by separating the carbon dioxide from the synthesis gas stream in a vacuum pressure swing adsorption system, thereby to produce a hydrogen-rich synthesis gas stream and a crude carbon dioxide stream and then purifying the crude carbon dioxide stream by a sub-ambient temperature distillation process thereby to produce the carbon dioxide product. A hydrogen synthesis gas feed stream to the hydrogen pressure swing adsorption unit is formed at least in part from the hydrogen rich stream.
4977745	1989	0.868	individual(s)	Method for the recovery of low purity carbon dioxide	A process for the economical recovery of carbon dioxide from a gas stream containing less than 85% carbon dioxide, by cooling the contaminating gas to remove water vapor, compressing the cooled gas to an elevated temperature and pressure, and drying the gas to a dewpoint of not more than about -85.degree. F.; condensing and removing the carbon dioxide from the dried compressed gas; and heating the remaining noncondensed gas mixture and expanding it to produce and recover kinetic energy and a cooled gas mixture.
4963339	1988	0.838	The BOC Group, Inc.	Hydrogen and carbon dioxide coproduction	Highly purified gaseous hydrogen and liquid carbon dioxide are produced from a steam reformer/shift converter by passing the effluent from the latter through a multibed hydrogen PSA unit followed by an uncoupled carbon dioxide PSA unit. The carbon dioxide PSA unit produces a hydrogen-rich stream which is recycled to the feed to the steam reformer, a carbon dioxide-rich recycle stream which is recycled to the carbon dioxide PSA unit feed and a carbon dioxide-rich product stream which is introduced under pressure to a liquifier. A waste stream from the liquifier is recylced to the carbon dioxide PSA unit feed. A portion of the carbon dioxide-rich product stream is withdrawn from the compressor at a stage such that its pressure is higher than that of the carbon dioxide PSA unit and returned thereto as a cocurrent purge preceding bed regeneration to obtain product.
4976849	1988	0.832	Snamprogetti S.p.A.	Fractionation process for gaseous hydrocarbon mixtures with a high acid gas content	A fractionation process for gaseous hydrocarbon mixtures of high acid gas content is described, for separating at least a fraction containing ethane, propane and heavier hydrocarbons, a fraction containing essentially acid gases and a fraction containing essentially methane and possible inert gases, characterized by comprising the following stages: PA0 (a) feeding the gaseous hydrocarbon mixture after dehydration to a first distillation column to which a liquid hydrocarbon stream is fed, to obtain a gaseous overhead product stream containing methane, ethane, acid gases and possibly light inert gases, and a bottom product stream containing ethane and higher hydrocarbons; PA0 (b) feeding the overhead product of the first distillation column to a second distillation column to obtain a gaseous overhead product stream containing methane, the ethane-carbon dioxide azeotrope and possibly light inert gases, and a bottom product stream consisting essentially of acid gases; PA0 (c) feeding the

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					overhead product of the second distillation column to a third distillation column the condenser of which is injected with a liquid hydrocarbon stream, to obtain a gaseous overhead product stream consisting essentially of methane and possibly inert gases, and a bottom product stream which is recycled to the first column and contains the ethane-carbon dioxide azeotrope and the liquid hydrocarbon stream injected into the condenser; PA0 (d) feeding the bottom product of the first distillation column to a fourth distillation column to obtain a gaseous overhead product stream containing ethane and a bottom product stream containing higher hydrocarbons than butane.
4639257	1985	0.828	Costain Petrocarbon Limited	Recovery of carbon dioxide from gas mixture	Carbon dioxide is recovered from gas mixtures containing it in a concentration not greater than the equilibrium concentration at the freezing temperature of the mixture, by subjecting the gas mixture to membrane separation and recovering from the membrane separation a permeate having a carbon dioxide concentration between the equilibrium concentration and 98% (by volume), distilling said permeate at subambient temperature above the freezing temperature of the permeate and recovering substantially pure carbon dioxide as a liquid bottoms product of the distillation. Carbon dioxide is recovered from gas mixtures containing it in a high concentration by supplying the gas mixture at superatmospheric pressure and distilling said gas mixture at sub-ambient temperature in a distillation column, recovering substantially pure carbon dioxide as a liquid bottoms product of the distillation, warming the overhead stream from the distillation to a temperature suitable for membrane separation, passing the overhead stream at superatmospheric pressure over a membrane which is selectively permeable for carbon dioxide and thereafter recycling carbon dioxide-rich permeate for recompression and feeding to the distillation column.
4449994	1982	0.816	Air Products and Chemicals, Inc.	Low energy process for separating carbon dioxide and acid gases from a carbonaceous off-gas	A process is disclosed for the separation of carbon dioxide and sulfide gases from oil shale retort off-gases, coal gasification off-gases, oxygen fire-flooding or carbon dioxide miscible flood enhanced oil recovery off-gases for recycle to a retort, gasifier or petroleum reservoir or alternately delivery to another process. The process separates the off-gases into an essentially sulfur-free fuel gas and an acid gas for recycle to such a retort, gasifier or reservoir wherein the off-gas is compressed if necessary and cooled to separate the two streams, the acid gas is expanded in an auto refrigeration step to provide the necessary process refrigeration and the acid gas is then recycled to such a retort, gasifier or reservoir. In the oil shale retorting and coal gasification applications, the gas' sulfur constituents are sorbed on spent oil shale particles or coal ash.

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4759786	1986	0.807	The BOC Group plc	Separation of gaseous mixtures	An incoming stream of gas mixture typically comprising methane and up to 12% by volume of carbon dioxide is subjected to rectification in a first column to form a carbon dioxide depleted fraction that is withdrawn as product from the top of the column and a carbon dioxide-enriched fraction which is withdrawn from the bottom of the column is warmed in a heat exchanger and is introduced into a second rectification column operating at a higher pressure than the first column. A stream in which carbon dioxide predominates is withdrawn from the bottom of the higher pressure column while a stream 34 containing a lower proportion of carbon dioxide than said enriched fraction is withdrawn from the top of the higher pressure column is throttled through a valve and is united with the incoming stream of gas mixture upstream of or in the lower pressure column.
4462814	1983	0.79	Koch Process Systems, Inc.	Distillative separations of gas mixtures containing methane, carbon dioxide and other components	Distillative separations of hydrocarbon feed mixtures containing at least methane and carbon dioxide, as well as other components, such as ethane, higher hydrocarbons, and hydrogen sulfide are disclosed. In the separations described, methane is preferably separated from an acid gas under conditions of composition, temperature and pressure which would normally produce acid gas solids. Acid gas solids are prevented by adding a liquid solids-preventing agent into this distillation column. A second distillation column is subsequently employed to further separate the feed gas mixture. The second distillation column is operated under conditions which an azeotrope would normally form between the light hydrocarbon and carbon dioxide, which azeotrope would limit the carbon dioxide overhead composition. The azeotrope is prevented by introducing an agent for preventing azeotrope formation. Alternatively, the second distillation column may be operated to separate carbon dioxide from hydrogen sulfide. In this case, a liquid agent is added to the second distillation column to increase the relative volatility of carbon dioxide to hydrogen sulfide. All liquid agents preferably comprise a C.sub.3 -C.sub.6 alkane, such as butane, or a mixture of such alkanes.
6685903	2001	0.79	Praxair Technology, Inc.	Method of purifying and recycling argon	This invention is directed to a method for purifying argon from an impure argon stream. If the oxygen concentration in the impure argon is less than about 10 mole percent of oxygen, the invention is proceeded in the sequential steps of a) removing chlorine from the impure argon stream; b) adding hydrogen to the impure argon stream; c) removing carbon dioxide and water from the impure argon stream; d) removing hydrogen from the impure argon stream; and e) removing nitrogen from the impure argon stream to form a purified argon stream. If the oxygen concentration in the impure argon is greater than about 10 mole percent of oxygen, the method comprises the sequential steps of a) removing chlorine from the impure argon stream; b) removing carbon dioxide and water from the impure argon stream; c) removing nitrogen and oxygen from the impure argon stream; d) adding hydrogen to the impure argon stream; e) removing water from the impure argon stream; f) removing hydrogen from the impure argon stream; and g) removing nitrogen from the impure argon stream to form a purified stream.

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5927103	1998	0.732	Praxair Technology, Inc.	Carbon dioxide production system with integral vent gas condenser	A system for producing carbon dioxide, particularly from a feed which contains significant levels of light contaminants, wherein light overhead from a distillation column is partially condensed against heat exchange fluid containing both carbon dioxide and light contaminants and the resulting heat exchange fluid passed into the feed for the distillation column.
5000925	1990	0.725	The BOC Group, Inc.	Hydrogen and carbon dioxide coproduction apparatus	Highly purified gaseous hydrogen and liquid carbon dioxide are produced from a steam reformer/shift converter by passing the effluent from the latter through a multibed hydrogen PSA unit followed by an uncoupled carbon dioxide PSA unit. The carbon dioxide PSA unit produces a hydrogen-rich stream which is recycled to the feed to the steam reformer, a carbon dioxide-rich recycle stream which is recycled to the carbon dioxide PSA unit feed and a carbon dioxide-rich product stream which is introduced under pressure to a liquifier. A waste stream from the liquifier is recycled to the carbon dioxide PSA unit feed. A portion of the carbon dioxide-rich product stream is withdrawn from the compressor at a stage such that its pressure is higher than that of the carbon dioxide PSA unit and returned thereto as a cocurrent purge preceding bed regeneration to obtain product.
7332146	2005	0.717	Research Foundation of the University of Central Florida, Inc.	Method for zero emission liquid hydrogen production from methane and landfill gas	Processes, methods, systems and devices for zero emission liquid hydrogen production directly from a variety of methane sources, such as natural gas and landfill gas, are disclosed. Five embodiments of plant designs for liquid hydrogen production are presented. The embodiments combine hydrogen production and liquefaction into a single process to produce liquid hydrogen directly via methane containing gases; thus, eliminating the conventional technology of pressure swing adsorption process for gas mixture separation. The innovative process can be applied to produce high purity liquid hydrogen with no carbon dioxide emission to the atmosphere; and can also co-produce highly pure solid carbon and liquid carbon dioxide as by-products for industrial application. The invention has provided advantages over conventional approaches that result in up to approximately 85% of first low efficiencies and approximately 56% of second law efficiency, up to approximately 100% of hydrogen and methane recovery, and a very high purity of liquid hydrogen (99.9999%).
6298652	1999	0.708	Exxon Mobil Chemical Patents, Inc.	Method for utilizing gas reserves with low methane concentrations and high inert gas concentrations for fueling gas turbines	The invention is directed to a method of fueling gas turbines from natural gas reserves with relatively low methane concentrations. The invention uses such reserves to generate electric power. The invention permits the use of these reserves at significantly lower cost than by producing pipeline natural gas to fuel gas turbines to generate electric power. These reserves currently generally are used only after the removal of impurities to produce pipeline natural gas quality turbine fuel. The latter current technology is capital intensive, and at current natural gas prices, economically unattractive. The process of the invention can remove the impurities from the gas from the natural gas reserve necessary for protection of the environment, and leaves inert gasses in the fuel in an amount which will increase the output of a gas turbine for the generation of power by about 5 to about 20%.

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5414190	1993	0.706	individual(s)	Process to recover liquid methane	To recover liquid methane from a feed gas mixture (1) essentially consisting of methane, C.sub.2+ hydrocarbons, carbon dioxide and nitrogen, the feed gas mixture (1) is fed first to an adsorption unit (E) and freed from water; dried feed gas mixture (2) is fed to a membrane separating unit (F), wherein the carbon dioxide is separated down to a residual content less than 2% by volume (9) and resultant gas mixture (3) now essentially consisting of methane, C.sub.2+ hydrocarbons and nitrogen is fed to a low-temperature distillation (A) wherein the C.sub.2+ hydrocarbons as well as the residual content of carbon dioxide are separated by distillation.
5233837	1992	0.702	Enerfex, Inc.	Process and apparatus for producing liquid carbon dioxide	A process for producing liquid carbon dioxide. A process stream which comprises carbon dioxide, balance substantially nitrogen and water, is cooled so that a minor amount of the water is condensed out. The process stream is compressed so that substantially all of the water but trace amounts is condensed out. Next, the process stream is cleaned to remove the trace amounts of water, any long-chain hydrocarbons present and any particulates present. The process stream is then separated into a nitrogen-rich gaseous stream and a carbon dioxide-rich gaseous stream. The carbon dioxide-rich gaseous stream is then compressed and the nitrogen-rich gaseous stream is expanded to produce an expanded nitrogen-rich gaseous stream. The energy of the expanding is used to compress the carbon dioxide-rich gaseous stream. The compressed carbon dioxide-rich gaseous stream is cooled to liquefy the carbon dioxide in the stream and reduce the temperature of the gaseous nitrogen in the stream. The liquefied carbon dioxide is withdrawn as product. The liquefying of the carbon dioxide-rich gaseous stream is by using the expanded nitrogen-rich gaseous stream. After the liquefying, the nitrogen-rich gaseous stream is used to perform at least part of the first cooling. In a preferred form, the process stream results from combusting a mixture of fuel and oxygen in a heat engine to drive an electrical generator with the product of the heat engine to produce electricity and also yielding the process stream. Apparatus for the production of liquid carbon dioxide which includes devices to perform each of the process steps.
5133190	1991	0.7	individual(s)	Method and apparatus for flue gas cleaning by separation and liquefaction of sulfur dioxide and carbon dioxide	Sulfur dioxide and carbon dioxide, emitted in flue gases are separated by gas centrifuge separators, and liquefied by gas mechanical compression and cooling means.
4599096	1984	0.694	individual(s)	Process for fractionation of a gaseous mixture employing side stream withdrawal, separation, and recycle	In fractionating a gaseous mixture, e.g. an acid gas and hydrocarbon, in a column wherein, during distillation, components of the gaseous mixture tend to form a substantially azeotropic mixture, or at least one of the components of the gaseous mixture tends to freeze out, withdrawing a side stream fluid from the column during fractionation, and separating said side stream fluid, e.g. by membranes or scrubbing, so as to remove preferentially at least a portion of one of the components of the substantially azeotropic mixture, or of at least one of the components tending to freeze out, and recycling resultant depleted side stream to said fractionating column.

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5100635	1990	0.694	The BOC Group, Inc.	Carbon dioxide production from combustion exhaust gases with nitrogen and argon by-product recovery	The present invention is directed to a method for producing carbon dioxide and nitrogen from combustion exhaust gas containing less than about 10% oxygen by weight which comprises the steps of (a) treating the exhaust gas to remove particulate matter, (b) compressing the exhaust gas to a pressure in the range from about 25 psia to about 200 psia, (c) purifying the exhaust gas to remove trace contaminants, (d) separating the exhaust gas to produce a carbon dioxide rich fraction and a nitrogen rich fraction, (e) liquifying the carbon dioxide rich fraction and distilling off volatile contaminants to produce pure carbon dioxide, (f) purifying the nitrogen rich fraction to remove contaminants, and (g) cryogenically fractionally distilling the nitrogen rich fraction to produce pure nitrogen. In another embodiment, the invention is directed to a method for producing carbon dioxide, nitrogen, and argon from a combustion exhaust gas. The combustion exhaust gas in the present invention may be obtained from an ammonia plant reformer furnace and the nitrogen produced may be employed as a synthesis gas in the ammonia reactor.
8557024	2010	0.685	Fluor Technologies Corporation	Configurations and methods of carbon capture	An IGCC plant has a precombustion decarbonization unit in which acid gas is removed from a combustion gas before the combustion gas enters a combustion turbine. In one preferred configuration, a sulfur removal unit removes hydrogen sulfide from a feed gas before the desulfurized feed gas enters an autorefrigeration unit in which carbon dioxide is removed. In another preferred configuration, hydrogen sulfide is converted to carbonyl sulfide in a dryer, and the carbonyl sulfide is absorbed in the liquid carbon dioxide that is prepared from the feed gas using autorefrigeration.
6516631	2001	0.672	individual(s)	Hydrocarbon gas processing	A cryogenic natural gas liquids recovery process which includes the use of a demethanizer and a deethanizer includes a step of recycling a portion of the deethanizer overhead to the demethanizer.
4274850	1979	0.66	individual(s)	Rectification of natural gas	For separating a C.sub.2+ -hydrocarbon fraction from compressed CO.sub.2 -containing natural gas by rectification, wherein the compressed natural gas is, prior to rectification, subjected to partial condensation and engine-expansion steps to achieve the desired pressure and temperature conditions in the rectification column and wherein said column is fed by resultant condensate of natural gas, the improvement comprising: PA0 conducting the engine expansion of the natural gas to a point well above the temperature at which the CO.sub.2 would otherwise precipitate out, and recovering from the engine expansion step an unliquefied gaseous fraction, and passing said fraction in indirect heat exchange relationship with engine-expanded overhead product from said column, whereby peak cooling and partial condensation of said fraction is achieved, and feeding resultant partially condensed fraction to the top of said column.

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6782714	2003	0.657	Mitsubishi Heavy Industries, Ltd.	Plant and method for producing liquefied natural gas	A plant for producing liquefied natural gas comprises a carbon dioxide recovery apparatus for natural gas absorbing and removing carbon dioxide from natural gas, a liquefying apparatus having a steam turbine, for liquefying the natural gas from which carbon dioxide has been removed by the carbon dioxide recovery apparatus, a boiler equipment for supplying steam to the steam turbine of the liquefying apparatus, and a carbon dioxide recovery apparatus for combustion exhaust gas including an absorption tower for absorbing carbon dioxide from combustion exhaust gas exhausted from the boiler equipment by absorbing liquid, and a regeneration tower for separating and recovering carbon dioxide from the absorbing liquid.
8535638	2010	0.653	Air Liquide Large Industries U.S. LP	Process for recovering hydrogen and carbon dioxide	The present invention provides a process for recovering hydrogen and carbon dioxide from a process stream of a process unit wherein the process stream contains at least carbon dioxide, hydrogen, and methane.

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Table S10. The patents with highest SPNP values in the "Subterranean or submarine CO2 storage" domain

Patent number	Filing year	Centrality measure	Organization	title	abstract
6389814	2000	0.996	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid phase or super critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
6170264	1998	0.975	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining gas is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen-containing fuel, such as hydrogen, methane or a light alcohol. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control the temperature of the combustion products. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is collected for further processing and use and the remainder is routed back to the gas generator. The carbon dioxide is compressed and cooled so that it is in a liquid phase or super

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					critical state. The dense phase carbon dioxide is then further pressurized to a pressure matching a pressure, less hydrostatic head, existing deep within a porous geological formation, a deep aquifer, a deep ocean location or other terrestrial formation from which return of the CO2 into the atmosphere is inhibited.
6412559	2000	0.906	Alberta Reasearch Council, Inc.	Process for recovering methane and/or sequestering fluids	A process for recovering methane from a coal bed and/or sequestering a fluid more strongly adsorbing than methane (?SAG?) in a coal bed involves fracturing an injection well and cyclically injecting SAG with intervening shut-in periods. Even though the absolute permeability of the coal bed decreases with continued SAG sorption, the SAG injectivity, surprisingly and unexpectedly, increases while injecting SAG at pressures greater than reservoir pressure, but less than fracture pressure or fracture extension pressure. The increased injectivity is thought to be due to a reduction in near-well flow resistance.
8485252	2012	0.88	Shell Oil Company	In situ recovery from a hydrocarbon containing formation	An oil shale formation may be treated using an in situ thermal process. Heat may be applied to the formation to raise a temperature of a portion of the formation to a pyrolysis temperature. Heat input into the formation may be controlled to raise the temperature of portion at a selected rate during pyrolysis of hydrocarbons within the formation. A mixture of hydrocarbons, H₂, and/or other formation fluids may be produced from the formation.
7644993	2007	0.854	ExxonMobil Upstream Research Company	In situ co-development of oil shale with mineral recovery	A method of producing hydrocarbon fluids from a subsurface organic-rich rock formation, for example an oil shale formation, in which the oil shale formation contains water-soluble minerals, for example nahcolite, is provided. In one embodiment, the method includes the step of heating the organic-rich rock formation in situ. Optionally, this heating step may be performed prior to any substantial removal of water-soluble minerals from the organic-rich rock formation. In accordance with the method, the heating of the organic-rich rock formation both pyrolyzes at least a portion of the formation hydrocarbons, for example kerogen, to create hydrocarbon fluids, and converts at least a portion of the water-soluble minerals, for example, converts nahcolite to soda ash. Thereafter, the hydrocarbon fluids are produced from the formation.
8763710	2010	0.829	Bergen Teknologioverforing AS	Method for integrated enhanced oil recovery from heterogeneous reservoirs	A method of recovering oil from a heterogeneous reservoir, comprising a plurality of permeable porous blocks of rock whose pores contain oil and which form interfaces with regions between the blocks, e.g. fractures, having a higher permeability than the blocks. Treating the interfaces such that the wettability of the surfaces of the blocks is in a predetermined wettability range, then reducing the permeability in the highly permeable regions, and finally flooding the reservoir by injecting a chase fluid into the reservoir. With the present method, water phase bridges are established between adjacent blocks in the reservoir thus allowing a transmission of injection pressure for viscous displacement from one block to the next across the reservoir. A method for long-time storage of CO₂by using CO₂as chase fluid or foaming gas according to the present method for oil recovery from heterogeneous reservoirs.
8096934	2007	0.74	Mizuho Information & Research Institute, Inc.	System for treating carbon dioxide, and method for storing	The present invention provides a system for treating carbon dioxide, and a method by which such treated carbon dioxide can be stored underground at low cost and

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				such treated carbon dioxide underground	with high efficiency. The present invention' method for storing carbon dioxide underground includes: a step for pumping up to the ground groundwater from a pumping well in a deep aquifer, and then producing injection water. Carbon dioxide that has been separated and recovered from exhaust gas from a plant facility is changed into the bubbles. The bubbles are mixed with the injection water, and hereby produces a gas-liquid mixture a step for injecting into. The deep aquifer is injected into the gas-liquid mixture from the injection well. The method preferably further includes a step for dissolving a cation-forming material in the injection water, and a step for injecting the injection water, in which the cation-forming material is dissolved, into the deep acquifer at its top and above the place at which injection water has already been injected.
6491616	2002	0.719	Terralog Technologies, Inc.	Method for biosolid disposal and methane generation	A method for the disposal of biosolids, the method comprising a) providing a supply of biosolids; creating a slurry of the biosolids suitable for injecting; selecting an injection formation below a ground surface, the injection formation comprising a natural gas formation in a gas accumulation zone; injecting the biosolids slurry into the injection formation at a pressure sufficient to create and maintain fractures within the selected injection formation; and allowing degradation of the injected biosolids slurry.
4719972	1985	0.714	Chevron Research Company	Treatment of steam feedwater with CO.sub.2 to reduce oil well reservoir gravel and sand dissolution during steam injection	A method of inhibiting the dissolution of the gravel pack and/or the erosion of silicate-containing formations subjected to steam-enhanced oil recovery processes. The method includes the addition of CO.sub.2 into the residual liquid phase of the steam, prior to injection down the well bore, to reduce the pH to form about pH 5 to about pH 9.
6287248	2000	0.697	Terralog Technologies, Inc.	Method for biosolid disposal and methane generation	A method for the disposal of biosolids, such as municipal sewage waste, comprising injecting the biosolids into a subsurface injection formation. The method can include recovering methane generated from the degradation of the biosolids.
6962561	2002	0.666	Terralog Technologies, Inc.	Method for biosolid disposal and methane generation	A method for the disposal of biosolids, the method comprising providing a supply of biosolids; selecting an introduction formation below a ground surface, the introduction formation comprising a natural gas formation in a gas accumulation zone; introducing the biosolids into the introduction formation at a pressure sufficient to create and maintain fractures within the selected introduction formation; and allowing degradation of the introduced biosolids.

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8225867	2011	0.632	Schlumberger Technology Corporation	Systems and methods for distributed interferometric acoustic monitoring	Acoustic monitoring is carried out using a fiber optic cable. Coherent Rayleigh noise generated by the transmission of a coherent beam of radiation through the fiber optic cable is detected, a phase of the coherent Rayleigh noise is measured and the measured phase is processed to identify an acoustic occurrence along the fiber optic cable. In certain aspects an optical fiber serves as a distributed interferometer that may be used to monitor a conduit, wellbore or reservoir. The distributed interferometric monitoring provides for accurate detection of acoustic occurrences along the fiber optic cable and these acoustic occurrences may include fluid flow in a pipeline or wellbore, processes taking place in a wellbore or pipeline, fracturing, gravel packing, or production logging.
7664624	2006	0.616	Institut Francais du Petrole	Method for determining the acid gas storage capacities of a geologic medium by means of a multiphase reactive transport model	Method for determining acid gas storage capacities of an underground geologic medium by means of a multiphase reactive transport model. The geologic medium is divided into a set of sub-volumes for which connections are defined. A multiphase reactive transport model is then defined by dividing, according to a transfer rate principle, the phenomena involved in the behaviour of said geologic medium into two parts. A first part is treated by a first sub-model of ?compositional multiphase reservoir? type allowing the transfer rates linked with the gas phase to be determined. A second part is treated by a model of ?single-phase reactive transport? type allowing the transfer rates linked with the water and the solid to be determined. The model is initialized by means of data acquired in the field or in the laboratory. The acid gas storage capacities of the medium are determined from the reactive transport model. Application: acid gas storage in a natural reservoir.
8684085	2009	0.611	Toho Gas Co., Ltd.	Storing device for stored substance and method for storing stored substance	A filter (13) is provided at a tip portion of an injection well (9). A pumping apparatus (5) pumps carbon dioxide stored in a carbon dioxide tank (3). The pumping apparatus (5) feeds carbon dioxide from the carbon dioxide tank (3) into the injection well (9) by means of a pump. In the pumping apparatus, the pressure and temperature of carbon dioxide are maintained at respective predetermined levels or higher by means of a pressure regulation valve, a temperature regulator, etc., whereby carbon dioxide enters a supercritical state. The carbon dioxide having entered a supercritical state is fed in the direction of arrow A through the injection well (9), passes through the filter (13) provided at an end portion of the injection well (9), and is injected into a brine aquifer (11). Carbon dioxide injected into the brine aquifer (11) assumes the form of microbubbles.
8225866	2010	0.597	Shell Oil Company	In situ recovery from a hydrocarbon containing formation	An oil shale formation may be treated using an in situ thermal process. Heat may be applied to the formation to raise a temperature of a portion of the formation to a pyrolysis temperature. Heat input into the formation may be controlled to raise the temperature of portion at a selected rate during pyrolysis of hydrocarbons within the formation. A mixture of hydrocarbons, H₂, and/or other formation fluids may be produced from the formation.

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7704746	2009	0.551	The United States Government as represented by the Department of Energy	Method of detecting leakage from geologic formations used to sequester CO₂	The invention provides methods for the measurement of carbon dioxide leakage from sequestration reservoirs. Tracer moieties are injected along with carbon dioxide into geological formations. Leakage is monitored by gas chromatographic analyses of absorbents. The invention also provides a process for the early leak detection of possible carbon dioxide leakage from sequestration reservoirs by measuring methane (CH₄), ethane (C₂H₆), propane (C₃H₈), and/or radon (Rn) leakage rates from the reservoirs. The invention further provides a method for branding sequestered carbon dioxide using perfluorcarbon tracers (PFTs) to show ownership.
7726402	2008	0.548	Schlumberger Technology Corporation	Methods for downhole sequestration of carbon dioxide	Carbon dioxide is sequestered in a formation using a dual completion and injection method that reduces or eliminates upward leak rates of the sequestered carbon dioxide. The dual completion and injection method involves the injection of a benign fluid such as brine (water) into a permeable layer of the formation located above the sequestration layer and which is separated form the sequestration layer by a nearly impermeable layer. The water is preferably injected at the same time the carbon dioxide is injected.
6860147	2002	0.517	Alberta Reasearch Council, Inc.	Process for predicting porosity and permeability of a coal bed	A method for predicting the secondary porosity system (SPS) porosity, and thereby permeability, of a coal bed involves determining an initial condition in the coal bed, including an initial SPS pressure and an initial sorbed gas composition, determining a pressure strain effect due to increasing the SPS pressure to a value greater than the initial SPS pressure, and determining a sorption strain effect due to changes in the sorbed gas composition resulting from decreasing the methane content and increasing the content of a stronger adsorbing fluid (SAG) relative to the initial sorbed gas composition. Preferably, the method uses data from test injections of water and/or a weaker adsorbing fluid (WAG) and a SAG. The data is used in the inventors' model to compute a SPS porosity and an absolute permeability at a reference SPS pressure and a reference sorbed gas composition. Preferably, the reference pressure is atmospheric pressure. The inventors' model accounts for both dynamic pressure strain and dynamic multicomponent sorption strain effects. As a result, a calibrated model can be produced for the coal bed for predicting the coal bed's SPS porosity, and thereby permeability, as a function of a pre-selected injection or production fluid's composition and/or SPS pressure conditions.
7946341	2007	0.514	Schlumberger Technology Corporation	Systems and methods for distributed interferometric acoustic monitoring	Acoustic monitoring of a conduit, a wellbore or a reservoir associated with hydrocarbon production or transportation and/or carbon dioxide sequestration is carried out using a fibre optic cable extending along or appurtenant to it as a distributed interferometer. Coherent Raleigh noise generated by the transmission of the coherent beam of radiation through the fiber optic is detected and processed to identify an acoustic occurrence.

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8425149	2010	0.504	Praxair Technology, Inc.	Hydrogen storage method and system	A method and system for storing and supplying hydrogen to a hydrogen pipeline in which a compressed hydrogen feed stream is introduced into a salt cavern for storage and a stored hydrogen stream is retrieved from the salt cavern and reintroduced into the hydrogen pipeline. A minimum quantity of stored hydrogen is maintained in the salt cavern to produce a stagnant layer having a carbon dioxide content along the cavern wall and the top of a residual brine layer located within the salt cavern. The compressed hydrogen feed stream is introduced into the salt cavern and the stored hydrogen stream is withdrawn without disturbing the stagnant layer to prevent carbon dioxide contamination from being drawn into the stored hydrogen stream being reintroduced into the hydrogen pipeline. This allows the stored hydrogen stream to be reintroduced into the hydrogen pipeline without carbon dioxide removal.
8549857	2007	0.474	individual(s)	Methods and/or systems for magnetobaric assisted generation of power from low temperature heat	Methods and/or systems using magnetically assisted pressurization of a gas for the generation of useful power from heat transfer using heat sources at lower temperatures in a manner that does not require the emission of CO₂.
7859943	2007	0.45	WESTERNGECO L.L.C.	Processing a seismic monitor survey	A technique includes accessing seismic data that is associated with seismic measurements taken from a reservoir and a surrounding rock mass at a given time. Based on a velocity model developed from a predicted change in the reservoir and surrounding rock mass occurring from a prior to the given time, processing the seismic data to generate a survey of the reservoir and surrounding rock mass.
7043920	2003	0.441	Clean Energy Systems, Inc.	Hydrocarbon combustion power generation system with CO2 sequestration	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed. The remaining gas is primarily oxygen, which is then routed to a gas generator. The gas generator has inputs for the oxygen and a hydrocarbon fuel. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide. The combustion products are then expanded through a power generating device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is routed back to the gas generator. The carbon dioxide is compressed and delivered to a terrestrial formation from which return of the CO2 into the atmosphere is inhibited.

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8256992	2009	0.435	SEQEnergy, LLC	Underground sequestration system and method	Underground sequestration system and method in which a liquid or gas is stored in a sequestration zone of enhanced porosity in an underground geological formation, with a containment barrier around the sequestration zone. Conditions within the formation are monitored to verify the integrity of the sequestered substance, and any necessary repair or maintenance is done through wells that extend into the formation. In some disclosed embodiments, the porosity of the formation in the sequestration zone is enhanced by boreholes and laterals that are drilled with high velocity hydraulic cutting jets, and the sequestered liquid or gas is injected into the sequestration zone through the boreholes and laterals. Additional boreholes and laterals are employed in the containment barrier, and the barrier is formed of a thixotropic material that is injected into the formation through the additional boreholes and laterals.
7753972	2009	0.426	Pioneer Energy, Inc.	Portable apparatus for extracting low carbon petroleum and for generating low carbon electricity	The Portable Renewable Energy System for Enhanced Oil Recovery (?PRESEOR?) is a truck mobile system that reforms biomass into CO₂and hydrogen, following which the gases are separated, with the CO₂sequestered underground for enhanced oil recovery (EOR) and the hydrogen used to generate several megawatts of carbon-free electricity. In contrast to large central power plants that are generally not well-located to support EOR, the small PRESEOR can go directly to the oilfields where it is needed, and do so in a timely manner. The PRESEOR sequesters more biomass-derived carbon than is released by the burning of the oil it yields, thereby producing not only carbon-free electricity but carbon-free oil. Using PRESEOR, over 80 billion barrels of U.S. oil would be made recoverable, without the need to drill new wells in pristine areas.
8622129	2008	0.409	BP Exploration Operating Company Limited	Method of injecting carbon dioxide	A method of storing CO₂in a porous and permeable hydrocarbon reservoir having at least one injection well and at least one production well penetrating the reservoir, by recovering a produced fluid stream including produced hydrocarbons, produced water, and produced CO₂from the production well; passing the produced fluid stream to a production facility where a produced vapor stream of carbon dioxide and volatile hydrocarbons is separated from the produced fluid stream; compressing the produced vapor stream to above the cricondenbar for the produced vapor stream; cooling the compressed stream to form a cooled stream that in a dense phase state; importing a CO₂stream to an injection facility wherein the imported CO₂is either in a liquid state or a supercritical state; mixing the cooled stream with the imported CO₂stream thereby forming a co-injection stream; and injecting the co-injection stream into the hydrocarbon bearing reservoir from said injection well.

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8596355	2010	0.406	ExxonMobil Upstream Research Company	Optimized well spacing for in situ shale oil development	A method for spacing heater wells for an in situ conversion process includes the steps of determining a direction along which thermal energy will travel most efficiently through a subsurface formation, and completing a plurality of heater wells in the subsurface formation, with the heater wells being spaced farther apart in the determined direction than in a direction transverse to the determined direction. In one aspect, the step of determining a direction along which thermal energy will travel most efficiently is performed based upon a review of geological data pertaining to the subsurface formation. The geological data may comprise the direction of least horizontal principal stress in the subsurface formation. Alternatively, the geological data may comprise the direction of bedding in the subsurface formation, the tilt of the subsurface formation relative to the surface topography, the organic carbon content of the kerogen, the initial formation permeability, and other factors.
7922643	2008	0.404	individual(s)	Method for reducing the emission of green house gases into the atmosphere	A method for reducing the emission of greenhouse gases, such as for example carbon dioxide, into the atmosphere above a ground surface, the method comprising injecting a gas stream comprising one or more than one greenhouse gas into a subsurface injection formation, where the subsurface injection formation comprises a water-laden layer comprising formation water, and where some or all of the greenhouse gases present in the gas stream become dissolved in the formation water in the subsurface injection formation, sequestering the one or more than one greenhouse gas in the subsurface injection formation, separating non-greenhouses gas in situ from the greenhouse gas, venting the non-greenhouse gas from the formation and thereby reducing the emission of greenhouse gases into the atmosphere.
7380598	2005	0.399	BP Corporation North America Inc.	Method for detecting fluid leakage from a subterranean formation	A method for the detection of a fluid leak from a plugged well extending from a surface of the earth to penetrate a subterranean formation which contains fluid by logging a collection chamber positioned in the plugged well.
7624801	2008	0.395	Pioneer Energy, Inc.	Control system and method for controlling a hybrid petroleum extractor/power generator	A control system and control method for controlling a modular apparatus for extracting petroleum and/or generating electricity based on subsurface data as well as market prices of electricity and/or petroleum. One or more probes measure subsurface total pressure, partial pressure of carbon dioxide, partial pressure of hydrogen, oil flow rate, gas flow rate, underground temperature, and/or viscosity of the oil. The control system/method controls the apparatus based on the subsurface parameters by controlling an injection module and/or a gas separator module to increase or decrease output of driver gas. The control system/method may also control the injection module and/or the gas separator module to increase (or decrease) output of driver gas when the market price of electricity decreases (or increases) and/or petroleum increases (or decreases).

Table S11. The patents with highest SPNP values in the “Integrated gasification combined cycle (GCC) combined with carbon capture and storage (CCS)” domain

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Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
8557024	2010	0.685	Fluor Technologies Corporation	Configurations and methods of carbon capture	An IGCC plant has a precombustion decarbonization unit in which acid gas is removed from a combustion gas before the combustion gas enters a combustion turbine. In one preferred configuration, a sulfur removal unit removes hydrogen sulfide from a feed gas before the desulfurized feed gas enters an autorefrigeration unit in which carbon dioxide is removed. In another preferred configuration, hydrogen sulfide is converted to carbonyl sulfide in a dryer, and the carbonyl sulfide is absorbed in the liquid carbon dioxide that is prepared from the feed gas using autorefrigeration.
7083658	2003	0.677	ALSTOM Technology Ltd.	Hot solids gasifier with CO₂removal and hydrogen production	A gasifier 10 includes a first chemical process loop 12 having an exothermic oxidizer reactor 14 and an endothermic reducer reactor 16. CaS is oxidized in air in the oxidizer reactor 14 to form hot CaSO₄which is discharged to the reducer reactor 16. Hot CaSO₄and carbonaceous fuel received in the reducer reactor 16 undergo an endothermic reaction utilizing the heat content of the CaSO₄, the carbonaceous fuel stripping the oxygen from the CaSO₄to form CaS and a CO rich syngas. The CaS is discharged to the oxidizer reactor 14 and the syngas is discharged to a second chemical process loop 52. The second chemical process loop 52 has a water-gas shift reactor 54 and a calciner 42. The CO of the syngas reacts with gaseous H₂O in the shift reactor 54 to produce H₂and CO₂. The CO₂is captured by CaO to form hot CaCO₃in an exothermic reaction. The hot CaCO₃is discharged to the calciner 42, the heat content of the CaCO₃being used to strip the CO₂from the CaO in an endothermic reaction in the calciner, with the CaO being discharged from the calciner 42 to the shift reactor 54.

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8409307	2007	0.602	Praxair Technology, Inc.	Gasification and steam methane reforming integrated polygeneration method and system	This invention is a process and system for providing hydrogen at a high level of reliability from a gasification system by integrating it with SMR. Carbonaceous feedstock such as petroleum coke or coal or biomass is gasified to co-produce SNG, fuel gas, hydrogen, power and steam in conjunction with hydrogen production through steam methane reforming. Carbon dioxide may also be recovered in this process. The integrated schemes are designed in a way that maximizes the reliability of production of high value products such as hydrogen through gasification and minimizes the impact of high natural gas prices on hydrogen production by SMR.
8349504	2010	0.502	individual(s)	Electricity, heat and fuel generation system using fuel cell, bioreactor and twin-fluid bed steam gasifier	The process and system of the invention converts solid and liquid carbonaceous feedstock into electricity, steam, fuels, and carbon dioxide with minimal air emissions. Oxygen is partially consumed in a fuel cell then exhausted to a combustor of a Twin-Fluid Bed Steam Gasifier Unit (TFBSGU) where it is consumed in burning carbon contained in ash. After particulates are separated, the flue gas is expanded then cooled to recover power before returning to atmosphere or a bio-reactor. Synfuel leaving the TFBGSU is cooled in a heat recovery unit, producing steam and hot water. Carbon monoxide in this stream reacts with steam producing hydrogen and carbon dioxide. The stream is then cooled and compressed. The compressed gas passes through an acid gas removal system removing carbon dioxide and sulfur bearing compounds. Steam is added to the clean gas to prevent coking and the stream enters the anode space of the fuel cell.
6632846	2001	0.498	Rentech, Inc.	Integrated urea manufacturing plants and processes	A plant for manufacturing urea from carbonaceous materials, oxygen from an air separation unit and water, preferably steam, is made up of a syngas generator unit, an air separation unit, Fischer-Tropsch unit, a CO2 removal unit, a hydrogen removal unit, a methanator unit, an ammonia converter unit and a urea synthesizer unit. Each of Fischer-Tropsch liquids, ammonia, hydrogen and urea can be recoverable under proper economic conditions. Electrical power is recoverable by the addition of at least one of a steam turbine and a gas turbine which is/are coupled to an electrical generator.

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7937948	2009	0.474	Pioneer Energy, Inc.	Systems and methods for generating electricity from carbonaceous material with substantially no carbon dioxide emissions	A reformation power plant generates clean electricity from carbonaceous material and high pressure CO₂which can be easily sequestered or utilized for a beneficial purpose, such as fuel production. The reformation power plant design utilizes a reformation process that reforms carbonaceous fuel with super-heated steam into a high-pressure gaseous mixture that is rich in carbon dioxide and hydrogen gas. This high-pressure gas exchanges excess heat with the incoming steam from a boiler and continues onward to a condenser. Once cooled, the high-pressure gas goes through a methanol separator, after which the CO₂-rich gas is sequestered underground or beneficially re-used. The remaining hydrogen-rich gas is combusted through a gas turbine. The gas turbine provides power to a generator and also regenerative heat for the boiler. Finally, the generator converts mechanical energy into electricity, which is transferred to the electric grid. Therefore, carbon-free electricity is generated from coal, biomass, or other carbon-based feedstock.
6148602	1998	0.444	Norther Research & Engineering Corporation	Solid-fueled power generation system with carbon dioxide sequestration and method therefor	A method of generating power with sequestration of carbon-dioxide emission includes compressing ambient air, separating substantially pure oxygen from the ambient air and then further compressing the substantially pure oxygen separated from the ambient air. After the oxygen has been further compressed, the oxygen is divided into a first oxygen stream and a second oxygen stream. The method includes introducing the first oxygen stream and a solid fuel, such as coal, into a solid-fuel gasifier for converting the first oxygen stream and the solid fuel into a combustible gas and combusting the gas in the presence of the second oxygen stream, the combusting step including the step of introducing water into the combustor during the combusting step for generating an exhaust stream of carbon dioxide and steam. The exhaust stream of carbon dioxide and steam is then passed through a turbine for driving the turbine and generating power. The exhaust stream is then cooled for producing carbon dioxide gas and water so that the carbon dioxide gas may be separated from the water and collected. Introducing water into the combustor during the combusting step increases the mass flow and the volume flow of the exhaust stream passing through the turbine, thereby elevating the amount of power generated by the turbine.

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7445649	2006	0.387	ALSTOM Technology Ltd.	Hot solids gasifier with CO₂removal and hydrogen production	A gasifier 10 includes a first chemical process loop 12 having an exothermic oxidizer reactor 14 and an endothermic reducer reactor 16. CaS is oxidized in air in the oxidizer reactor 14 to form hot CaSO₄which is discharged to the reducer reactor 16. Hot CaSO₄and carbonaceous fuel received in the reducer reactor 16 undergo an endothermic reaction utilizing the heat content of the CaSO₄, the carbonaceous fuel stripping the oxygen from the CaSO₄to form CaS and a CO rich syngas. The CaS is discharged to the oxidizer reactor 14 and the syngas is discharged to a second chemical process loop 52. The second chemical process loop 52 has a water-gas shift reactor 54 and a calciner 42. The CO of the syngas reacts with gaseous H₂O in the shift reactor 54 to produce H₂and CO₂. The CO₂is captured by CaO to form hot CaCO₃in an exothermic reaction. The hot CaCO₃is discharged to the calciner 42, the heat content of the CaCO₃being used to strip the CO₂from the CaO in an endothermic reaction in the calciner, with the CaO being discharged from the calciner 42 to the shift reactor 54.
8959884	2011	0.378	ALSTOM Technology Ltd.	Power plant with CO₂capture and compression	CO₂compression is a main step in carbon capture and storage, which is essential to control global warming. CO₂compressors are powered by electric motors, which increase operational flexibility but require much energy leading to additional expenses, power and efficiency losses. A method is provided for optimized operation of a plant including a power generation unit with a CO₂capture system and compressor with minimum losses during normal operation, allowing flexible part load. The method allows steam from the power unit to drive a steam turbine, which drives the CO₂compressor via an engaged overrunning clutch if a sufficient amount of steam is available from the power unit, and to drive it by the generator, which is used as motor when insufficient steam is available from the power unit. When no or insufficient steam is available the clutch is disengaged and the steam turbine may be at standstill or idling.

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8597384	2009	0.355	General Electric Company	Gasification cooling system having seal	A system, in certain embodiments, includes a gasification cooling system having an annular seal with a bellows. For example, the gasification cooling system may include a housing with an inlet, an outlet, and an interior between the inlet and the outlet, wherein the interior has a throat adjacent the inlet, and the throat expands in a flow direction from the inlet toward the outlet. The annular seal may be disposed in the throat of the housing, wherein the annular seal includes the bellows.
8168144	2010	0.253	Eventix, Inc.	System and method for providing an integrated reactor	A system and method for providing an integrated indirectly fired reactor and steam generator are disclosed. According to one embodiment, the reactor comprises an indirect heating zone heating water and generating steam, a mixing zone mixing feedstock and the steam and providing a mixture of the feedstock and the steam, and a reaction zone comprising a first reactor and a second reactor. The first reactor converts the mixture to a first syngas at a first temperature. The second reactor converts the first syngas to a second syngas at a second temperature, the second temperature being higher than the first temperature.
8372251	2010	0.249	General Electric Company	System for protecting gasifier surfaces from corrosion	According to various embodiments, a system includes a gasifier that includes a shell made of a first material exposed to a gasification region inside the gasifier and a patterned anode layer coupled to the shell inside the gasifier. The patterned anode layer is made of a second material, and the patterned anode layer is configured to protect the shell from corrosion by condensing hot gas in the gasification region.
6976362	2003	0.231	Rentech, Inc.	Integrated Fischer-Tropsch and power production plant with low CO2 emissions	A plant for producing Fischer-Tropsch liquids and electrical power with greatly reduced emissions of carbon dioxide to the atmosphere is made up of a syngas generator unit, an air separation unit, a Fischer-Tropsch unit, a CO₂removal unit, and a combined cycle electricity generation unit. Each of Fischer-Tropsch liquids, carbon dioxide, and electrical power can be recoverable under proper economic conditions. Electrical power is recoverable by the use of a gas turbine fueled by predominantly hydrogen and a steam turbine powered by steam generated by cooling exhaust gases from the gas turbine. Sequestration of CO₂and fueling the gas turbine with hydrogen reduces the amount of greenhouse gases emitted to the atmosphere.

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7634915	2005	0.174	General Electric Company	Systems and methods for power generation and hydrogen production with carbon dioxide isolation	A power generation system includes a first gas turbine system. The first turbine system includes a first combustion chamber configured to combust a first fuel stream of primarily hydrogen that is substantially free of carbon-based fuels, a first compressor configured to supply a first portion of compressed oxidant to the first combustion chamber and a first turbine configured to receive a first discharge from the first combustion chamber and generate a first exhaust and electrical energy. The power generation system further includes a second gas turbine system. The second turbine system includes a second combustion chamber configured to combust a second fuel stream to generate a second discharge, wherein the first compressor of the first gas turbine system is configured to supply a second portion of compressed oxidant to the second combustion chamber and a second turbine configured to receive the second discharge from the second combustion chamber to generate a second exhaust and electrical energy. A second compressor is configured to receive the second exhaust comprising carbon dioxide and to discharge a recycle stream to the second combustion chamber and a split stream to a separator system adapted to recover carbon dioxide. The power generation system also includes a hydrogen generation system configured to receive a third fuel and steam to generate the first fuel and a third exhaust gas, wherein the third exhaust gas is recycled into the second combustion chamber.
8557173	2011	0.157	Air Products and Chemicals, Inc.	Blast furnace iron production with integrated power generation	An integrated system for blast furnace iron making and power production based upon higher levels of oxygen enrichment in the blast gas is disclosed. The integrated system leads to; 1) enhanced productivity in the blast furnace, 2) more efficient power production, and 3) the potential to more economically capture and sequester carbon dioxide. Oxygen enhances the ability of coal to function as a source of carbon and to be gasified within the blast furnace thereby generating an improved fuel-containing top gas.
8047007	2011	0.142	Pioneer Energy, Inc.	Methods for generating electricity from carbonaceous material with substantially no carbon dioxide emissions	Disclosed herein is a method for generating ?clean? electricity from carbonaceous material, and producing high-pressure CO₂which can be easily sequestered or utilized for a beneficial purpose, such as fuel production. This method utilizes a reformation process that reforms carbonaceous fuel with superheated steam into a high-pressure gaseous mixture that is rich in carbon dioxide and hydrogen gas. This high-pressure gas exchanges excess heat with the incoming steam from a boiler. Once cooled, the high-pressure gas goes through a CO₂separator, after which the

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					CO₂-rich gas is sequestered underground or beneficially re-used. The remaining hydrogen-rich gas is used to generate power in a power generation subsystem, such as a gas turbine or a fuel cell. Therefore, carbon-free power is produced from coal, biomass, natural gas, or another carbon-based feedstock.
8133298	2008	0.14	Air Products and Chemicals, Inc.	Blast furnace iron production with integrated power generation	An integrated system for blast furnace iron making and power production based upon higher levels of oxygen enrichment in the blast gas is disclosed. The integrated system leads to; 1) enhanced productivity in the blast furnace, 2) more efficient power production, and 3) the potential to more economically capture and sequester carbon dioxide. Oxygen enhances the ability of coal to function as a source of carbon and to be gasified within the blast furnace thereby generating an improved fuel-containing top gas.
7988752	2008	0.069	ALSTOM Technology Ltd.	Hot solids gasifier with CO₂removal and hydrogen production	A gasifier 10 includes a first chemical process loop 12 having an exothermic oxidizer reactor 14 and an endothermic reducer reactor 16. CaS is oxidized in air in the oxidizer reactor 14 to form hot CaSO₄which is discharged to the reducer reactor 16. Hot CaSO₄and carbonaceous fuel received in the reducer reactor 16 undergo an endothermic reaction utilizing the heat content of the CaSO₄, the carbonaceous fuel stripping the oxygen from the CaSO₄to form CaS and a CO rich syngas. The CaS is discharged to the oxidizer reactor 14 and the syngas is discharged to a second chemical process loop 52. The second chemical process loop 52 has a water-gas shift reactor 54 and a calciner 42. The CO of the syngas reacts with gaseous H₂O in the shift reactor 54 to produce H₂and CO₂. The CO₂is captured by CaO to form hot CaCO₃in an exothermic reaction. The hot CaCO₃is discharged to the calciner 42, the heat content of the CaCO₃being used to strip the CO₂from the CaO in an endothermic reaction in the calciner, with the CaO being discharged from the calciner 42 to the shift reactor 54.

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6306917	1999	0.064	Rentech, Inc.	Processes for the production of hydrocarbons, power and carbon dioxide from carbon-containing materials	Apparatus and processes for producing power, liquid hydrocarbons and carbon dioxide from heavy feedstocks, using a partial oxidation reactor to produce a synthesis gas, a Fischer-Tropsch reactor to convert the synthesis gas to hydrocarbon products and tail gases containing hydrogen and carbon dioxide, and a combined cycle plant to produce power from steam generated by recovering heat from the reactors and from combustible tail gases. By varying operating conditions and utilizing hydrogen for recycle to the Fischer-Tropsch reactor and/or hydrocracking wax products to produce lighter hydrocarbons, the process can selectively maximize the production of power, hydrocarbons or carbon dioxide. In preferred embodiments, the Fischer-Tropsch reactor can be a slurry reactor and can employ an iron-based catalyst.
8776532	2013		Palmer Labs, LLC	Partial oxidation reaction with closed cycle quench	The present disclosure relates to a power production system that is adapted to achieve high efficiency power production with complete carbon capture when using a solid or liquid hydrocarbon or carbonaceous fuel. More particularly, the solid or liquid fuel first is partially oxidized in a partial oxidation reactor. The resulting partially oxidized stream that comprises a fuel gas is quenched, filtered, cooled, and then directed to a combustor of a power production system as the combustion fuel. The partially oxidized stream is combined with a compressed recycle CO₂stream and oxygen. The combustion stream is expanded across a turbine to produce power and passed through a recuperator heat exchanger. The expanded and cooled exhaust stream is scrubbed to provide the recycle CO₂stream, which is compressed and passed through the recuperator heat exchanger and the POX heat exchanger in a manner useful to provide increased efficiency to the combined systems.

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Table S12. The patents with highest SPNP values in the "Oxyfuel combustion" domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
4671069	1985	0.994	Hitachi, Ltd.	Combustor for gas turbine	A premixture of compressed air and gaseous fuel is supplied and conbusted into a head combustion chamber of a combustor for gas turbine and main combustion of lean, low flame temperature is carried out in a rear combustion chamber following the heat combustion chamber to prevent the formation of high flame temperature which tends to promote NOx generation.
4854249	1988	0.984	Institute of Gas Technology	Two stage combustion	A process for combusting sulfur and nitrogen containing carbonaceous materials in a two stage combustion process wherein sulfur and nitrogen containing carbonaceous materials and sulfur fixation agent particulates are introduced into a first combustion stage single fluidized bed having a density/size selective solids withdrawal conduit. The carbonaceous materials are combusted in the fluidized bed under substoichiometric oxygen conditions at temperatures of about 1600.degree. to about 2000.degree. F. producing ash and reducing gases forming a reducing region in a major portion of the single fluidized bed, the reducing gases comprising gaseous sulfur compounds. In a reducing region of the fluidized bed, the gaseous sulfur compounds are reacted with oxides of the sulfur fixation agent forming an intermediate solid metallic sulfur compound and nitrogen contained in the carbonaceous materials is converted to molecular nitrogen. The intermediate sulfur compound is reacted in an oxidizing region maintained at a base portion of the fluidized bed to form a stable, solid, environmentally acceptable sulfur containing compound which is withdrawn through the selective solids withdrawal conduit with agglomerated ash.
4270466	1979	0.977	Klockner-Humboldt-Deutz AG	Method and apparatus for rendering an ignitable fuel-oxygen mixture inert	Method and apparatus for operating a process in which combustible solid particles are mixed during processing with air and circulated through a plurality of stages, thereby tending to build up an oxygen enriched combustible mixture during shutdown, the invention involving adding additional fuel to the oxygen enriched combustible mixture during such shutdown in a closed burner system, burning the resulting mixture in the closed burner system, and recirculating the flue gas from such combustion back into the plurality of stages to thereby function as an inert gas to prevent accidental combustion or explosion.
6247316	2000	0.964	Clean Energy Systems, Inc.	Clean air engines for transportation and other power applications	A low or no pollution engine is provided for delivering power for vehicles or other power applications. The engine has an air inlet which collects air from a surrounding environment. At least a portion of the nitrogen in the air is removed using a technique such as liquefaction, pressure swing adsorption or membrane based air separation. The remaining air is primarily oxygen, which is then compressed and routed to a gas generator. The gas generator has an igniter and inputs for the high pressure oxygen and a high pressure hydrogen containing fuel, such as hydrogen or methane. The fuel and oxygen are combusted within the gas generator, forming water and carbon dioxide with carbon containing fuels. Water is also delivered into the gas generator to control a temperature of the combustion products. The combustion products are then expanded through a power generating

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					device, such as a turbine or piston expander to deliver output power for operation of a vehicle or other power uses. The combustion products, steam and, with carbon containing fuels, carbon dioxide, are then passed through a condenser where the steam is condensed and the carbon dioxide is collected or discharged. A portion of the water is discharged into the surrounding environment and the remainder is routed back to the gas generator.
4850194	1987	0.956	BBC Brown Boveri AG	Burner system	The present invention relates to a burner system, in particular for a gas turbine, with a main supply channel (2), debouching into a combustion chamber (1), for a fuel/air mixture having a swirler (5) and a burner lance (3) which passes through the swirler (5). To improve the transverse ignition properties between several such burner systems, optionally disposed on the burner chamber (1), and also to increase the flame stability, the burner lance (3) has, on the combustion chamber side with respect to the swirler (5) exit openings (12, 16) for fuel supplied to its interior or for a fuel-rich fuel/air mixture supplied to, or formed in, its interior.
4863371	1988	0.954	Union Carbide Corporation	Low NO.sub.x high efficiency combustion process	A process to combust fuel and oxidant at high efficiency and with low NO.sub.x generation even when the fuel has non-uniform characteristics and the oxidant is pure oxygen, wherein fuel and oxidant are first combusted within a high velocity oxidant-rich jet, fuel is mixed with combustion products in a recirculation zone and the mixture is aspirated into the oxidant-rich jet and combusted in a diffuse secondary flame at the periphery of the oxidant-rich jet.
4946382	1989	0.951	Union Carbide Corporation	Method for combusting fuel containing bound nitrogen	A method for combusting fuel containing bound nitrogen to achieve reduced NO.sub.x emissions wherein the oxidant and fuel are injected separately into a combustion zone through a burner and the oxidant is injected with a momentum equal to at least three times the fuel stream momentum and at an angle equal to or greater than the sum of the angles of the fuel stream periphery and oxidant stream periphery with their respective centerlines.
6190160	1999	0.947	L'Air Liquide, Societe Anonyme pour pour l'Etude et l'Exploitation des	Process for combustion of a fuel with an oxygen-rich oxidant	The invention relates to a process for combustion of a fuel with an oxygen-rich oxidant, in a combustion chamber (3), in which, cyclically: at least one principal variable representing the combustion in the said combustion chamber (3) is measured, and, as a function of the result of the measurement of the at least one principal variable, a control instruction for regulating the flowrates of fuel and oxidant to be injected into the combustion chamber (3) is determined. Then the regulating control instruction is applied in order to make the fuel burn with the oxidant in the chamber (3). Additionally at least one secondary variable associated with an operational constraint of the combustion chamber (3) or with a perturbation in the operation of the latter is measured, and for the determination of regulating control instruction, the measurement result of the at least one secondary variable is also taken into account. The invention is useful in glass furnaces, rotary furnaces, and incineration furnaces.

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6360524	2001	0.944	Praxair Technology, Inc.	Oxygen separator designed to be integrated with a gas turbine and method of separating oxygen	An oxygen separator and method for separating oxygen from a heated oxygen containing gas that employs oxygen-selective ceramic membranes of elongated, tubular configuration within a duct for separation of oxygen from a heated gas. The duct can be attached between the exhaust of a gas turbine and a power generator driven by the exhaust or can be connected to one or more burners of a gas turbine. Supplementary compressed feed air may be added at a flow rate at least equal to that of the permeated oxygen for cooling and flow balancing purposes. A purge stream can also be introduced. Additionally, combustor tubes fabricated from an oxygen-selective ceramic membrane material may also be provided to produce combustion products that in turn can be used as a purge for downstream oxygen-selective ceramic membranes.
4627367	1984	0.937	Coal Industry (Patents) Limited	Hot gas generation	In a hot gas generating apparatus coal is fed to a first gasifying fluidized bed wherein it is partially gasified to generate a combustible gas and char. The char is circulated to a second combustion fluidized bed for burning in the presence of excess air. The combustible gas is mixed with the oxygen rich gases from the second bed and burnt to give a hot gas product.
4800825	1988	0.934	TRW Inc.	Slagging-combustor sulfur removal process and apparatus	In the operation of a slagging combustor, including an apertured baffle defining part of a cylindrical combustion chamber having a head end which includes a nozzle for injection of sulfur-containing particulate carbonaceous material to be combusted in a whirling oxidant flow field, there is injected a particulate sulfur sorbent at the aperture of the baffle towards the nozzle to react with released sulfur. The sulfur sorbent is injected into the combustion zone from a location near the exit end thereof. Fuel is injected near the center of the head end. A relatively fuel-rich recirculation zone is established and maintained along the longitudinal axis of the combustion chamber surrounded by a relatively oxygen-rich annular region. Sorbent mixes intimately with, and flows co-currently with, recirculating gases, generally toward the head end of the combustion zone, whereby the mixture of sorbent and gaseous products of combustion are maintained at temperatures and stoichiometric conditions favoring conversion of sulfur to compounds that dissolve in the molten slag.
5065680	1990	0.917	Phoenix Environmental, Inc.	Method and apparatus for making solid waste material environmentally safe using heat	Harmful constituents are removed from non-combustible solid waste, such as incinerator ash, by continuously feeding a mixture of the solid waste and a combustible excitation material into a reaction chamber, igniting the mix in said chamber and causing it to react in the presence of oxygen until the heat of the reaction causes the solid waste material to become a molten slag and the temperature within the chamber above the molten slag is high enough to destroy substantially all of the harmful constituents in the gaseous effluent released by the formation of the molten slag. The excess molten slag is conducted from the reaction chamber. The effluent is conducted from the reaction chamber into a second chamber where it is rapidly cooled to cause particulate material to precipitate out of the effluent. The effluent is thereafter treated to remove substantially all of the remaining particulate and harmful gases to achieve

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					acceptable environmental quality. The thus treated effluent is released into the atmosphere.
5500194	1994	0.916	Petrocon Technologies, Inc.	Hybrid low NO.sub.x process for destruction of bound nitrogen compounds	A process for treating an exhaust stream which includes high levels of noxious compounds containing chemically bound nitrogen, to produce an effluent stream that is extremely low in oxides of nitrogen and environmentally safe for discharge into the atmosphere. A source of oxygen and fuel is added to the exhaust stream to create a fuel-rich mixture, the quantity of fuel being sufficient to react with the available oxygen. The fuel-enriched stream is provided to a thermal reactor and reacted to provide a heated oxygen-depleted stream which includes quantities of by-product NO.sub.x, which stream is then cooled to 800.degree. to 1000.degree. F. Conversion oxygen is added to the cooled stream which is then passed over a first catalyst bed under overall reducing conditions, the quantity of conversion oxygen added being in stoichiometric excess of the amount of NO.sub.x in the stream, but less than the amount of combustibles, whereby the NO.sub.x is first oxidized to NO.sub.2, and then the NO.sub.2 is reduced by the excess combustibles. The stream is cooled to a temperature of about 450.degree. to 550.degree. F., and air is added to produce a further cooled stream at a temperature of about 400.degree. to 500.degree. F., and having a stoichiometric excess of oxygen. This is passed over an oxidizing catalyst bed to oxidize remaining excess combustibles, and provide an effluent stream having environmentally safe characteristics.
7384452	2005	0.916	Praxair Technology, Inc.	Fluid heating method	A method of heating a fluid utilizing a process heater having one or more first combustion zones and one or more second combustion zones. The combustion of a fuel is divided between the first and second combustion zones. The oxygen is provided for combustion within the first combustion zone by one or more oxygen transport membranes that contribute between about 50 and 99 percent of the stoichiometric amount of oxygen required for complete combustion of the fuel passing through the process heater. A supplemental or secondary oxidant is introduced into second combustion zone to complete combustion of the fuel and thereby produce a flue gas stream containing between about 1 and 3 percent oxygen to ensure complete combustion of the fuel. In this manner, the surface area of the oxygen transport membranes may be reduced below the surface area that otherwise would be required if 100 percent of the oxygen were contributed by the oxygen transport membranes.

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3945942	1972	0.9	Texaco Development Corporation	Fuel burner and process for gas manufacture	A partial oxidation burner and process for the manufacture of synthesis gas, reducing gas and other gas mixtures substantially comprising H.sub.2 and CO. A hydrocarbon, oxygen-rich gas and, optionally, H.sub.2 O or some other temperature moderator are introduced into the reaction zone of a synthesis gas generator in which, by partial oxidation at an autogenous temperature in the range of about 1700.degree. to 3500.degree.F. and a pressure in the range of about 1 to 250 atmospheres, said synthesis, fuel, or reducing gas is produced. For example, a hydrocarbon is introduced into the reaction zone by way of the inner assembly of a novel multitube burner, and a mixture of oxygen-rich gas and steam is passed through a coaxial conduit disposed about the outside of said inner assembly. Said inner assembly comprises a central conduit of circular cross-section, having a plurality of parallel open-ended tubes extending downstream from the exit end of said central conduit and in communication therewith. The tubes terminate in a surrounding nozzle, which is the exit end of the coaxial outer conduit.
6293084	2000	0.9	Praxair Technology, Inc.	Oxygen separator designed to be integrated with a gas turbine and method of separating oxygen	An oxygen separator and method for separating oxygen from a heated oxygen containing gas that employs oxygen-selective ceramic membranes of elongated, tubular configuration within a duct for separation of oxygen from a heated gas. The duct can be attached between the exhaust of a gas turbine and a power generator driven by the exhaust or can be connected to one or more burners of a gas turbine. Supplementary compressed feed air may be added at a flow rate at least equal to that of the permeated oxygen for cooling and flow balancing purposes. A purge stream can also be introduced. Additionally, combustor tubes fabricated from an oxygen-selective ceramic membrane material may also be provided to produce combustion products that in turn can be used as a purge for downstream oxygen-selective ceramic membranes.
4260361	1978	0.89	individual(s)	Resonant or pulsating combustion heating apparatus	A resonant or pulsating combustion heating apparatus of the present invention provides a high thermal efficiency heater with low concentrations of carbon monoxide and nitrogen oxides in the exhaust gas. The pulsation heater is constructed to provide an afterburner or late-combustion reactor in the pulsation tube. Combustion in the combustion chamber is of a relatively rich fuel/air mixture in which no nitrogen oxides are produced. The afterburning in the pulsation tube is carried out in the presence of excess air providing late combustion to remove carbon monoxide (CO).
4493635	1983	0.886	Osaka Gas Company Limited	Oxygen-enriched air ratio control device for combustion apparatus	A control device controls the air ratio in a combustion apparatus constructed so that combustion fuel supplied via a combustion fuel supplying pipe is burned with oxygen-enriched air obtained by drawing air through an oxygen permeable selective membrane by means of a vacuum pump provided at the downstream side of the oxygen permeable selective membrane and supplied via an air supplying pipe. The control device has an air flow meter and an oxygen concentration analyzer, both provided at the air supplying pipe, and a fuel flow meter provided at the combustion fuel supplying pipe. The air ratio is calculated from the values of the flow rate of of air, the oxygen concentration and flow rate of the

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					combustion fuel. The amount of air drawn by the vacuum pump is controlled so that the actual air ratio is equal to an predetermined air ratio.
6382958	2000	0.884	Praxair Technology, Inc.	Air separation method and system for producing oxygen to support combustion in a heat consuming device	A method and system to separate oxygen from air for producing oxygen to support combustion of a fuel, thereby to produce heat in a heat consuming device. In accordance with the method and system a heated and compressed air stream is introduced into a ceramic membrane system having one or more oxygen-selective, ion conducting membranes to produce an oxygen permeate stream which is used to support combustion of the fuel. The compressed air stream is heated within the heat consuming device itself which can be, for instance, a furnace or a boiler, through indirect heat exchange with flue gases or by radiant heat within a radiant heat exchange zone thereof. An oxygen lean retentate stream, produced through separation of oxygen from the compressed and heated air stream, can be expanded with the performance of work to produce an expanded air stream. The work of expansion can be applied to the compression of the incoming air stream. The expanded air stream can be used to preheat the compressed and heated air stream.
4960380	1989	0.881	Phoenix Environmental, Inc.	Method and apparatus for the reduction of solid waste material using coherent radiation	Coherent radiation is used to provide the energy, excite and sustain of plasma in which solid waste materials are reduced to a slag-like material from which has been removed the more harmful constituents. The effluvia of the plasma reduction process is scrubbed to remove particulates and the gas is processed by additional heating to eliminate products of incomplete combustion and/or chemically convert harmful constituents. The remaining gas is then safely exhausted into the atmosphere. The solid waste material may be the ash by-product of prior incineration.
6539719	2001	0.871	Praxair Technology, Inc.	Integration of ceramic oxygen transport membrane combustor with boiler furnace	An oxygen selective ion transport membrane is integrated with a boiler furnace to generate steam and, optionally, high purity oxygen and nitrogen. The heat required to drive the system is obtained by the combustion of an oxygen transported through the oxygen selective ion transport membrane with a high BTU fuel such as methane or natural gas. NOx compound formation is minimized either by utilizing a combustion products diluted air/fuel mixture for combustion in the boiler furnace or by limiting combustion to a mixture of oxygen and a fuel.
5439373	1993	0.84	Praxair Technology, Inc.	Luminous combustion system	A combustion system wherein a defined uniform nonstoichiometric mixture of fuel and oxygen is made in a compartment outside a furnace zone and burned inside the furnace zone in a luminous flame while additional make up oxygen is provided into the furnace zone under conditions which avoid diminution of flame luminosity and high NO.sub.x generation.
6527828	2001	0.834	Advanced Technology Materials, Inc.	Oxygen enhanced CDA modification to a CDO integrated scrubber	A method and system for retrofitting an integrated scrubber to provide maximum oxygen content in a controlled decomposition oxidation (CDO) abatement process including a thermal/wet integrated scrubber, and a compressed air supply for supplying air to an oxygen separation device that separates the air into a nitrogen-enriched component and an oxygen-enriched component. The oxygen separation device includes a module, such as a vessel containing ceramic-materials arranged in an adsorbent bed or coated on a substrate. The present invention uses a ceramic

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					oxide material through which only oxygen can diffuse. The composition of the ceramic oxide adsorbent material is such that a significant number of oxygen vacancies exist in the material. By placing either a voltage potential or a pressure gradient across the membrane, oxygen is selectively diffused in and through the oxide material to separate the air supply into an oxygen component for introduction into the integrated scrubber.
5309850	1992	0.815	The Babcock & Wilcox Company	Incineration of hazardous wastes using closed cycle combustion ash vitrification	A closed combustion system is used to incinerate hazardous wastes and vitrify ash. An incinerator is provided with pure oxygen, hazardous waste and fuel for incinerating the hazardous waste. Slag from the incinerator is treated separately. Combusted products from the incinerator such as flue gases, liquids, solids and ash are channeled through the system and recirculated back to the incinerator for incineration. A dust collector is used to collect ash from the combusted product and recirculate back to the incinerator. A condensing heat exchanger is used to collect and dispose of waste liquids. Filters are used for filtering particulates from the combusted product. A CaO pebble bed is provided for causing reactions with the flue gases. Remaining insert gas in the system are bled into the atmosphere. Flue gases from the system are recirculated back into the pure oxygen for entry into the incinerator in order to provide temperature control.
6907845	2004	0.814	Krebs & Sisler L.P.	Boiler improvements with oxygen-enriched combustion for increased efficiency and reduced emissions	A method and apparatus to conduct 0₂/CO₂combustion or oxygen-enriched combustion. The boiler exhaust gas passes through a Gas Primer Sector (GPS) combined with the boiler to effect heat transfer to the combustion gas in indirect counter-flow heat exchange. Sharply reduced gas flows result from using largely moisture-free CO₂as diluent for O₂in the combustion gas which allows long residence time at low velocity for maximum heat transfer from the exhaust gas to the combustion gas. Most particulate drops out and most moisture is condensed from the cooled mostly CO₂exhaust gas. The larger portion is blended with oxygen for the combustion gas and reheated and returned to the boiler through the integrated GPS; the smaller portion is cleaned and separated, the CO₂released or recovered. The complete exhaust gas-combustion gas cycle may be 30 to 90 seconds and preferably about 60 seconds. The high heat capacity of CO₂allows a much higher oxygen content in the combustion gas compared to open-cycle air combustion with a large nitrogen content of lower heat capacity. Efficiency is increased. Final exhaust gas separation and recovery is simplified. Condensate is processed to boiler feedwater or potable water quality. NO_x, is eliminated, mercury fume captured and CO₂output reduced.
4928606	1988	0.812	Air Products and Chemicals, Inc.	Combustion of low B.T.U./high moisture content fuels	A process for combusting low B.T.U. high moisture content fuels by enriching the normal process air used in the combustion process.

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5405537	1993	0.811	Air Products and Chemicals, Inc.	Process for combusting dewatered sludge waste in a municipal solid waste incinerator	This invention relates to an improved process for the coincineration of municipal solid waste and municipal sewage sludge by dewatering the sludge, breaking it up into sufficiently small particles and employing oxygen enrichment of the combustion process. These small particles of sludge are introduced into the combustion zone above the grate in the combustion zone but at a distance above the grate no higher than that of the point of introduction of secondary air. This is accomplished without undesired excursions of flue gas flow rate and temperature.
4867756	1987	0.809	Institute of Gas Technology	Removal of sulfur compounds in fluidized bed carbonaceous solids gasification	A method for removing sulfur compounds from gasification product gas during gasification of carbonaceous materials in a fluidized bed, agglomerating discharge reactor and converting harmful and unstable sulfur compounds to an environmentally acceptable form for safe disposal. Particulate sulfur fixation agent is introduced into an ash agglomerating fluidized bed gasifier along with carbonaceous feed solids and reacts with gaseous sulfur compounds formed when gasifying feed solids under reducing conditions in the fluidized bed. Unstable sulfur compounds formed by reaction with the fixation agent are then converted to a stable, environmentally disposable, solid in a lower oxidizing portion of the gasifier for discharge with the ash.
6298664	1999	0.809	Norsk Hydro ASA	Process for generating power including a combustion process	The present invention relates to a process for generating power and/or heat in a combustion process having a fuel combusted with an oxygen-containing gaseous mixture as an oxidant supplied from a mixed conducting membrane capable of separating oxygen from oxygen-containing gaseous mixtures at elevated temperatures. The oxygen is picked up from the permeate side of the membrane by means of a sweep gas. The sweep gas can be obtained from at least one combustion process upstream the membrane. The sweep gas can be formed by mixing a recycled part of the exhaust gas containing oxygen and fuel which are passed over a catalytic or non-catalytic burner or combuster. The process produces a resultant exhaust gas with a high concentration of CO.sub.2 and a low concentration of NO.sub.x making the exhaust gas stream suitable for direct use in different processes, for injection in a geological formation for long term deposition or for enhanced oil and natural gas recovery.
4279208	1979	0.808	L'Air Liquide Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude	Method and apparatus for heat treatment of industrial wastes	A method and apparatus for the heat treatment of industrial wastes wherein at least some of the constituent materials of the wastes are subjected to combustion and/or to pyrolysis to produce flue gases and, in some applications, a residue. The supply of an oxygenated combustion-supporting gas to the wastes is regulated as a function of at least one sensed predetermined characteristic of the flue gases. The oxygenated gas may be a mixture of air and substantially pure oxygen, the feed rate of one or both of these being regulated in response to the sensed temperature and/or oxygen content of the flue gases. Such regulation maintains the oxygen content of the flue gases within the range of from 0 to 7%; and the temperature of the flue gases may be maintained from 400.degree. to 1200.degree. C. and, preferably within a range of 50.degree. C. in this region.

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Table S13. The patents with highest SPNP values in the “Unmixed combustion (Chemical Looping)” domain

Patent number	**Filing year**	**Centrality measure**	**Organization**	**title**	**abstract**
3969089	1975	0.761	Exxon Research and Engineering Company	Manufacture of combustible gases	Substantially sulfur-free combustible fuel gas under superatmospheric pressure is produced by partial combustion or gasification under superatmospheric pressure of a sulfur-containing solid, liquid or gaseous fuel. The gasification is effected within a fluidized bed of particles containing alkaline earth metal compounds (e.g. the oxides) which are capable of reacting with, and of fixing, the fuel sulfur as sulfides under reducing conditions. Sulfide-containing particles are exposed to an oxidizing atmosphere and the sulfides are thereby converted to oxides with the liberation of SO.sub.2 in useful concentrations, and with the liberation of heat. Particles containing regenerated oxides are re-used for fixing more sulfur during fuel gasification. Expedients are described by which it is ensured that the sulfur-fixing activity of the particles is substantially maintained and that the temperatures of the particles during sulfur-fixing and regeneration are maintained within predetermined ranges. The pressurized sulfur-free fuel gas may be directly used to power a gas turbine.
5776226	1995	0.311	"Holderbank" Financiere Glarus AG'	Method for working up refuse or metal-oxide-containing refuse incineration residues	A method for working up refuse or metal-oxide-containing refuse incineration residues or metallurgical residues includes an at least partial oxidation in a meltdown oxidizing reactor followed by a two-stage reduction. The first reduction stage is effected in an iron bath reactor in which iron oxides are not yet reduced. In the second reduction stage also iron oxides are reduced in an iron bath calciner, a pig iron bath being obtained. The metal bath discharged from the iron bath reactor reaches a segregation mold, from which crude bronze can be drawn off.
6911057	2003	0.109	General Electric Company	Apparatus for converting coal into fuel cell quality hydrogen and sequestration-ready carbon dioxide	An apparatus for burning coal to produce substantially pure hydrogen for use in fuel cells, together with ?sequestration ready? carbon dioxide and a stream of oxygen depleted air for powering gas turbines. The apparatus includes two fluidized bed reactors and a third transfer line reactor. The first reactor is supplied with coal particles or ?char? and fluidized with high temperature steam. The second reactor is fluidized with high temperature steam and the third reactor is fluidized by compressed air. Solids circulated among these three reactors include a mixture of materials containing coal, calcium compounds (present as CaO, CaCO₃and mixtures thereof) and iron compounds (present as FeO, Fe₂O₃and mixtures thereof).

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5827496	1997	0.106	Energy and Environmental Research Corp.	Methods and systems for heat transfer by unmixed combustion	An improved methods and systems are provided for transferring heat in a combustion system. The methods and systems provide for alternately exposing a reducing gas and a gas containing molecular oxygen to an unmixed combustion catalyst to respectively reduce and oxidize the unmixed combustion catalyst. The unmixed combustion catalyst is readily reducible when in its oxidized state and is readily oxidized when in its reduced state. The alternating reduction and oxidation reactions enable the unmixed combustion catalyst to efficiently release heat to a heat receiver in efficient thermal contact with the unmixed combustion catalyst. In most embodiments of the present invention, the unmixed combustion catalyst is in a reactor bed of a combustion system.
6669917	2001	0.088	General Electric Company	Process for converting coal into fuel cell quality hydrogen and sequestration-ready carbon dioxide	A process for burning coal to produce substantially pure hydrogen for use in fuel cells, together with ?sequestration ready? carbon dioxide and a stream of oxygen depleted air for powering gas turbines, characterized by using a combination of two fluidized bed reactors and a third transfer line reactor, the first reactor being supplied with coal particles or ?char? and fluidized with high temperature steam; the second reactor being fluidized with high temperature steam and the third reactor being fluidized by compressed air. Solids circulated among these three reactors include a mixture of materials containing calcium compounds (present as CaO, $CaCO_3$ and mixtures thereof) and iron compounds (present as FeO, Fe_2O_3 and mixtures thereof). The coal is gasified by the steam in the presence of CaO to produce $CaCO_3$ and relatively pure hydrogen for use in fuel cells per a CO_2 acceptor process. Because only part of the coal char input to the first reactor is gasified to produce hydrogen, the remainder can be burned to supply thermal energy necessary to regenerate the $CaCO_3$ back to CaO. Carbon in the middle bed fluidized bed reactor reacts with Fe_2O_3 in the third reactor and the temperature in the middle fluidized bed reactor is sufficiently high to decompose $CaCO_3$ back into CaO.
6494153	2001	0.086	General Electric Company	Unmixed combustion of coal with sulfur recycle	An improved method of burning low sulfur coal in order to power gas turbines using unmixed combustion that ensures virtually complete oxidation of the coal, with the sulfur content of the coal being recovered as elemental sulfur for use as recycle in the unmixed combustion process. An unmixed combustion catalyst is circulated between two fluid bed reactors and becomes reduced by low sulfur coal in the first fluid bed reactor and oxidized by air in the second fluid bed reactor. The first reactor produces carbon-containing fly ash which is then separated and contacted with gases containing SO_2 from the first fluid bed reactor to produce CO_2, CO, H_2S, COS, CS_2, and elemental sulfur. The elemental sulfur is separated and a portion thereof recycled back to the first fluid bed reactor.

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6025403	1997	0.016	Mobil Oil Corporation	Process for heat integration of an autothermal reformer and cogeneration power plant	A process for integration of an autothermal reforming unit and a cogeneration power plant in which the reforming unit has two communicating fluid beds. The first fluid bed is a reformer reactor containing inorganic metal oxide and which is used to react oxygen and light hydrocarbons at conditions sufficient to produce a mixture of synthesis gas, hydrogen, carbon monoxide, and carbon dioxide. The second fluid bed is a combustor-regenerator which receives spent inorganic metal oxide from the first fluid bed and which provides heat to heat the inorganic metal and balance the reaction endotherm, by combusting fuel gas in direct contact with the inorganic metal oxide producing hot flue gas. In preferred embodiments, steam is also fed to the reformer reactor and a catalyst may be used with the inorganic metal oxide. The cogeneration power plant has a gas turbine equipped with an air compressor and a combustor and in the integration a portion of compressed air is drawn off from the power plant gas turbine air compressor leaving remainder compressed air; the drawn off compressed air is introduced to the combustor-regenerator; the hot flue gas from the combustor-regenerator is mixed with the remainder of the compressed air to produce a recombined gas stream and this recombined gas stream is fed to the combustor of the cogeneration gas turbine power plant.

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2. Sensitivity of the results

The present research was based on several assumptions, including the CPC classification of the technologies and the fact that there are shared bodies of knowledge between some technological domains. A comprehensive set of sensitivity analyses are presented in this part of the online Supplementary Materials to examine the robustness of the results considering the assumptions, as discussed in the following.

First, a correlation analysis was conducted between the data matrixes in **Figures 2 and 4**, as well as **Figures 3 and 5**. The aim was to investigate if there is a correlation between the number of shared patents and the citation z-scores, of every two technological domains. In this analysis, only off-diagonal cells are considered. The estimated Pearson Correlation Coefficients were 0.13 for the major technological domains (**Figures 2 and 4**), and 0.5 for the CCS subdomains (**Figures 3 and 5**). Therefore, it can be concluded that the more granular classification of patents has resulted in a higher degree of consistency between the patent co-classification and citation relationship.

In the second analysis, the data matrix of **Figure 4** is further analysed by removing the patents found in more than one domain. This analysis enables disentangling the impact of various domain intersections and co-classification of patents. We now observe a large share of citations from the “non-CO_2 GHG capture and disposal” to the “CO_2 capture and storage” domain and from the “Combined combustion” domain to the “more efficient combustion domain” (see left figure below). All other non-diagonal cells report very low shares (<6%). However, when we normalize the shared citations as z-scores given the size of each domain, we now observe many more cells with positive z-scores (right figure below). If we focus on “CO_2 capture and storage”, we see that this domain has 25% of its patents in common with “Combined combustion”, and 6% each with “non-CO_2 GHG capture and with “more efficient combustion” (see **Figure 2** in the original manuscript). **Figure 4** in the original manuscript tells us that the improvements in the “CO_2 capture” domain benefit the most from prior inventions in the “non-CO_2 GHG capture” domain (in addition to benefiting from prior inventions in the same domain). However, if we now remove overlapping patents, we see that the z-score of citations from “CO_2 capture” to “non-CO_2 GHG capture” drops to negative. This means that the patents that mostly built on “non-CO_2 GHG capture” patents were those co-classified with the “Combined combustion”, “non-CO_2 GHG capture”, or “Efficient combustion” domains. The unique CO_2 capture patents interact more with (themselves) and with two combustion-related domains. A similar observation was made when we looked at the “non-CO_2 GHG capture” domain. The major overlap here was with the “CO_2 capture” domain (20% of patents co-classified) and the strongest z-score of citations to other domains was with this same domain. After removing all overlaps, we observed that 30% of the citations from the “non-CO_2 GHG capture” unique patents still go to the “CO_2 capture” patents. However, the z-score is negative, and it suggests that unique “non-CO_2 GHG capture” patents interact more with the two combustion-related domains. Investigating these last two domains suggests that their unique patents interact more with each other than expected (the z-scores of citations between them are positive).

In summary, the comparison of changes in **Figure 4** (original manuscript) when we remove overlapping patents as suggested by the reviewer does reveal interesting changes in the interaction with prior inventions. However, co-classification is an inherent property of the patents investigated in this research, and illustrates the permeable boundaries between the underlying knowledge bodies, and how these technologies have evolved. Often the same technology is co-classified in several groups. This is not best understood as a mistake by the examiners, but rather a revealing fact about the relatedness between the two technologies. Therefore, the co-classified patents should not be simply removed from the analysis.

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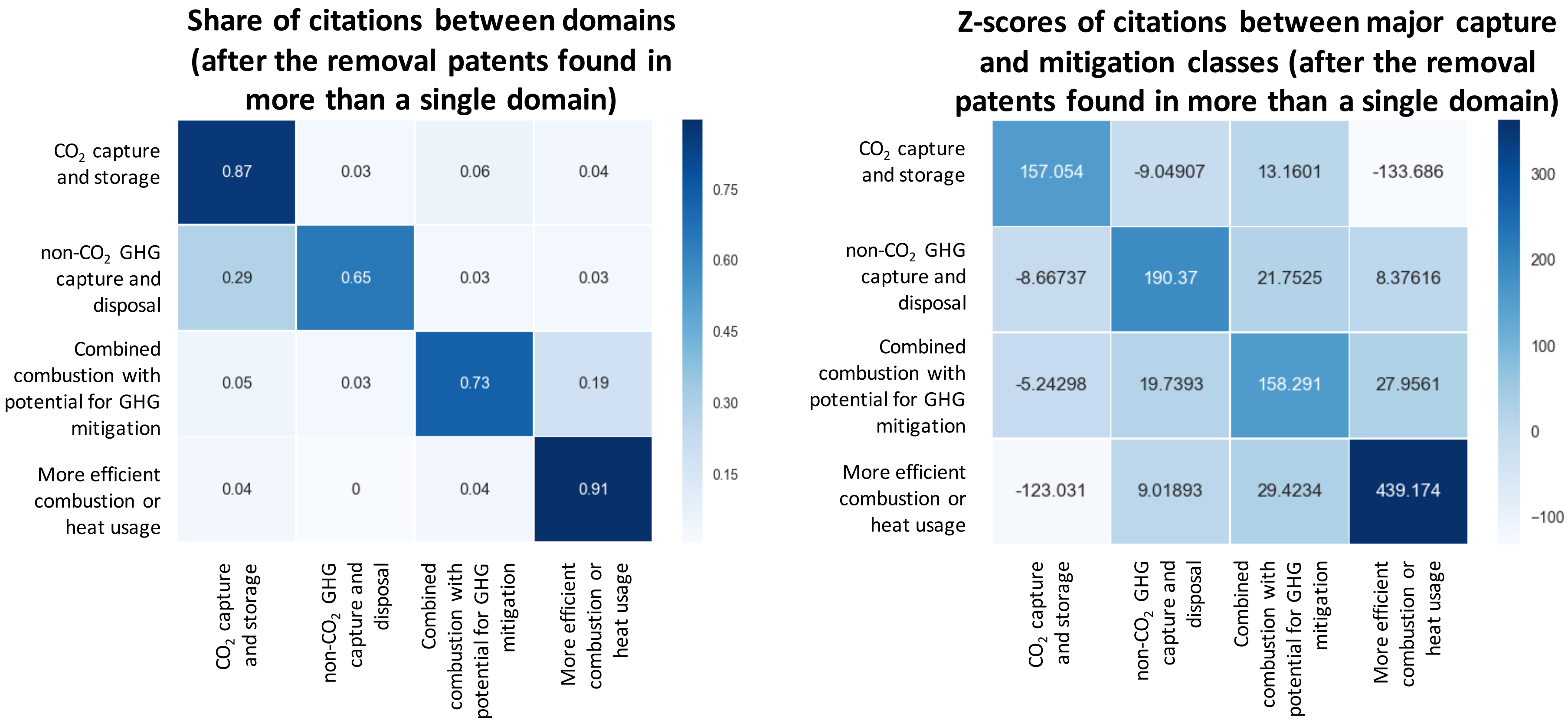

Figure S1. (a) the share of citations, and (b) the corresponding z-scores between major domains when the patents present in other domains are removed. These figures are comparable with **Figure 4** in the original manuscript, where all the patents in each domain were considered.

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As mentioned earlier, the common technical knowledge that explains the interactions between subdomains are measured by the citation z-score. In Figure 4, there are only two positive off-diagonal z-scores corresponding to the “CO_2 capture and storage” and “non-CO_2 GHG capture and disposal” domains. To further investigate this shared knowledge, in the third analysis, the top 30 patents from the “CO_2 capture and storage” domain that are most cited by the patents in the “non-CO_2 GHG capture and disposal” domains are shown in **Table S14**, and discussed in the following. Similar analysis is presented for **Table S15** regarding the top 30 patents from the “non-CO_2 GHG capture and disposal” domain, which are most cited by the patents in the “CO_2 capture and storage” domain.

Investigating **Table S14** suggests that most of the CCS patents highly cited by non-CO2 GHG capture and disposal refer to inventions in which CO_2 is mixed with other gases especially non-CO_2 GHGs including methane in the form of natural gas mixture or landfill gases (7699914, 8800671, 8529666, 8388747, 8007571, 8118915, 7883569, 5938819, 7806965), carbon monoxide (7524358), hydrogen (8551217, 8491704), urea (8071037), or atmosphere (9205372, 8246723, 8221527, 9108145, 7993432, 8734571, 6106593). Mixtures of methane and carbon dioxide are separated using adsorption or cryogenic fractionation. Hydrogen and carbon monoxide are often separated using adsorption. The method of treating urea is conversion to ammonia. Other shared bodies of knowledge refer to process equipment, devices and materials which are presented in the most general form and less restricted to a specific application. Examples include various configurations of adsorbers (6723155, 5106396, 8808426, 5026406), rotatory fluid processing (8852328), or adsorbent materials (9126139, 7524358, 8858685, 8679231).

Similar patterns are observed in **Table S15**. Inventions reported in Patents 5906673, 8551217, 8491704, 8435328, 6210466, 6610124, 9162175, 8673059, 8906138, 8784534, 6565628, 5042995, 8808426, 8852322, and 8858683 discuss various adsorption-based process systems. Invention in Patent 7569193 reports a two-stage reactor system for controlled combustion of gaseous pollutants. Invention in Patent 9186650 reports an adsorbant selective toward CO_2. In some other inventions (5792239, 5536300, 8921637, 9034079, 7828877) natural gas is being sweetened and purified from a mixture containing carbon dioxide and nitrogen. Inventions in Patents 5234472 and 5669960 are concerned with the separation from syngas. Invention in Patents 9168485, and 8241400 report separation from a hydrocarbon mixture. Patents 7927573 and 9005561 report separation of SO_2 and H_2S from carbon dioxide. Several key observations can be made. Firstly, some of the shared bodies of knowledge are focused on applications in which CO_2 and other gases are also physically mixed. Secondly, the knowledge can be shared with respect to processes which are capable of treatment and separation of multiple gases for a range of applications. Finally, some of the most cited patents (e.g. 9186650, 8491704) are co-classified. In other words, not only they share a significant body of knowledge, but also their contributions are recognized by the inventions in both domains.

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Table S14. The top 30 patents in the "CO_2 capture and storage" domain, cited by the "non-CO_2 GHG capture and disposal" domain.

	Patent number	**Domain cited**	**Count ***	**Domain citing**	**Title**	**Abstract**
1	8071037	CO_2 capture and storage	70	non-CO_2 GHG capture and disposal	Catalytic devices for converting urea to ammonia	Described are apparatuses, systems, and methods for treating exhaust. The described apparatus and systems typically include a catalytic device for converting aqueous urea to ammonia. The catalytic device may include a pyrolysis catalyst and a hydrolysis catalyst for converting aqueous urea to ammonia. The catalytic device typically includes an upstream face that is positioned at an angle relative to exhaust flow when the device is positioned in a selective catalytic reduction (SCR) system.
2	9205372	CO_2 capture and storage	60	non-CO_2 GHG capture and disposal	Air collector with functionalized ion exchange membrane for capturing ambient CO2	An apparatus for capture of CO2 from the atmosphere comprising an anion exchange material formed in a matrix exposed to a flow of the air.
3	8551217	CO_2 capture and storage	49	non-CO_2 GHG capture and disposal	Six bed pressure swing adsorption process operating in normal and turndown modes	The present invention relates to a six bed pressure swing adsorption (PSA) system utilizing new and advanced cycles to obtain enhanced hydrogen recovery from a hydrogen containing feed gas (i.e., synthesis gas). In one such cycle each of the six beds has four pressure equalization steps, and at least one of the beds is receiving and processing said feed gas to obtain a hydrogen product gas (i.e., a 6-1-4 cycle).
4	8491704	CO_2 capture and storage	49	non-CO_2 GHG capture and disposal	Six bed pressure swing adsorption process operating in normal and turndown modes	The present invention relates to a six bed pressure swing adsorption (PSA) system utilizing new and advanced cycles to obtain enhanced hydrogen recovery from a hydrogen containing feed gas (i.e., synthesis gas). In one such cycle each of the six beds has four pressure equalization steps, and at least one of the beds is receiving and processing said feed gas to obtain a hydrogen product gas (i.e., a 6-1-4 cycle).
5	8246723	CO_2 capture and storage	40	non-CO_2 GHG capture and disposal	Air collector with functionalized ion exchange membrane for capturing ambient CO2	An apparatus for capture of CO2 from the atmosphere comprising an anion exchange material formed in a matrix exposed to a flow of the air.
6	8221527	CO_2 capture and storage	40	non-CO_2 GHG capture and disposal	Air collector with functionalized ion exchange membrane for capturing ambient CO2	An apparatus for capture of CO2 from the atmosphere comprising an anion exchange material formed in a matrix exposed to a flow of the air.
7	7699914	CO_2 capture and storage	31	non-CO_2 GHG capture and disposal	Triple-effect absorption system for recovering methane gas	A method of using a triple-effect absorption system to recover methane from landfill gas contaminated with CO2 and trace contaminates such as chlorinated hydrocarbons and aromatics involves processing the landfill gas with three absorbers and a flash system. One absorber uses a solvent to absorb the trace contaminants from the landfill gas, the second absorber in conjunction with the flash system extracts CO2 from the gas, and just a first portion of that CO2 is used for stripping the trace contaminates from the solvent in the third absorber. The rest of the extracted CO2 is vented to atmosphere to prevent dampening the combustion of the trace contaminants absorbed by the first portion of CO2.
8	8800671	CO_2 capture and storage	24	non-CO_2 GHG capture and disposal	System for separating a waste material from a produced gas and injecting the waste material into a well	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.
9	8529666	CO_2 capture and storage	20	non-CO_2 GHG capture and disposal	System for dehydrating and cooling a produced gas to remove natural	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is

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					gas liquids and waste liquids	pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.
10	8388747	CO_2 capture and storage	19	non-CO_2 GHG capture and disposal	System for separating a waste material and hydrocarbon gas from a produced gas and injecting the waste material into a well	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.
11	9108145	CO_2 capture and storage	18	non-CO_2 GHG capture and disposal	Purification of air	Process of reducing water, CO2 and N2O in feed air, which: a first adsorbent such as alumina (25-40% volume) and a second adsorbent such as X zeolite (60-75% volume) are used; the online time of the adsorbent is determined by determining the concentration measured by an analyzer for CO2 concentration at a position within the length of the second adsorbent when a maximum level of N2O is simultaneously obtained at the downstream end of the second adsorbent in the feed direction, wherein the online time is the time taken from commencing passing the feed air to the first and second adsorbents to the measurement by the analyzer of the determined concentration of CO2; at least the second adsorbent is regenerated by heated regeneration gas at a temperature of 140Â° C.-220Â° C.; and the molar ratio of the regenerating gas to feed air supplied during one iteration of the cycle is 0.08-0.5.
12	6723155	CO_2 capture and storage	18	non-CO_2 GHG capture and disposal	Purification of gas streams	A method for removing a first and a second minor component from a gas mixture comprising the first and second minor components and one or more major components. The method comprises providing a first adsorbent zone containing a first adsorbent material and a second adsorbent zone containing a second adsorbent material wherein the selectivity of the first adsorbent material for the first minor component relative to the second minor component is greater than the selectivity of the second adsorbent material for the first minor component relative to the second minor component. The average particle diameter of the first adsorbent material and the average particle diameter of the second adsorbent material preferably are substantially the same. The gas mixture is passed through the first adsorbent zone and subsequently through the second adsorbent zone. A purified gas containing the one or more major components and depleted in the first and second minor component is withdrawn from the second adsorbent zone.

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13	7993432	CO_2 capture and storage	18	non-CO_2 GHG capture and disposal	Air collector with functionalized ion exchange membrane for capturing ambient CO2	An apparatus for capture of CO2 from the atmosphere comprising an anion exchange material formed in a matrix exposed to a flow of the air.
14	8007571	CO_2 capture and storage	15	non-CO_2 GHG capture and disposal	System for separating a waste liquid from a produced gas and injecting the waste liquid into a well	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.
15	8734571	CO_2 capture and storage	15	non-CO_2 GHG capture and disposal	Purification of air	Reduction of water, CO2 and N2O in an air stream comprising: passing said air stream at a feed temperature through a first adsorbent, whose Henry's Law selectivity for CO2/N2O is at least 12.5, and a second adsorbent, whose Henry's Law constant for CO2 is less than 1020 mmol/g/atom and whose Henry's Law selectivity for CO2/N2O is at most 5; and passing a heated regenerating gas at a temperature which is between 20Â° C. and 80Â° C. to at least the second adsorbent, and passing a second regenerating gas at a temperature less than the temperature of the heated regenerating gas to the first and second adsorbents in a direction opposite to the feed direction; the second adsorbent occupying from 25% to 40% of the total volume of the adsorbents, and the temperature of the heated regenerating gas being 10Â° C. to 60Â° C. higher than the feed temperature.
16	6106593	CO_2 capture and storage	15	non-CO_2 GHG capture and disposal	Purification of air	Carbon dioxide, water, nitrous oxide and optionally ethylene are removed from a feed air stream by a temperature swing adsorption using a first adsorbent such as alumina to adsorb water, a second adsorbent such as 13X zeolite to adsorb carbon dioxide, and a third adsorbent such as binderless calcium exchanged X zeolite to adsorb nitrous oxide and optionally ethylene, prior to cryogenic separation of the purified air stream.
17	8118915	CO_2 capture and storage	15	non-CO_2 GHG capture and disposal	System for separating carbon dioxide and hydrocarbon gas from a produced gas combined with nitrogen	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.

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18	5106396	CO_2 capture and storage	15	non-CO_2 GHG capture and disposal	Adsorption processes with intermediate product recovery using two adsorption zones	Adsorption processes are provided for the separation of a feedstream containing less readily, intermediately, and more readily adsorbable components using first and second adsorption zones. The second adsorption zone utilizes a cycle that includes a cocurrent displacement step and the intermediately adsorbable components are recovered therefrom by countercurrent depressurization. The first adsorption zone is purged with a stream from the second adsorption zone to recover the more readily adsorbable components. The processes are particularly suitable for recovering carbon monoxide from feedstreams containing hydrogen, carbon monoxide and other compounds such as methanol and higher alcohols, methane, dimethyl ether, dimethyl ketone, water, carbon dioxide, oxygen and mixtures thereof. The processes are particularly applicable to methanol reforming processes wherein hydrogen and carbon monoxide product streams are recovered from a methanol reactor effluent stream also containing components selected from methanol, methane, dimethyl ether, carbon dioxide, oxygen and water.
19	9126139	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Carbon adsorbent for hydrogen sulfide removal from gases containing same, and regeneration of adsorbent	A durable carbon pyrolyzate adsorbent having reversible sorptive affinity for hydrogen sulfide, and including the following characteristics: (a) a bulk density as measured by ASTM D2854 in a range of from 0.55 g/cc adsorbent to 1.25 g/cc adsorbent; (b) an H2S capacity in a range of from 140 cc H2S/g adsorbent to 250 cc H2S/g adsorbent, at normal conditions (1 atm, 293.15Â° K); (c) an H2S capacity in a range of from 1.0 cc H2S/g adsorbent to 15.0 cc H2S/g adsorbent, at partial pressure of 0.76 torr (101.3 Pa) (1000 ppm) of H2S at 293.15Â° K; and (d) a single pellet radial crush strength in a range of from 7 kilopond (kP) to 40 kilopond (kP) as measured by ASTM D4179. Such adsorbent is usefully employed for capture of hydrogen sulfide from gases containing same, such as H2S-containing gas associated with flowable hydrocarbonaceous material in refining operations, biogas produced by biomass digesters, gas mixtures produced by fluid catalytic cracking (FCC) units, and effluents from power plants gasifying sulfur-containing coal in an integrated gasification combined cycle (IGCC) process.
20	6719827	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Process for nitrous oxide removal	The present invention relates to a process and apparatus for the removal of nitrous oxide from a feed gas stream using an adsorbent having a nitrogen diffusion parameter of 0.12 sec−1 or higher and a nitrous oxide capacity of 79 mmol/g/atm or higher at 30° C.
21	6660064	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Activated carbon as sole absorbent in rapid cycle hydrogen PSA	A pressure swing adsorption process for recovering a product gas from a feed gas, includes: supplying a pressure swing adsorption apparatus including an adsorbent composition containing activated carbon as a major ingredient, wherein the adsorbent composition and the apparatus are substantially free of zeolite adsorbents; feeding a feed gas into the pressure swing adsorption apparatus during a feed period not exceeding 20 seconds; and recovering the product gas from the pressure swing adsorption apparatus. The process and apparatus are particularly suitable for use with fuel cells and other applications requiring compact, rapid cycling systems for producing high purity hydrogen.
22	7883569	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Natural gas processing system	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas; and the helium is recovered and sold. Excess nitrogen is vented.

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23	7524358	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Production of high purity and ultra-high purity gas	Trace amounts of carbon monoxide and optionally hydrogen are removed from gaseous feed streams by passing the feed stream through a carbon monoxide adsorbent (33) prior to passing it through a supported metal catalyst (34). The invention saves significant capital and operational costs over existing processes.
24	8858685	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Gas storage and dispensing system with monolithic carbon adsorbent	A pyrolyzed monolith carbon physical adsorbent that is characterized by at least one of the following characteristics: (a) a fill density measured for arsine gas at 25Â° C. and pressure of 650 torr that is greater than 400 grams arsine per liter of adsorbent; (b) at least 30% of overall porosity of the adsorbent including slit-shaped pores having a size in a range of from about 0.3 to about 0.72 nanometer, and at least 20% of the overall porosity including micropores of diameter <2 nanometers; and (c) having a bulk density of from about 0.80 to about 2.0 grams per cubic centimeter, preferably from 0.9 to 2.0 grams per cubic centimeter.
25	8852328	CO_2 capture and storage	14	non-CO_2 GHG capture and disposal	Rotary fluid processing systems and associated methods	Rotary fluid processing systems and associated methods are disclosed. A purification system in accordance with the particular embodiment includes a rotatable adsorbent-containing heat/mass transfer element that is generally symmetric about a rotation axis, and includes multiple radial flow paths oriented transverse to the rotation axis and multiple axial flow paths oriented transverse to the radial flow paths. The axial flow paths and radial flow paths are in thermal communication with each other, and are generally isolated from fluid communication with each other at the heat transfer element. Particular embodiments can further include a housing arrangement having multiple manifolds with individual manifolds having an entry port and an exit port, and with individual manifolds having different circumferential locations relative to the rotation axis. Still further embodiments can include a seal arrangement positioned between the heat transfer element and the housing arrangement to expose the radial flow paths, but not the axial flow paths, to the entry and exit ports of one of the manifolds, and expose the axial flow paths, but not the radial flow paths, to the entry and exit ports of another of the manifolds.
26	5938819	CO_2 capture and storage	13	non-CO_2 GHG capture and disposal	Bulk separation of carbon dioxide from methane using natural clinoptilolite	Bulk separation of carbon dioxide from methane is accomplished using a modified pressure swing adsorption system where the adsorbent used is a naturally occurring sodium-rich clinoptilolite. Most of the carbon dioxide can be removed at low operating pressures, and the principal agent of regeneration is a high volume air rinse rather than pressure reduction.
27	8808426	CO_2 capture and storage	13	non-CO_2 GHG capture and disposal	Increasing scales, capacities, and/or efficiencies in swing adsorption processes with hydrocarbon gas feeds	The invention relates to an increased efficiency high-capacity pressure and/or temperature swing adsorption process comprising: contacting a feedstream at a rate of more than 75 MSCFD with an adsorbent material under conditions sufficient for the adsorbent material to selectively adsorb at least one of the component gases in the feedstream, so as to form a first effluent; and selectively desorbing the adsorbed gas from the adsorption material, so as to form a second effluent The adsorption module can contain rotary valves both on the feed end and on the product end and a rotational member defining a central rotational axis, with the adsorption bed(s) oriented circumferentially thereto. The adsorption bed walls can be angled, the feed end cross-sectional area of the adsorption bed(s) can be larger than the product end, and/or the feed end rotary valve diameter of the module(s) can be larger than the product end.
28	5026406	CO_2 capture and storage	13	non-CO_2 GHG capture and disposal	Adsorptive process for producing two gas streams from a gas mixture	An adsorptive separation process is set forth for recovery of two gas products in high recovery and high purity using adsorptive, depressurization low pressure purge, evacuation and repressurization. Depressurization and purge effluents are recycled to feed and optionally pressure equalizations are performed after the adsorption and after the evacuation as well as a pressure equalization using the low pressure purge effluent.

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29	8679231	CO_2 capture and storage	13	non-CO_2 GHG capture and disposal	PVDF pyrolyzate adsorbent and gas storage and dispensing system utilizing same	A polyvinylidene fluoride (PVDF) pyrolyzate adsorbent is described, having utility for storing gases in an adsorbed state, and from which adsorbed gas may be desorbed to supply same for use. The PVDF pyrolyzate adsorbent can be of monolithic unitary form, or in a bead, powder, film, particulate or other finely divided form. The adsorbent is particularly suited for storage and supply of fluorine-containing gases, such as fluorine gas, nitrogen trifluoride, carbo-fluoride gases, and the like. The adsorbent may be utilized in a gas storage and dispensing system, in which the adsorbent is contained in a supply vessel, from which sorbate gas can be selectively dispensed.
30	7806965	CO_2 capture and storage	13	non-CO_2 GHG capture and disposal	System for separating carbon dioxide from a produced gas with a methanol removal system	Produced natural gas containing carbon dioxide is dehydrated and chilled to liquefy the carbon dioxide and then fractionated to produce a waste stream of liquid carbon dioxide and hydrogen sulfide. Natural gas liquids may be first separated and removed before fractionation. After fractionation, the waste stream is pressurized and transmitted to a remote injection well for injection either for disposal of the waste stream and preferably to urge hydrocarbons toward the producing well. A hydrocarbon stream proceeds from fractionation to a methanol absorber system which removes carbon dioxide gas. The hydrocarbon stream is thereafter separated into at least hydrocarbon gas, nitrogen and helium. Some of the nitrogen is reintroduced into a fractionation tower to enhance the recovery of hydrocarbons. A methanol recovery system is provided to recover and reuse the methanol. The hydrocarbons are sold as natural gas and the helium is recovered and sold. Excess nitrogen is vented.

* the number of citations made by the patent listed in the "citing domain", directed to patents belonging to the “cited domain”.

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Table S15. The top 30 patents in the "non-CO_2 GHG capture and disposal" domain cited by the "CO_2 capture and storage" domain.

	Patent number	**Domain cited**	**Count***	**Domain citing**	**Title**	**Abstract**
1	5906673	non-CO_2 GHG capture and disposal	27	CO_2 capture and storage	Pressure swing system with auxiliary adsorbent bed	The invention is a pressure swing adsorption system. The pressure swing adsorption system has a plurality of primary adsorbent beds and at least one secondary adsorbent bed. The feed gas stream is flowed to a primary adsorbent bed loaded with an adsorbent that will preferentially adsorb certain components in the feed gas. Non-preferentially adsorbed components flow from the adsorbent bed during this time. Upon saturation of the adsorbent with the adsorbed components, the flow of feed gas is ceased. The adsorbent is fully loaded with the preferentially adsorbed component and there is feed gas in the void space between the adsorbent particles. This primary adsorbent bed undergoes regeneration by partial depressurization through the secondary adsorbent bed followed by a complete depressurization to a final lower pressure. There can be two or more primary adsorbent beds and there will be at least one secondary adsorbent bed. The preferred separation is the separation of carbon dioxide from a hydrocarbon containing stream.
2	5792239	non-CO_2 GHG capture and disposal	24	CO_2 capture and storage	Separation of gases by pressure swing adsorption	A natural gas feed stream containing significant quantities of nitrogen and/or carbon dioxide can be increased to a content of greater than 95 percent by volume of natural gas, and preferably greater than about 98 percent, by passing the natural gas feed stream sequentially through three adsorbent beds that are cycled through seven phases comprising: an adsorption phase to adsorb a first gas, a first depressurization phase to remove feed gas from the voids in the adsorbent bed, a recycle phase to remove a second gas from the adsorbent by the passage of a second depressurization gas therethrough and to produce a recycle gas, a second depressurization phase to reduce the adsorbent bed pressure to about ambient and to produce the second depressurization gas, an evacuation phase where the pressure in the adsorbent is further reduced and an enriched primary gas product stream recovered, a pressurization phase where the pressure in the adsorbent bed is increased using secondary product gas from a bed in an adsorption phase, and further pressurizing the adsorbent bed in a pressurization phase by the flow of the recycle gas and feed gas into the adsorbent bed. Various gases can be separated using this process. Nitrogen can be removed from natural gas (adsorbed gas) and carbon dioxide (adsorbed gas) can be removed from natural gas.
3	7569193	non-CO_2 GHG capture and disposal	22	CO_2 capture and storage	Apparatus and method for controlled combustion of gaseous pollutants	The present invention relates to systems and methods for controlled combustion of gaseous pollutants while reducing and removing deposition of unwanted reaction products from within the treatment systems. The systems employ a two-stage thermal reactor having an upper thermal reactor including at least one inlet for mixing a gaseous waste stream with oxidants and combustible fuels for thermal combustion within the upper thermal reactor. The upper thermal reactor further includes a double wall structure having an outer exterior wall and an interior porous wall that defines an interior space for holding a fluid and ejecting same, in a pulsating mode, through the interior porous wall into the upper thermal reactor to reduce deposition of the reaction products on the interior of the upper reactor chamber. The two-stage thermal reactor further includes a lower reactor chamber for flowing reaction products formed in the upper thermal reactor through a water vortex that provides a water overflow along the interior of the lower reactor chamber thereby reducing deposition of unwanted products on the interior surface of the lower reactor.
4	8551217	non-CO_2 GHG capture and disposal	18	CO_2 capture and storage	Six bed pressure swing adsorption process operating in normal and turndown modes	The present invention relates to a six bed pressure swing adsorption (PSA) system utilizing new and advanced cycles to obtain enhanced hydrogen recovery from a hydrogen containing feed gas (i.e., synthesis gas). In one such cycle each of the six beds has four pressure equalization steps, and at least one of the beds is receiving and processing said feed gas to obtain a hydrogen product gas (i.e., a 6-1-4 cycle).
5	8491704	non-CO_2 GHG capture and disposal	18	CO_2 capture and storage	Six bed pressure swing adsorption process operating in normal and turndown modes	The present invention relates to a six bed pressure swing adsorption (PSA) system utilizing new and advanced cycles to obtain enhanced hydrogen recovery from a hydrogen containing feed gas (i.e., synthesis gas). In one such cycle each of the six beds has four pressure equalization steps, and at least one of the beds is receiving and processing said feed gas to obtain a hydrogen product gas (i.e., a 6-1-4 cycle).
6	8435328	non-CO_2 GHG capture and disposal	18	CO_2 capture and storage	Ten bed pressure swing adsorption process	The present invention relates to a ten bed pressure swing adsorption (PSA) system utilizing new and advanced cycles to obtain enhanced hydrogen recovery from a hydrogen containing feed gas (i.e., synthesis gas). More specifically, through the newly developed process cycles, the ten bed PSA system is capable of matching the

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					operating in normal and turndown modes	hydrogen recovery of conventional twelve bed PSA systems designed to manufacture 100 million standard cubic feet per day of gas.
7	6210466	non-CO_2 GHG capture and disposal	12	CO_2 capture and storage	Very large-scale pressure swing adsorption processes	According to the present invention, a process is provided which overcomes historical limitations to the capacity of PSA units for a wide variety of gas separations. Capacities in excess of about 110 thousand normal cubic meters per hour (100 million standard cubic feet per day) can now be achieved in a single integrated process train. The corresponding significant equipment reduction results from a departure from the accepted principle in the PSA arts that the length of the purge step must be equal to or less than the length of the adsorption step. Applicants have discovered that by increasing the purge time relative to the adsorption step combined with supplying the purge gas for any adsorption bed in the train from one or more other adsorption beds and during the provide-purge step, the other adsorption beds simultaneously provide the purge gas to essentially all adsorption beds undergoing the purge step, that the single train can provide for significant increases in capacity with a minimum loss in recovery or performance. The benefit of this discovery is that very large-scale PSA units can now be constructed as a single train of equipment for a cost significantly lower than the cost of two or more parallel trains of equipment.
8	8535417	non-CO_2 GHG capture and disposal	12	CO_2 capture and storage	Recovery of carbon dioxide from flue gas	Carbon dioxide-containing gas such as flue gas and a carbon dioxide-rich stream are compressed and the combined streams are then treated to desorb moisture onto adsorbent beds and then subjected to subambient-temperature processing to produce a carbon dioxide product stream and a vent stream. The vent stream is treated to produce a carbon dioxide-depleted stream which can be used to desorb moisture from the beds, and a carbon dioxide-rich stream which is combined with the carbon dioxide-containing gas.
9	6610124	non-CO_2 GHG capture and disposal	12	CO_2 capture and storage	Heavy hydrocarbon recovery from pressure swing adsorption unit tail gas	A pressure swing adsorption process for the separation of impurities such as nitrogen and carbon dioxide and recovery of hydrocarbons from a natural gas stream utilizes two separate adsorption systems, the first containing an adsorbent selective for nitrogen, carbon dioxide or both and the second containing a hydrocarbon-selective adsorbent. In the process, the natural gas stream is passed through a first adsorbent to form a product stream enriched with methane and to adsorb nitrogen and/or carbon dioxide and which further co-adsorbs at least a portion of the hydrocarbons contained in the feed stream. The hydrocarbons are recovered by passing a low pressure waste stream from the first pressure swing adsorption stage which contains co-adsorbed nitrogen and/or carbon dioxide and hydrocarbons and directing the waste stream to the second pressure swing adsorption stage to adsorb the hydrocarbons and produce a product stream enriched in nitrogen and/or carbon dioxide. The hydrocarbons are recovered from the hydrocarbon-selective adsorbent by an intermediate pressure methane-containing stream from the first pressure swing adsorption stage which purges the adsorbent in the second stage and forms a combined stream comprising methane and C3+ hydrocarbons. The C3+ hydrocarbons can be separated from the methane such as by compression with flash separation or refrigeration.
10	5536300	non-CO_2 GHG capture and disposal	11	CO_2 capture and storage	Natural gas enrichment process	A natural gas feed stream containing significant quantities of nitrogen can be increased to a content of greater than 95 percent by volume of natural gas, and preferably greater than about 98 percent, by passing the natural gas feed stream sequentially through at least four adsorbent beds which are cycled through six phases comprising an adsorption phase to adsorb natural gas, a recycle phase to remove feed gas from the voids in the adsorbent bed and nitrogen from the adsorbent by the passage of a depressurization gas therethrough to produce a recycle gas, a depressurization phase to reduce the adsorbent bed pressure to about ambient and to produce the depressurization gas, an evacuation phase where the pressure in the adsorbent is further reduced and an enriched natural gas product stream recovered, a pressurization phase where the pressure in the adsorbent bed is increased using nitrogen gas from a bed in an adsorption phase, and further pressurizing the adsorbent bed in a recycle feed pressurization phase by the flow of the recycle gas therein.
11	5234472	non-CO_2 GHG capture and disposal	11	CO_2 capture and storage	Separation of gas mixtures including hydrogen	A process for separation of a gas mixture containing three components, e.g. a mixture comprising hydrogen, carbon monoxide and carbon dioxide produced by steam reforming a hydrocarbon, by pressure swing adsorption is disclosed. In one embodiment of the process, the gas mixture is sequentially passed through first and second adsorptive regions each of which adsorbs a second component more strongly than a first component but less strongly than a third component, a first fraction enriched in the first component is withdrawn from the downstream end of the second region, introduction of gas mixture to the first region is stopped and the second

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						region is closed to the first region, a second fraction enriched in the second component is withdrawn first from the upstream end of the second adsorptive region while passing gas mixture enriched in the third component into the first region from its upstream end and then from the downstream end of the first region, and withdrawing a third fraction enriched in the third component from the upstream end of the first region. The separation process is also applicable to other gas mixtures such as a mixture of hydrogen, argon, methane and nitrogen commonly available as ammonia plant purge gas from which ammonia has been removed.
12	9168485	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Methods of removing contaminants from a hydrocarbon stream by swing adsorption and related apparatus and systems	A swing adsorption process for removing contaminants from a gaseous feed stream through a combination of a selective adsorbent material containing an effective amount of a non-adsorbent filler, adsorbent contactor design, and adsorption cycle design.
13	8921637	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Kinetic fractionators, and cycling processes for fractionation of gas mixtures	A process for separating methane from a natural gas mixture employs pressure swing adsorption in one or more vessels. Each vessel has an adsorbent material having a kinetic selectivity for contaminants over methane greater than 5. Contaminants within the natural gas mixture become gases kinetically adsorbed within the adsorbent material. The vessel is placed under pressure to cause contaminants to be adsorbed in the surfaces and micro-pores of the adsorbent material. The process includes releasing a product stream comprised at least 95% by volume methane from a first gas outlet in the vessel, and desorbing the contaminant gases from the adsorbent material by reducing the pressure within the vessel. The desorbing step is done without applying heat to the vessel, thereby delivering a waste gas stream comprised at least 95% by volume of the contaminant gases. An improved fractionation vessel having both major and minor flow channels is also provided.
14	8241400	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Process for the production of carbon dioxide utilizing a co-purge pressure swing adsorption unit	The present invention provides a process for recovering gaseous hydrogen and gaseous carbon dioxide from a mixture of hydrocarbons by utilizing a system that includes a reformer unit, an optional water gas shift reactor, and a pressure swing adsorption unit in conjunction with a carbon dioxide purification unit such as a cryogenic purification unit or a catalytic oxidizer. In this process, purified CO2 from the CO2 purification unit is used as a co-feed/co-purge in the pressure swing adsorption unit in order to produce a CO2 tail gas that includes a higher concentration of CO2.
15	9162175	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Apparatus and systems having compact configuration multiple swing adsorption beds and methods related thereto	A compact configuration for a plurality of swing adsorption beds. The beds are configured within a single vessel such that one or more beds of adsorbent material are position as successive rings about a first, or core, bed of adsorbent material.
16	7927573	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Multi-stage process for purifying carbon dioxide and producing acid	Carbon dioxide is purified by processes employing NOx-rich sulfuric acid that can be formed by removal of SO2 from the carbon dioxide.
17	5669960	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Hydrogen generation process	A process for the production of hydrogen that purifies a synthesis gas stream, containing hydrogen, carbon monoxide and combustibles, in a PSA unit. The PSA unit produces at least three streams: a substantially pure hydrogen product stream, a combustible-rich first tail-gas stream, and a carbon dioxide-rich second tail gas stream.
18	9034079	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Methods of removing contaminants from hydrocarbon stream by swing adsorption and related apparatus and systems	A pressure swing adsorption process for removal of CO2 from natural gas streams through a combination of a selective adsorbent material containing an effective amount of a non-adsorbent filler, adsorbent contactor design, and adsorption cycle design. The removal of contaminants from gas streams, preferably natural gas streams, using rapid-cycle swing adsorption processes, such as rapid-cycle pressure swing adsorption (RC-PSA). Separations at high pressure with high product recovery and/or high product purity are provided through a combination of judicious choices of adsorbent material, gas-solid contactor, system configuration, and cycle designs. For example, cycle designs that include steps of purge and staged blow-down as well as the inclusion of a mesopore filler in the adsorbent material significantly improves product (e.g., methane) recovery. An RC-

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						PSA product with less than 10 ppm H2S can be produced from a natural gas feed stream that contains less than 1 mole percent H2S.
19	9186650	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Adsorbent having utility for CO2 capture from gas mixtures	A carbon pyrolyzate adsorbent is described that is selective for carbon dioxide in contact with gas mixtures including carbon dioxide and methane. The adsorbent has a carbon dioxide adsorbent capacity at 1 bar pressure of greater than 50 cm3 carbon dioxide per gram of adsorbent at 273K, a methane adsorption capacity at 1 bar pressure of less than 35 cm3 methane per gram of adsorbent at 21Â° C., and a bulk density of greater than 0.55 gram per cubic centimeter of volume. Such adsorbent can be utilized, for example, for biogas upgrading, natural gas purification, coal bed methane purification, and refining operations.
20	7828877	non-CO_2 GHG capture and disposal	10	CO_2 capture and storage	Separation of carbon dioxide from other gases	An inventive adsorptive gas separation process is provided capable of producing a purified methane product gas as a light non-adsorbed product gas as opposed to a heavy desorbed exhaust gas component, from a feed gas mixture comprising at least methane, and carbon dioxide. In an embodiment of the invention, the feed gas mixture may comprise at least about 10% carbon dioxide, and the purified methane product gas may be desirably purified to contain less than about 5000 ppm carbon dioxide. In another embodiment of the invention, the feed gas mixture may comprise at least about 50% carbon dioxide, and the purified methane product gas may be desirably purified to contain less than about 5000 ppm carbon dioxide.
21	9005561	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Selective sulfur removal process	A cyclic process for selectively separating hydrogen sulfide from a gas mixture including CO2 is operated by contacting the gas mixture under sorption conditions with a non-aqueous sorbent comprising a basic non-protogenic nitrogenous compound to react the H2S with the basic compound so that the H2S can be sorbed by the compound. The compound containing the sorbed H2S can then be subjected to desorption conditions by which the H2S is desorbed and the sorbent readied for another sorption step in the cycle. The basic nitrogenous compound can be carried on a porous solid sorbent, e.g., a solid oxide such as alumina, silica, silica-alumina, zeolites, or a mesoporous and/or macroporous solid oxide. The process may be operated using a pressure swing, temperature swing, partial pressure swing, purge displacement, or a combination thereof between the sorption and desorption portions of the cycle, preferably in a rapid cycle operation.
22	8673059	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Rapid temperature swing adsorption contactors for gas separation	Novel adsorbent contactors and methods are disclosed herein for use in temperature swing adsorption for gas separation applications, as well as for heat exchange applications.
23	8784533	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Temperature swing adsorption process for the separation of target species from a gas mixture	A temperature swing adsorption process for the removal of a target species, such as an acid gas, from a gas mixture, such as a natural gas stream. Herein, a novel multi-step temperature swing/pressure swing adsorption is utilized to operate while maintaining very high purity levels of contaminant removal from a product stream. The present process is particularly effective and beneficial in removing contaminants such as CO2 and/or H2S from a natural gas at relatively high adsorption pressures (e.g., at least 500 psig) to create product streams of very high purity (i.e., very low contaminant levels).
24	8906138	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Methods of generating and utilizing utility gas	The present application is directed to a method and system for preparing gaseous utility streams from gaseous process streams, nitrogen process streams, and other types of streams. The methods and systems may include at least one swing adsorption process including pressure swing adsorption, temperature swing adsorption, and rapid-cycle adsorption processes to treat gaseous streams for use in dry gas seals of rotating equipment such as compressors, turbines and pumps and for other utilities. The systems and processes of the present disclosure are further applicable to high pressure gaseous streams, for example, up to about 600 bar.
25	8784534	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Pressure-temperature swing adsorption process	A pressure-temperature swing adsorption process for the removal of a target species, such as an acid gas, from a gas mixture, such as a natural gas stream. Herein, a novel multi-step temperature swing/pressure swing adsorption is utilized to operate while maintaining very high purity levels of contaminant removal from a product stream. The present process is particularly effective and beneficial in removing contaminants such as CO2 and/or H2S from a natural gas at high adsorption pressures (e.g., at least 500 psig) to create product streams of very high purity (i.e., very low contaminant levels).
26	6565628	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Pressure swing adsorption process with	A method to reduce the cycle time in a pressure swing adsorption process by reducing the required pressure equalization time in a cycle, thereby reducing the overall cycle time and increasing product recovery per unit of adsorbent used. This reduces the amount of adsorbent required in the beds for a given feed rate while

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					reduced pressure equalization time	continuing to provide product at an acceptable product purity, and has the desirable effect of reducing the capital cost of the process equipment required for a given volumetric production rate.
27	5042995	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Pressure swing adsorption with intermediate product recovery using two adsorption zones	A pressure swing adsorption process is provided for the separation of a feedstream containing less readily, intermediately readily, and more readily adsorbable components using first and second adsorption zones. The second adsorption zone utilizes a cycle that includes a cocurrent displacement step and the intermediately adsorbable components are recovered therefrom by countercurrent depressurization. The first adsorption zone is purged with a stream from the second adsorption zone to recover the more readily adsorbable component. In one aspect of the invention, there is provided a methanol reforming process wherein hydrogen and carbon monoxide product streams are recovered from a methanol reactor effluent stream also containing components selected from methanol, methane, dimethyl ether, carbon dioxide, oxygen and water.
28	8808426	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Increasing scales, capacities, and/or efficiencies in swing adsorption processes with hydrocarbon gas feeds	The invention relates to an increased efficiency high-capacity pressure and/or temperature swing adsorption process comprising: contacting a feedstream at a rate of more than 75 MSCFD with an adsorbent material under conditions sufficient for the adsorbent material to selectively adsorb at least one of the component gases in the feedstream, so as to form a first effluent; and selectively desorbing the adsorbed gas from the adsorption material, so as to form a second effluent The adsorption module can contain rotary valves both on the feed end and on the product end and a rotational member defining a central rotational axis, with the adsorption bed(s) oriented circumferentially thereto. The adsorption bed walls can be angled, the feed end cross-sectional area of the adsorption bed(s) can be larger than the product end, and/or the feed end rotary valve diameter of the module(s) can be larger than the product end.
29	8852322	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Gas purification process utilizing engineered small particle adsorbents	A gas separation process uses a structured particulate bed of adsorbent coated shapes/particles laid down in the bed in an ordered manner to simulate a monolith by providing longitudinally extensive gas passages by which the gas mixture to be separated can access the adsorbent material along the length of the particles. The particles can be laid down either directly in the bed or in locally structured packages/bundles which themselves are similarly oriented such that the bed particles behave similarly to a monolith but without at least some disadvantages. The adsorbent particles can be formed with a solid, non-porous core with the adsorbent formed as a thin, adherent coating on the exposed exterior surface. Particles may be formed as cylinders/hollow shapes to provide ready access to the adsorbent. The separation may be operated as a kinetic or equilibrium controlled process.
30	8858683	non-CO_2 GHG capture and disposal	9	CO_2 capture and storage	Swing adsorption processes utilizing controlled adsorption fronts	A process for reducing the loss of valuable products by improving the overall recovery of a contaminant gas component in swing adsorption processes. The present invention utilizes at least two adsorption beds, in series, with separately controlled cycles to control the adsorption front and optionally to maximize the overall capacity of a swing adsorption process and to improve overall recovery a contaminant gas component from a feed gas mixture.

* the number of citations made by the patent listed in the "citing domain", directed to patents belonging to the “cited domain”.

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In the fourth analysis, the improvement rates of various technological domains were recalculated excluding the patents that can be found in more than a single technological domain. The results are reported in **Tables S16** and **S17** (see below) for both scenarios, suggesting that the ranking and magnitude of differences in the rates across domains do not significantly change. The implication is that the estimation of these rates is not sensitive to removing co-classified patents. This also means that co-classified patents are not much more (or less) central than the other unique patents found in the same domain. The only exception is the £Integrated gasification combined cycle (GCC) combined with carbon capture and storage (CCS)" domain. As discussed in the manuscript, this domain does not represent an independent technological domain. It rather represents the scenario in which the knowledge bodies of the "CO_2 capture" and "combined combustion" are integrated. Therefore, the recalculated improvement rate shows more difference for this domain, when shared patents are ignored. Finally, it is interesting to note that the prediction intervals are shorter after removing co-classified patents, giving a higher confidence in the improvement rates.

In the fifth analysis, for each domain (and sub-domain), all the external CPC (4 digit) classes that they cite are sorted by the share of citations, as reported in **Figure S2**. This analysis provides insights into the impact of the external (other than the four studied domains) technological bases on the improvement rate of these technological domains.

For instance, the two CPC classes that CO_2 capture cites the most are B01D - Separation (23% of citations) and E21B - Earth Drilling (11%). B01D is broadly related to separation technologies. Examples of important subclasses include:

- B01D 3/00 - Distillation or related exchange processes in which liquids are contacted with gaseous media, e.g. stripping
- B01D 5/00 - Condensation of vapours; Recovering volatile solvents by condensation
- B01D 45/00 - Separating dispersed particles from gases or vapours by gravity, inertia, or centrifugal forces
- B01D 47/00 - Separating dispersed particles from gases, air or vapours by liquid as separating agent
- B01D 51/00 - Auxiliary pretreatment of gases or vapours to be cleaned
- B01D 53/00 - Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases, aerosols
- B01D 61/00 - Processes of separation using semi-permeable membranes, e.g. dialysis, osmosis, ultrafiltration; Apparatus, accessories or auxiliary operations specially adapted therefor
- B01D 63/00 - Apparatus in general for separation processes using semi-permeable membranes
- B01D 2311/00 - Details relating to membrane separation process operations and control
- B01D 2315/00 - Details relating to the membrane module operation
- B01D 2317/00 - Membrane module arrangements within a plant or an apparatus
- B01D 2319/00 - Membrane assemblies within one housing
- B01D 2321/00 - Details relating to membrane cleaning, regeneration, sterilization or to the prevention of fouling
- B01D 2323/00 - Details relating to membrane preparation
- B01D 2215/00 - Separating processes involving the treatment of liquids with adsorbents
- B01D 2252/00 - Absorbents, i.e. solvents and liquid materials for gas absorption
- B01D 2253/00 - Adsorbents used in separation treatment of gases and vapours
- B01D 2258/00 - Sources of waste gases
- B01D 2259/00 - Type of treatment

The above subclasses can be clearly mapped to the carbon capture technologies listed in **Table 1** and thus the high relevance of B01D is reasonable.

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Similarly, within the E21B domain, the two subclasses of E21B 43/164 and E21B 43/166 are directly related to CO_2 injection to geological formations.

- E21B 43/164 - Injecting CO2 or carbonated water (in combination with organic material C09K 8/594)
- E21B 43/166 - Injecting a gaseous medium; Injecting a gaseous medium and a liquid medium (CO2 injection E21B 43/164; steam injection E21B 43/24)
- E21B 43/168 - Injecting a gaseous medium

B01D (discussed above) is also the most cited class by non-CO_2 GHG capture and combined combustion. Other relevant subdomains in this class are:

- B01D 2251/00 - Reactants
- B01D 2255/00 - Catalysts
- B01D 2256/00 - Main component in the product gas stream after treatment
- B01D 2257/00 - Components to be removed
- B01D 2258/00 - Sources of waste gases

The other relevant major class that is cited by non-CO_2 GHG capture is B01J which broadly covers the chemical or physical processes, involved in the separation of non-CO_2 GHG through catalysis or colloid chemistry.

The two combustion-related domains both cite C01B and F23G in similar proportions, but they also cite other classes separately, or in different proportions.

The relevant subclasses in the C01B class include:

- C01B 13/00 - Oxygen; Ozone; Oxides or hydroxides in general
- C01B 2203/00 - Integrated processes for the production of hydrogen or synthesis gas
- C01B 2210/00 - Purification or separation of specific gases

The F23G class is concerned with cremation furnaces and consuming waste products by combustion:

- F23G 5/00 - Incineration of waste (of specific waste F23G 7/00); Incinerator constructions; Details, accessories or control therefor
- F23G 7/00 - Incinerators or other apparatus for consuming industrial waste, e.g. chemicals
- F23G 2200/00 - Waste incineration
- F23G 2201/00 - Pretreatment
- F23G 2202/00 - Combustion
- F23G 2203/00 - Furnace arrangements
- F23G 2204/00 - Supplementary heating arrangements
- F23G 2205/00 - Waste feed arrangements
- F23G 2206/00 - Waste heat recuperation
- F23G 2900/00 - Special features of, or arrangements for incinerators

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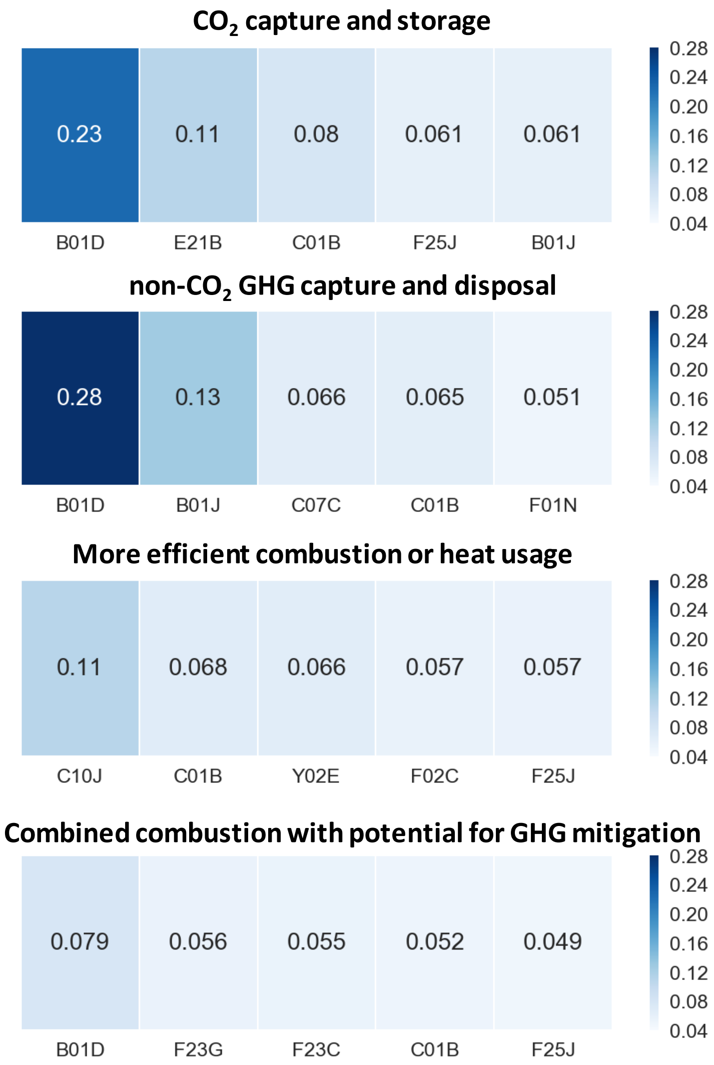

Figure S2. The most frequent cited classification in each major technological domain.

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Table S16. The predicted improvement rate in the performance of four major GHG capture, disposal and mitigation domains.

Technological domain	**Predicted improvement rate** (including all patents)	**The lower limit of the prediction interval (linear scale)** (including all patents)	**The upper limit of the prediction interval (linear scale)** (including all patents)	**Predicted improvement rate** (excluding patents shared by other domains)	**The lower limit of the prediction interval (linear scale)** (excluding patents shared by other domains)	**The upper limit of the prediction interval (linear scale)** (excluding patents shared by other domains)
non-CO_2 GHG capture and disposal	0.12130	0.02708	0.34507	0.112099	0.031585	0.397855
CO_2 capture and storage	0.09667	0.03426	0.42947	0.09107	0.025444	0.32596
Combined combustion with potential for GHG mitigation	0.087778	0.02448	0.31475	0.07783	0.021563	0.280915
More efficient combustion or heat usage	0.07108	0.01958	0.25801	0.069973	0.019258	0.25424

Table S17. The predicted improvement rate in the performance of the nine technological subdomains for CO_2 capture and storage considering all the patents in the technological domains and those exclusive to it.

Technological domain	**Predicted improvement rate** (including all patents)	**The lower limit of the prediction interval (linear scale)** (including all patents)	**The upper limit of the prediction interval (linear scale)** (including all patents)	**Predicted improvement rate** (excluding patents shared by other domains)	**The lower limit of the prediction interval (linear scale)** (excluding patents shared by other domains)	**The upper limit of the prediction interval (linear scale)** (excluding patents shared by other domains)
Capture by membranes or diffusion	0.2101518	0.059635	0.7405698	0.251689	0.071207	0.889616
Capture by rectification and condensation	0.1456773	0.041306	0.5137705	0.154075	0.043719	0.542994
Capture by adsorption	0.1172984	0.033097	0.4157103	0.126974	0.035905	0.449026
Oxyfuel combustion	0.1111069	0.031296	0.3944525	0.112075	0.031578	0.397772
Integrated gasification combined cycle (GCC) combined with carbon capture and storage (CCS)	0.0708227	0.019507	0.2571243	0.055871	0.015124	0.206401
Capture by absorption	0.0618414	0.016873	0.2266566	0.058771	0.015973	0.216241
Unmixed combustion (Chemical Looping)	0.0507067	0.013614	0.1888672	0.055329	0.014965	0.204561
Subterranean or submarine CO_2 storage	0.0497563	0.013336	0.1856377	0.049547	0.013275	0.184927
Capture by biological separation	0.037063	0.009649	0.1423584	0.036075	0.009364	0.138971

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3. The impact of time on the technological improvement rate

Technological trends such as Wright's law and Moore's law have been widely studied in literature using empirical data [3,4]. While there is significant empirical evidence that for a certain technological domain, the cost decreases as a power law of cumulative production, there is no consensus if the technological improvement rate decreases with the age. In fact, it is empirically shown in one of the working papers of co-authors[5] that performance improvements do not slow down in the latter parts of the diffusion curves, despite the decrease in the penetration rate. This empirical observation should not be confused with the fact that some technological growth is bounded by the natural laws (e.g., Carnot efficiency), and their performance indicators may eventually approach a resistance level. Nevertheless, the only underlying driver of the technological growth is the continuing *overall* progress in technological and scientific knowledge.

In this section, further analysis regarding the age of various technological domains is presented based on the position of a patent in the patent citation network sorted topologically by a depth-first search algorithm [6]. Through this procedure, for each patent, we compute a measure that we call backward path length. This measure is estimated using the number of steps that it takes for each patent, to find a start point (i.e., a patent that is cited but does not cite) when traveling backward in the patent citation network. More recent patents will naturally have a tendency to cite recent patents in greater numbers, and therefore tend to have a higher backward path length. Consequently, the comparison between domains must be done by looking at the average backward path length of the patents filed in the same filing year. **Figure S3** shows the backward path length of the patents in the major domains against their filing year. The figure suggests that until the second half of the 1990s all the four domains had similar trends and were in line with the benchmark for all other USPTO patents. Since then, the patents in the non-CO_2 GHG capture domain kept following the benchmark. The patents in the CO_2 capture domain followed the benchmark until around 2003. Then, this set of patents started having a lower mean backward path length, meaning that its patents started connecting to relatively older generation patents than expected. A similar conclusion applies to the two combustion domains, although the change started around 2000 for them. This analysis shows that there does not seem to be any significant difference between the subdomains analysed here and the overall technologies patented at the USPTO in terms of the influence of the age of their invention and their ability to benefit from knowledge generated before it. Therefore, it can be concluded that it is statistically unlikely that more mature technologies would have a different potential to absorb existing knowledge than emerging technologies, which, as we discussed, is a key factor affecting their yearly rate of improvement. It is also very important to note that the normalization procedure for the calculation of the centrality measures used to estimate the yearly improvement rate, takes into account the different patent ages, in order to exclude the confounding effect of age on the measurement of centrality, as explained in [7].

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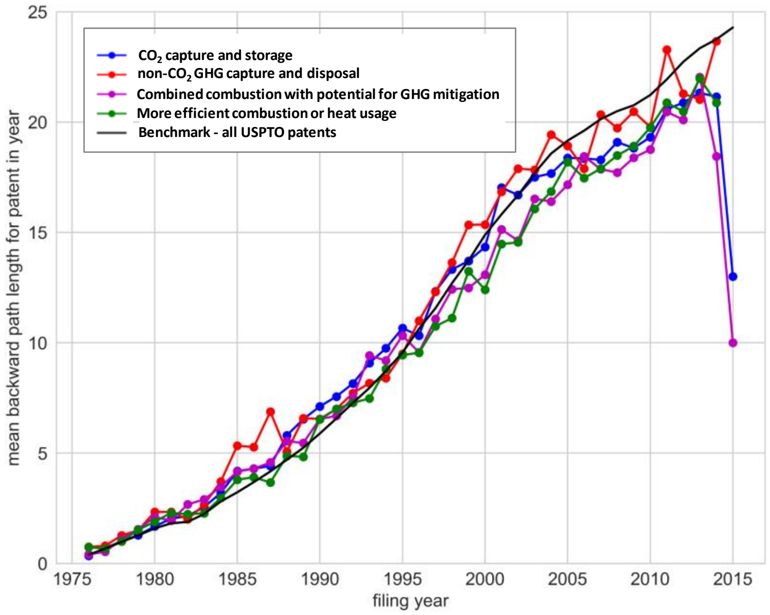

Figure S3. The mean backward path length of various patents against the filing year for the four major technological domains.

Another analysis can be conducted through studying the position of various patents on the citation path against the filing year. These are shown using the two joint-distributions of patents by backward path length and filing year for all USPTO patents (right figure below) and for the four domains combined (left figure below). These are essentially scatter plots. However, when dealing with very large data sets, scatter plots are not useful because many points may be overlapping, and obscure visual assessment of a relationship between the two variables. To solve this problem often heat maps are plotted, which split the graph in different micro-areas (the small hexagons) and color them according to the number of observations found in each area. The darker the color, the more observations (i.e. patents). This allows visually assessing where are most of the observations and, therefore, getting a quick understanding of the shape of the relation between the two variables (if there is any). The lateral bars are probability density functions. They allow comparing the shapes of them between the two variables. It is a further visual aid to understand if the two variables have very different distributions (this could affect the shape of the relationship between them) and help identifying in which part of the plot we have most of the observations.

The smoother trends in the right figure (all USPTO patents) should be attributed to the fact that more denser data set is applied resulting in a higher resolution. Nevertheless, both figures have similar slope and magnitude, and there do not seem to be noticeable differences. This is further evident from the Pearson correlation coefficients reported in the right top corners of the two figures below, and quantify the correlation between the filing year of a patent and its backward path length. Again, a very similar trend is observed for the aging of the technological domains studied in the present research and the overall performance of the USPTO patents.

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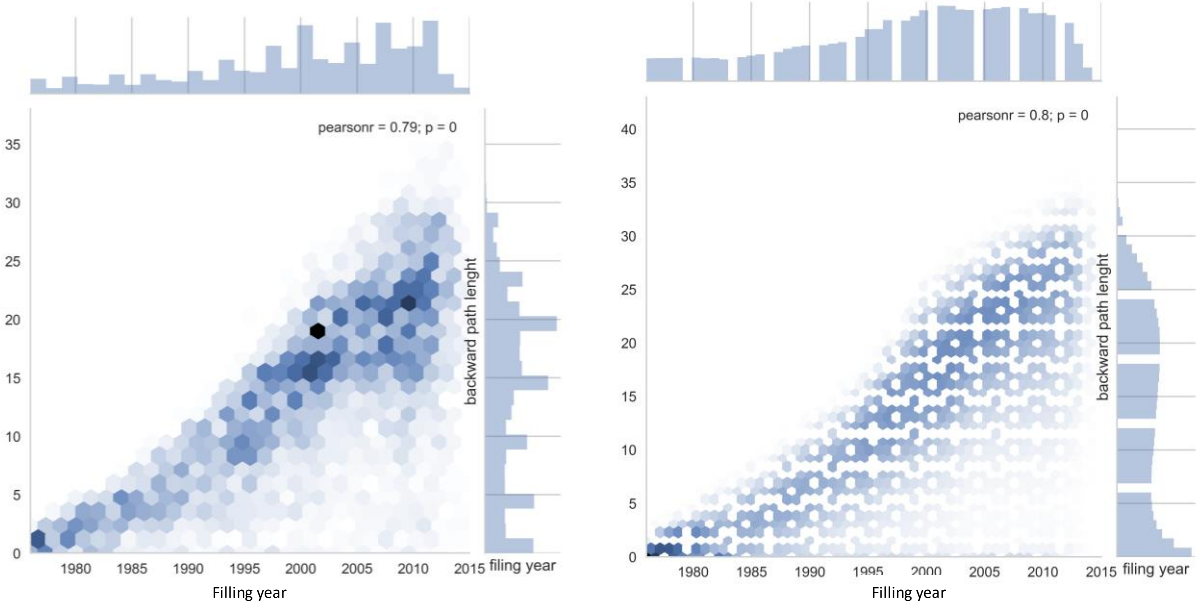

Figure S4. The joint-distributions of patents illustrating the backward path length against the filing year for all USPTO patents (right figure) and for the four domains combined studied in the present research (left figure).