

Carbon Capture and Sequestration

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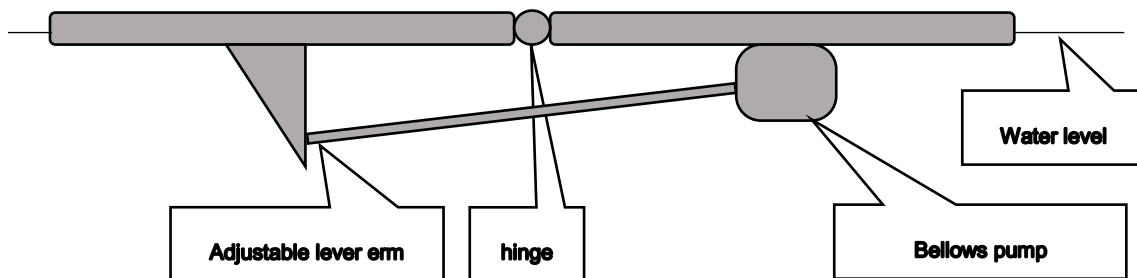
Introduction:

This is a proposal for taking CO₂ out of the environment and sequestering it at a rate of about 10,000 tonnes per day, (3.6 million tonnes/year), for a capital cost of around \$US 25 million. The process described can be scaled up or down to suit the situation. This is equivalent to 0.96 million tonnes per year of pure carbon. The CO₂ is taken from the sea; as there is an equilibrium between the CO₂ concentration in the sea and that in the atmosphere, (with a time constant of about a month), this will have the effect of reducing the global warming effect of atmospheric CO₂. To fully reverse the current climate crisis, about 300,000 such systems would be needed, distributed across the planet. This would bring the atmospheric CO₂ level to sustainable levels within about three years and to pre-industrial levels in about eight years.

The CO₂ is sequestered in disused oil and gas wells. This process will also take H₂S from the sea and sequester it with the CO₂.

Description:

Nodding ducks are used to pump seawater ashore. Each pair of nodding ducks is made from recycled plastic. The dimensions are optimised for the wave pattern at the location but will typically consist of two panels hinged together at the short edge, each pair being about 8-10 m (26-33 feet) long, 1.8 m (6 feet) wide and 0.5 m (20 inches) thick. Each panel has an outer shell of recycled plastic filled with recycled plastic foam to give a bulk density about half that of the seawater. On the underside of each pair is a bellows pump on one with an adjustable lever arm from the other. The adjustment of the lever arm allows the user to manipulate the pressure/flow-rate balance of the system.



The nodding duck operated diaphragm or bellows pump is the simplest and most robust mechanism for harnessing wave power and will ensure a long working life with minimal capital cost and easy maintenance. The nodding ducks are anchored offshore in deep water (ideally at least 80m or 270 feet deep); this is so that suction can be taken from the dark zone, (70m or 230 feet deep but well clear of the seabed), where sea life is at a minimum. The floats are each about 4-5 m (13-17 feet) long and 1.8 m (6 feet) wide hinged end-to-end in pairs. They form an array of two rows of 300 - 600 with a common manifold pipe made of recycled plastic between them. The whole array will occupy an area of 600m to 1.2km (2000 to 4000 feet long) by about 25 m (80 feet) wide. It should be located at a place that is open to a large ocean so that there are constant powerful waves in all local weather conditions.

A proportion of the nodding ducks in this array can pump about 1 million tonnes per day of seawater with a pressure of about 4.2 bar (61 psi) into a manifold connected to a pipeline, also of recycled plastic, of about 1.6 m (5.3 feet) diameter running to the shore. The remainder of the array is used to generate electricity, (about 5-12 MW depending on the available wave-power), by passing the water through turbine/alternator sets on rafts distributed along the array. For more details about electricity generation, see the reference: "Clean Electricity Generation".

The onshore section of the discharge pipe needs to be about 2.5 m (8 ft) internal diameter sloping continually upwards for at least 600 m (2000 feet), (preferably \approx 1 km or 3300 ft), to a gas separation vessel. The slope is to ensure that all of the gas released goes to the gas separation vessel. The onshore pipe must be lagged, perhaps by manufacturing it with a layer of closed cell insulating foam, (also made of recycled plastic), covering the outside.

The water is heated, (by three methods, described below), as it passes through the onshore section of pipe, to a temperature as close as possible to boiling point at that pressure to cause the dissolved gases to come out of solution and be collected in the gas separation vessel. The return water from the gas separation vessel goes through an array of smaller pipes (about 50 mm or 2 inches internal diameter), suspended on racks within the supply pipe. As the returning water cools, it heats the water in the supply pipe. It is in effect a long counter-current heat exchanger.

Close to the shoreline, the return pipes are taken outside the supply pipe and brought together into a single pipe. It has a pressure of perhaps 1.8 bar and can generate about 0.3 megawatts of electricity through a suitable turbine/alternator set.

A set of electrical heaters is distributed along the supply pipe to heat the water to close to boiling point. The heat input is regulated to maintain optimal gas separation without boiling the water. The gas thus separated consists mainly of carbon dioxide and oxygen with a smaller amount of H₂S. A system of continuous gas centrifuges is used to separate the oxygen from the carbon dioxide so that the oxygen can be dissolved in the return seawater in the discharge pipe and the carbon dioxide can be compressed to a liquid for long-term sequestration.

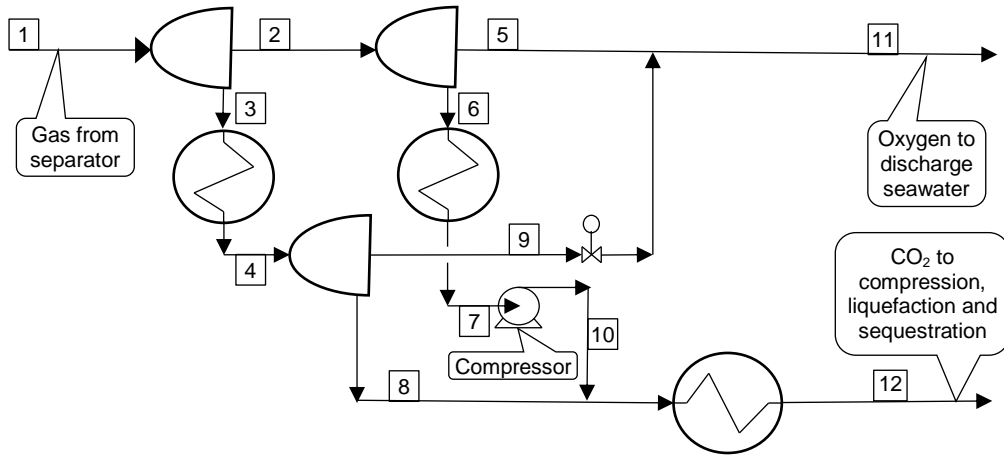
As the oxygen has a molecular weight of 32, CO₂ is 44 and H₂S is 37 or 38, and as there is about five times as much CO₂ as O₂, most of the H₂S will be in the CO₂ stream. For more details about the use of the continuous gas centrifuge for separation of gases of different molecular weights, see the reference: "Gas Separation using Continuous Gas Centrifuge".

The re-oxygenated water in the discharge pipe is returned to the sea through a distribution pipe below low tide level but within the wave zone close to shore to ensure good mixing. This is because the photosynthesizing sea-life close to shore requires some carbon dioxide in the water to thrive, and this is not sufficiently concentrated in the return water. We should avoid disturbing the habitat balance through our carbon capture and sequestration activities.

About 4 megawatts of electrical energy will be needed for heating the seawater in the supply pipe during start-up, reducing nearly to zero once steady state operation is established. This electrical energy can be provided by the array of nodding ducks described above.

The separation, compression and liquefaction processes generate heat, so the gases must be cooled after each stage. This is done by passing them through heat-transfer pipes in the seawater supply pipe. This is the main source of the additional heat input required during steady-state operation. All of the heat exchangers shown in the process schematic diagram below are located in the seawater supply pipe at positions designed to optimise energy recovery whilst ensuring that the return water is compatible with the local sea-life.

The liquefied CO₂ is sequestered by pumping it into disused oil and gas wells that are deep enough that the supercritical fluid is in equilibrium with the ground pressure at that depth. It should be noted that all oil and gas wells contain brine, and the CO₂ will dissolve in this brine up to about 35% concentration by weight. The brine will increase in bulk and, being denser than the oil or gas, it will displace these fuels, facilitating extraction.



Stream #	1	2	3	4	5	6	7	8	9	10	11	12
Flow te/day	16000	5200	10800	10800	4716	484	484	10304	496	484	5212	10788
CO ₂ % mass	64	10	90	90	2	88	88	98	2	88	2	98
CO ₂ te/day	10240	520	9720	9720	94	426	426	10098	10	426	104	10524
O ₂ % mass	36	90	10	10	98	12	12	2	98	12	98	2
O ₂ te/day	5760	4680	1080	1080	4622	58	58	206	486	58	5108	264
Temp °C	20	21	171	26	23	176	26	172	27	107	23	26
Press. Bar g	0.7	0.6	17.4	17.4	0.6	17.7	17.7	76.2	0.5	76.2	0.5	76.2

The liquefied CO₂ can also be used to generate synthetic fuel, and a proposal is available for generating methanol by hydrogenating CO₂ by passing it through an electric arc, see the reference: "Turning CO₂ into Fuel". The liquefied CO₂ may also be sold in cylinders or tankers for the various industrial processes that consume CO₂. The CO₂ used for these purposes must be further purified to remove the H₂S, thus preventing the sulphur compounds from being returned to the environment. This H₂S will dissolve in the liquid CO₂ that is being sequestered. Continuous Gas Centrifuge can be used to reduce the H₂S concentration in the CO₂ being used for industrial purposes, (including synthetic fuel production), to a currently acceptable level of around 10ppm. The power required for treating sufficient CO₂ to recover 2500 tonne/day of CO₂ with less than 10 ppm of H₂S using a gas centrifuge process is expected to be about 1.6MW.

The initial start-up of the system from cold will cause the gradual heating of the water at the separation vessel over several days, depending on the seawater temperature and the quality of insulation on the shore pipe. Once the system is up to temperature and with the gas separation and compressors running, the electrical power consumption for heating will considerably reduce, nearly to zero, as most of the additional heat required comes from the cooling of the centrifuge and compressor discharges. About 2.8 MW of electrical power is required during normal operation for gas separation and compression. The surplus power generated by the nodding ducks may be exported to the electricity grid.

It is envisaged that the objective is not to permit any future generation of CO₂ from fossil fuel extraction, refining and usage, without a proportional carbon capture being in place. The easiest way to achieve this is to require those companies extracting fossil fuels from the ground to install and use, (or to pay others to install and use), carbon capture and sequestration systems as part of their licence to operate. They will clearly pass on these costs to their customers. Energy companies clearly have the easiest access to oil and gas wells where the CO₂ can be stored indefinitely. They can also benefit, as pumping liquid CO₂ into the low point of an active oil or gas field will displace hydrocarbons upwards, raise the well-head pressure and facilitate extraction.

In the long term it is expected that fossil fuel extraction will cease and all transportable liquid fuels will take the form of methanol, (see the reference "Turning CO₂ into Fuel"), however, during the transition to this end, it is expected that some fossil fuels will continue to be processed. This is sustainable provided that the associated sequestering of CO₂ is sufficient.

It is estimated that the recycled plastic parts for the arrays of nodding ducks described, plus the associated low-pressure pipework, would cost about \$US 5 million. The metal equipment for separation of oxygen from CO₂, for compression and liquefaction of the CO₂ and for on-shore electricity generation would cost another \$US 12 million. The electrical power generation turbines, alternators and undersea power cables would cost about \$US 2.6 million. The transportation and sequestration costs would be very situation dependent and are not estimated here. Operational and maintenance costs are minimal as a 16-18 man team could operate six systems like this in close proximity. The total cost for installation of a system capturing and liquefying 10,000 tonnes/day, (3.6 million tonnes per year), of CO₂ would be about \$US 22 million. This cost is minor, however, when compared with the costs of oil and gas well drilling, extraction, refining and distribution, and very minor indeed when compared with the inevitable cost to the environment of doing nothing.

It is possible that some oil and gas companies, (and perhaps also their governments), will choose not to comply with this proposal. Reputable governments will either prohibit the importation of this fuel, will apply a levy at the point of importation to cover the cost of the necessary carbon capture and sequestration, or will require the importer to organise and fund the required carbon capture.

In order to reduce the atmospheric CO₂ concentration quickly to sustainable levels, (rather than simply to stabilise it), it is suggested that any fossil carbon extraction and use should be accompanied by carbon capture and sequestration. This should be sufficient in quantity to compensate for all the additional CO₂ from wild-fires, deforestation, and burning of permafrost that are currently increasing exponentially as a result of the already abnormally high concentration of atmospheric CO₂, plus an additional quantity to bring down the CO₂ concentration rapidly. At the time of writing, (October 2025 for this update), a multiplying factor of 133 is proposed; the longer we delay implementing widespread carbon capture, the higher the necessary multiplying factor will rise until we reach the point where no action we can perform will ever reverse these effects. This multiplying factor will rise by about 5% every month until we take effective action. When I penned the first version of this document, early in 2021, the multiplying factor that I calculated then was 15.

References: can all be found on <http://www.intint.co.uk/environ.html>

Gas Separation using Continuous Gas Centrifuge

Clean Electricity Generation - Capturing Wave Energy with Nodding Ducks

Turning CO₂ into Fuel