Having our cake, and eating it too



Carl T.F. Ross

Ross describes how the deep oceans can be both a source of hydrocarbons and a sink for their by-products.

Who should read this paper?

Anyone with an interest in ways and means to expand useable hydrocarbon reserves, while at the same time reducing atmospheric CO2 levels (and their concomitant effects on global warming) will find this paper intriguing.

Why is it important?

This paper represents a unique perspective on dwindling conventional hydrocarbon reserves and rising atmospheric CO2 levels.

The author presents the case that there is enough frozen methane hydrate in the deep oceans to serve mankind's need for hydrocarbons for roughly 1,000 years. However, additional research and development is needed to design and build submarine structures that would be needed to mine frozen methane hydrate, and that could withstand the extreme pressure in the deep oceans.

Burning the vast reserves of methane would add significantly to CO2 levels in the atmosphere, which are already being blamed, in part, for global warming. Again, new research would be needed to determine the most effective and efficient means to capture and dispose of this additional CO2. Freezing at the surface and disposal in the deep ocean is one method that is suggested.

About the author

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EXPLOITING THE DEEP OCEANS FOR ENERGY RESOURCES AND FOR REDUCING THE EFFECTS OF CLIMATIC CHANGE

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ABSTRACT

The paper describes two problems of much concern in the world at present; one of these is on dwindling energy resources and the other is on attempting to reduce man-made climatic change. The paper shows why these problems have occurred and how the deep oceans can be used to save our planet and at the same time allow the vast majority of mankind to enjoy the lifestyle of the west.

THE PROBLEMS AND THEIR SOLUTIONS

ENERGY RESOURCES

Dwindling energy resources is a topic of much current interest. This has been caused by the energy required to industrialise the world, especially by the industrial revival of the east and the Far East and the continuing popularity of the world's inhabitants to have private motorised transport. Sir Winston Churchill once said, "Do not pull the tail of the Chinese dragon or you will awaken it!" Today the Chinese dragon is awake and flapping its wings and very soon it will be in full-flight! When this occurs, one billion or so Chinese people will want the lifestyle that we enjoy in the west. Similarly, the Indian tiger will also want our lifestyle of 'milk and honey' and the world will be in even greater danger of suffering an energy resources crisis, together with the effects of man-made climate change. It must be emphasised that before the First World War, the percentage of CO₂ in the atmosphere was about 0.03%

[Lovelock, 1995] and that in the year 2006 the percentage of CO_2 had risen to about 0.038%, an increase of about 26% in a century. Many scientists [Lovelock, 1995, 2006] believe that this increase in CO_2 is largely responsible for the detrimental effects on climate change that we have recently experienced on our planet, namely global warming. Lovelock believes that this process must be changed as soon as possible or detrimental climate change may become worse.

According to press reports, Russia has 1/5th of the quantity of the world's methane. However, this information is based on the methane that is stored in the Earth's crust, on land and in shallow waters. This methane has been produced by biological decay and does not take into account the vast quantity of deep-sea methane that has been produced by bacterial action and is in the form of frozen methane hydrates millions of years ago. These methane hydrates were formed when the water froze around tiny methane bubbles, where the structure of the water cage surrounding each methane

bubble is in the form of a clathrate-like structure. A clathrate is a cage-like structure that is in the form of multiple cells. The walls of the cells are frozen water and each cell contains a compressed bubble of gas.

This bacterially produced methane is in the Earth's crust, covered by water, some 2 to 7 miles (3.22 to 11.52 km) deep. According to Dickens et al [1997], the quantity of this form of methane could be as much as 10,000 billion tonnes. That is, its mass is twice that of all the fossil fuels (methane, oil and coal) on land and shallow waters. If this quantity of methane is distributed equally amongst all of mankind, then each and every one of us will get a chunk of methane weighing about 1,670 tons. In monetary terms, this methane is worth about \$1,000,000- per person on Earth. This methane hydrate is guite stable and has been so for about 60 million years, despite the fact that its density is 0.91 gm/cm³ [Carroll, 1999] and less than that of seawater, whose density is 1.02 gm/cm³. Some scientists say that because the methane is stable, we should leave it where it is, but even if the west plays on a 'level playing field' and leaves the methane where it is, the present author doubts that the rest of the world will not show a very healthy interest in winning such a prize. Many senior British politicians do not seem to be aware of the existence of this vast source of untapped energy.

The problem with retrieving this methane is that much of it is frozen in the form of methane hydrates. For example in a typical gas field, such as the Blake Ridge, [Dickens et al, 1997], there may be about 200 m of 'soil', without methane, immediately below the sea floor. Under this soil, for another 300 m or more, there is frozen methane hydrate and below this, there is a reservoir of methane gas. The present author believes that if the gas field is drilled vertically downwards into the bottom reservoir containing the methane gas and that if this gas is sucked out, it will cause a void in the bottom reservoir that originally contained the methane gas. This will result in a vacuum in the bottom reservoir, causing the methane hydrate immediately above it, to evaporate into the bottom reservoir, as shown in Figure 1. By repeating the process, much of the frozen methane can be retrieved. In Figure 1, 'mbsf' represents 'metres below the sea floor'.





According to reports received by the present author from practising oceanographers, the Japanese who have no naturally occurring reservoirs of oil or methane on their land, are drilling in depths of water of up to 4.5 miles (7.25 km). Why are they doing this?

ENERGY CONSUMPTION

The average American consumes about 60 ft³ (1.7 m³) of methane per day. If we assume that all his other energy needs, such as for electricity and transport, etc., are also produced from methane, and if we round this figure upwards, we will find that he consumes about 2 tonnes of methane per year. If we then exaggerate this requirement for energy consumption and assume that all

of mankind will consume energy at this rate, then there will be enough methane energy to last mankind for more than 800 years. If alternative methods of energy production are used in addition to energy in this form, then we should have enough energy to last us for about 1000 years. Thus, we need not worry too much using nuclear power and its associated problems.

CARBON DIOXIDE EMISSIONS

The good news is that methane is a cleaner fuel than oil or gas, but the bad news is that if we burn this methane, we will produce 27,600 billion tonnes of carbon dioxide; this figure is some 110,000 times greater than the recently agreed proposed annual emission of carbon dioxide by Britain. Do not worry; there is sufficient oxygen in the atmosphere to combust this vast quantity of methane: the mass of oxygen in the atmosphere being about 100 times more than the mass of deep-sea methane. In any case, we are not going to combust this deep-sea methane all at once; hopefully we will combust it over a period of 1000 years. However, carbon dioxide is believed to be one of the worst culprits for causing environmental meltdown. According to press reports, the Arctic is melting and causing sea levels to rise. If the floating Arctic ice pack melts, it will not cause a significant rise in sea level, because according to Archimedes's Principle, the floating ice pack displaces its own mass in water. However, if some of the Ice Mountains on land in the Arctic melt, it will be a very different 'kettle of fish'. For example, Greenland is covered by a block of ice whose surface area is about 700,000 square miles (1.81 million sq. kms), and whose thickness is a little less than one mile (1.61 km). The average temperature during the Arctic summer is about -14° C. This high temperature is causing some of the Arctic's ice to melt

and some scientists (Lovelock, 2006) believe that it may completely melt within 45 years if its present rate of melting continues. If this takes place, the world's sea levels will rise by about 22 feet (6.7m) and large areas of cities such as London and New York will go 'underwater'. If the Antarctic melts it will be even worse, but fortunately the Antarctic's summer temperature is some 26°C less than the Arctic's summer temperature. Thus, at present, the possible melting of the Arctic is of more concern to us than that of the Antarctic.

Furthermore, according to Lovelock [2006], by the turn of the century the temperature in the tropics may rise by about 5°C and the temperature in the temperate zones of our Planet may rise by about 8°C. According to Lovelock, such rises in temperature will cause much of the agricultural land to turn into desert; this in turn will wipe out much of mankind. Additionally, according to many scientists, if the seas warm up, the basic food supply in the oceans, namely plankton can be destroyed and this will break the food cycle in the oceans, causing havoc to marine life. If the undersea methane hydrates are left where they are and the seas warm up, then a further consequence of this is that the methane hydrates can evaporate and cause even more greenhouse gas pollution in the atmosphere, as the density of frozen methane hydrate is less than the density of seawater. Also the methane can catch alight and burn for about 100 years or more [Ross, 2005].

CARBON DIOXIDE REMOVAL

According to Attenborough [2006], if an average car is driven for 30 miles (48.3 km) per day, it will produce 10 tonnes of carbon dioxide per year; this is an enormous output of carbon dioxide, especially as many families in the west have two or more cars per household. So how can we 'have' our private motorised transport and 'drive it' at the same time? Obviously, we have to eradicate the carbon dioxide somehow. One way is to plant trees, but according to press reports, some German scientists have found that trees and plants expel methane, which as a greenhouse gas is about 22 times worse than carbon dioxide [Lovelock, 2006]. Furthermore, according to recent press reports, the methane expelled by trees and plants makes up from 10% to 30% of the methane in the Earth's atmosphere. So planting trees may not solve the problem. There is, however, another way to eradicate the unwanted carbon dioxide. That is, to trap it and either scrub it or bury it in the deep oceans, as shown in Figure 2, where it will freeze as carbon dioxide hydrates due to the high pressures and low temperatures. Table 1 shows the pressure and temperatures at which carbon dioxide hydrates form [Carroll, 1999], together with the water depths. According to Carroll the density of frozen carbon dioxide hydrate is 1.1 gm/cm³ and as it is denser than seawater, it will sink to the bottom of the ocean.

Table 1: Carbon Dioxide Hydrate Formation atTemperatures, Pressures and Water Depths.

Temperature	Pressure	Water Depth	
(deg C)	(kPa)	(m)	
-1	1334	121	
0	1490	136	
1	1667	153	
2	1869	173	
3	2100	196	
4	2366	222	
5	2676	252	

This is in contrast to frozen methane hydrate that is less dense than seawater and will float to the surface. Thus, if the frozen methane hydrate has been stable for 60 million years in locations such as the Blake Ridge, there is no reason to believe that the frozen carbon dioxide hydrate will not be stable for millions of years, as its density is larger than that of both frozen methane hydrate and seawater

The process of burying the carbon dioxide is described in much detail later in this section. From Table 1, it can be seen that frozen CO_2 hydrates can form at quite modest temperatures and depths of water.

It is worth pointing here that the latest approaches of the United Nations Framework Convention on Climate Change / Code of Practice, Intergovernmental Panel on Climate Change and/or IMO for facilitating carbon dioxide capture and storage (CCS) is worth reading. Special reference should be made of the Special Report of Carbon Dioxide Capture and Storage, published in 2005 by the IPCC; this gives an overview of the current status of CCS technologies in various aspects, together with the latest revision of the 1996 London Protocol to allow the legal storage of CO₂ into sub-seabed geological formations.

It is also worth pointing out here that chemical engineering studies have elucidated the possibility that the methane in the deep-sea methane hydrate can be exploited by the injection of CO_2 and N_2 plume; this means that we can produce a double 'whammy', where the 'exploitation of resources' and the 'disposal of CO_2 ' can be carried out in a very stable way and at the same time.

So how can we trap or scrub carbon dioxide from an automobile? We can scrub the exhaust fumes by blowing the carbon dioxide fumes through (say) soda lime or potassium super-oxide or lithium hydroxide or some other chemical yet to be invented, the adopted chemical to reside in the automobile's exhaust itself. If carbon dioxide is blown through soda lime, it turns the soda lime into two harmless substances, namely calcium carbonate and water; calcium carbonate is better known as the chemical that is used to treat common indigestion. From time to time, the soda lime will need to be replaced. Thus, in this paper, the author has already 'invented' a means of weatherproof and can also be made soundproof. In Figures 3 and 4, the present author has shown what a north/south tube motorway may look like.



Figure 2: Carbon dioxide burial in the Blake Ridge. scrubbing unwanted carbon dioxide emitted through an automobile exhaust. Other chemicals can be used for the same purpose; some of which are yet to be invented. Alternatively, if the eradication of carbon dioxide is not to be left in the hands of the motorist, there is another way of dealing with the problem.

Tube and tunnel motorways can supplement conventional motorways [Ross, 2005], where the carbon dioxide can be trapped and treated or buried in the deep sea. To encourage motorists to use the tube and tunnel motorways, a carbon tax can be levied only on the conventional motorways that are supplemented by tube motorways. To reduce the costs of the tube motorways, they need not be placed underground; instead they can be placed above ground level and be factory built. A large conventional motorway costs about \$50 million per mile (1.61 km) and the author would estimate that the cost of a tube motorway would be about twice this value. The tube motorway will have the advantage that it is



Figure 3: Cross-section of north/south tube motorway.



Figure 4: Tube motorway.

Likewise, the CO_2 from industrial chimneys can be trapped and scrubbed or buried in the deep oceans.

The author has discussed the treatment of carbon dioxide with chemicals, but what about burying it in the deep oceans. The maximum depth of the oceans is in the Mariana's Trench, which is some 7.16 miles (11.52 km) deep, and the average depth of the oceans is some 2 to 3 miles (3.22 to 4.83 km) deep. According to Dickens et al, [1997] there are frozen methane hydrates in many gas fields, covered by water of about 2 miles (3.22 km) depth and more. These methane hydrates have laid there for millions of years and are quite stable. Thus, if we remove this methane for our own use, we can replace it with carbon dioxide, which should also freeze in the form of hydrates due to the high pressures and low temperatures, as shown in Figure 2. One must remember that as the freezing point of carbon dioxide at normal pressures is some 104°C higher than the freezing point of methane, there is no reason why the carbon dioxide will not freeze as a hydrate and stay there for millions of years. Another way of disposing of the carbon dioxide is simply to pump it out from (say) a submarine at a depth of more than 3.6 km. The carbon dioxide will simply freeze at this depth in the form of carbon dioxide hydrates and sink to the bottom of the ocean. The density of frozen carbon dioxide hydrate is about 1.1 times the density of water. So why will the carbon dioxide freeze due to pressure? We must remember that the freezing and boiling points of liquids do not depend on the temperature alone, but also on the pressure. If the pressure falls, the boiling point and the freezing point fall and if the pressure rises, the boiling point and the freezing point rise. This is why we cannot make a good cup of tea at the top of Mount Everest because the boiling point of water at the top of Mount Everest is about 72°C due to the fact that the atmospheric pressure at the top of Mount Everest is about 0.34 bars and the water cannot reach 100°C at this pressure.

UNDERWATER RIG

Figure 5 shows a manned underwater drilling rig [Ross and Laffoley-Lane, 1998] for extracting deep-sea methane, which was invented by the author and his student; this rig can also be adapted to pump the unwanted carbon dioxide into the sea at a suitable depth, where the carbon dioxide will freeze in the form of hydrates and sink to the ocean's bottom. The rig is very large and because of this it cannot be made in metal. This is



Figure 5: Underwater drilling rig.

because as the rig dives deeper and deeper into the sea, it is necessary to increase its wall thickness, so that it can sustain the resulting higher and higher pressures. This is shown in Table 2, where the wall thicknesses of the toroids are shown for various materials, if they are to be designed to operate at a depth of 7.16 miles (11.52 km). The wall thicknesses of the toroids of Table 2 were obtained by using the thick-shell theory of Lame [Ross, 1999, Ross et al, 1999]. The column under the symbol 'W' represents the weight per unit length of the toroid, neglecting weights such as those due to machinery, personnel, etc. The column in Table 2 under the symbol 'B' represents the buoyancy per unit length of toroid. It can be seen from Table 2 that at a depth of 7.16 miles (11.52 km), the wall thickness of the rig is so large that if it were made in metal it would have no reserve buoyancy and it would sink like a stone to the very bottom of the ocean.

Material	Specific density	'Yield' strength (MPa)	External Diameter (m)	Wall Thick(t) (m)	'W' kg/m	'B' kg/m
HY80 Steel	7.86	550	14.6	2.301	0.7E6	0.17E6
Aluminum alloy 7075-T6	2.9	503	15.2	2.6	0.27E6	0.19E6
Titanium alloy 6-4 STOA	4.5	830	13.78	1.39	0.22E6	0.15E6
GFRP composite Epoxy/S-glass	2.1	1200	11.8	0.91	0.066E6	0.112E6

Table 2: Wall thickness (t) of the circular section of the toroidal structure.

That is, if W>B the vessel sinks. Thus, the rig has to be made in a material that has a better strength / weight ratio than a very strong metal, such as high-tensile steel. Suitable construction materials for the rig are glass fibre reinforced plastic ('S' glass) and carbon fibre reinforced plastic, where the former is only 1/3rd the cost of the latter, but the latter is a better construction material than the former. The rig is powered by a pressurized water nuclear reactor and has a crew of 60. The rig is described in much detail in the above reference and because of this its description is only brief in the present text.

Another, even cheaper method of eradicating the carbon dioxide is to freeze it above sea level and simply to throw it overboard from a ship in the form of streamlined torpedoes, as described by Murray et al [1995] and as shown in Figure 6. According to Murray et al [1995], that as the density of the frozen carbon dioxide (dry ice) is 1.56 times the density of water, the frozen carbon dioxide will sink and remain stable when it reaches the appropriate depth of water. It is true that some of the frozen carbon dioxide will evaporate before it reaches the appropriate depth of water, but this may be the inexpensive alternative of disposing of the unwanted carbon dioxide.

Furthermore, according to Attenborough (2006), some 50% of the CO_2 in the Earth's atmosphere is naturally absorbed by the oceans. This phenomenon has the big disadvantage that it makes the oceans more acid.



Figure 6: Dumping frozen CO2 torpedoes from a ship.

and if the Earth's oceans become too acid the plankton and other forms of sea life can be destroyed and thus damage the food chain. This phenomenon, however, does have an advantage in that the CO_2 can be collected from the oceans by a fairly conventional offshore drilling rig and then be pumped into the Earth's crust deep underwater where it will freeze in the form of a carbon dioxide hydrate. Alternatively, the CO_2 can be collected by a surface ship, which will have the facility of freezing it and dumping the frozen CO_2 overboard, as illustrated in Figure 6. It may be preferable to power the ship with a fairly conventional PWR nuclear reactor, so that the ship will have no need to use fossil fuels. As the density of frozen carbon dioxide is 1.56 times the density of water, the frozen carbon dioxide will sink to the ocean's bottom where it will remain stable for millions of years in the form of a frozen carbon dioxide hydrate.

Another method of reducing carbon dioxide emissions is to separate the hydrogen from the carbon in methane and run engines, including fuel cell, aircraft and ship engines, using the hydrogen. The output of burning hydrogen to power an engine, including aircraft engines, or using it in a fuel cell, is water, which is pretty harmless. Thus, we can avoid the carbon footprints normally associated with aircraft and ship engines.

CONCLUSIONS

This paper has suggested solutions for solving the energy crisis and preventing climate change. It is unlikely that mankind will not be tempted to 'mine' the frozen methane hydrate from the deep oceans, as its monetary value is about 536 times the annual GDP of the USA. Combustion of this methane will result in the emission of 27,600 billion tonnes of carbon dioxide and this will have to be dealt with or we will suffer from detrimental man-made climate change. The paper has shown that it is possible for science and technology to eradicate much of this greenhouse gase. In the author's opinion, if the scientist and technologist are given the tools, they can 'finish the job'; we can save the planet! Urgent action is, however, required.

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