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#49 MITIGATION OF GLOBAL WARMING

This document summarizes the causes of global warming and the practical means of preventing further injection of fossil CO_2 into Earth's atmosphere.

The elemental and isotopic composition of planet Earth indicates that Earth was formed by gravitational aggregation of atoms made during a stellar supernova. At the time of planet Earth's orbital capture by our sun planet Earth had a high atmospheric CO_2 concentration, comparable to the atmosphere of planet Venus today. However, the orbit of Earth is further from the sun than is the orbit of Venus, so near Earth's poles it was cool enough for liquid water to exist, enabling biochemical reactions.

Over many millions of years solar energy driven biochemical reactions sequestered most of the carbon in atmospheric CO_2 and ocean HCO_3- ions into carbonate rock (limestone), and fossil fuels. As the atmospheric CO_2 concentration gradually decreased Earth's average surface temperature also gradually decreased.

Today, via production of Portland cement and via combustion of fossil fuels, mankind is transferring carbon from carbonate rock and from fossil fuels into atmospheric CO_2 and ocean HCO_3- ions many times faster than solar driven carbon sequestration naturally occurs.

The effect of increasing Earth's atmospheric CO_2 concentration is to change Earth's thermal infrared emission spectrum in a manner that increases Earth's average surface temperature. This surface temperature increase is amplified by a decrease in Earth solar reflectivity (albedo) due to melting of ice crystals both on Earth's surface and in clouds. The increase in average surface temperature melts land borne ice and causes upper ocean warming, leading to a rise in sea level and increased storm violence. The increase in ocean HCO_3- ion concentration threatens much of the marine food chain.

The situation that the public must face is that ongoing combustion of fossil fuels will further increase the atmospheric CO_2 concentration making the CO_2 driven climate change problems progressively worse. Even when all fossil fuel combustion has stopped, the average: Earth surface temperature, sea level and storm violence will not significantly decrease during a human lifetime.

From an astrophysical perspective, CO_2 induced climate change has been well understood for more than 50 years. The problem is not a lack of scientific knowledge, it is public inability to face astrophysical reality.

Converting atmospheric CO_2 into carbon (C) and oxygen (O_2) and sequestering the carbon deep underground via formation of carbonate rock and fossil fuels requires more energy than was yielded by the carbon's original combustion. If the only energy source for such carbon sequestration is radiant solar energy, the natural carbon sequestration process will require tens of thousands of years to reduce the atmospheric CO_2 concentration back to its pre-industrial level.

The only source of dependable non-fossil power with the capacity to sustainably displace fossil fuels is Fast Neutron Reactors (FNRs). FNRs together with appropriate fuel reprocessing are 100X more fuel efficient than today's water moderated nuclear power reactors and produce about 1000 fold less long lived nuclear fuel waste. However, deployment of a fleet of FNRs with sufficient capacity to stop the ongoing rise in atmospheric CO_2 concentration will take at least 50 years.

A practical problem with deployment of FNRs is that consumers cannot switch from existing fossil fuel power to new FNR supplied clean power until after the required FNRs and related services are constructed. Most present North American electricity systems have no practical provision for funding FNR deployment. A fossil carbon tax levied by a central government will not solve this problem until the fossil carbon tax revenue is directed to funding FNR deployment.

There are several important quantitative issues that the public must grasp.

1) Even under the most favorable circumstances, wind and solar generated electricity alone cannot solve the CO_2 problem.

2) The concept of CO_2 capture and permanent storage underground as a high-pressure liquid does not work. Carbon dioxide at ambient temperature and at a pressure greater than 1100 psi is a liquid with a density greater than the density of water. When this high-pressure liquid CO_2 is initially injected deep underground it sinks in ground water, giving the impression that the CO_2 is trapped. However, over time the CO_2 dissolves in the overhead ground water and gradually leaks out to the atmosphere via connected surface water bodies, water springs, water wells and inadequately capped boreholes. This CO_2 leakage process is similar to the gradual release of CO_2 from an open container of a soda drink.

3) Present world wide combustion of fossil fuels continuously produces a thermal power of about 21,000 GWt. In an industrialized country 1 GWt can meet the reasonable energy and power needs of about 100,000 people.

4) The 21,000 GWt heat flux provides a good standard of living for the (1 / 3) of the world's human population who mainly live at high latitudes.

5) The other (2 / 3) of the world population, who mainly live at low latitudes, receive comparatively little direct benefit from large scale combustion of fossil fuels. However, the lives of these people are threatened by the CO_2 driven rising sea level and the rising average Earth surface wet bulb temperature (humidity corrected temperature). These people are being forced to either migrate to higher latitudes or to install continuous air conditioning and water desalination. In either case by 2050 the equivalent world thermal heat demand is projected to be about 45,000 GWt.

6) Hence, in order to obtain worldwide cooperation with respect to CO_2 emission reduction, it is necessary to supply about 45,000 GWt of dependable and sustainable non-fossil heat or its equivalent, about 15,000 GWe of dependable and sustainable non-fossil (clean) electricity.

7) Of this 15,000 GWe, a maximum of 20% or 3000 GWe can come from wind, solar and hydroelectric generation. Hydroelectric power is limited by precipitation and available river geography. Wind and solar electricity generation are intermittent and lack spinning inertia, which together cause electricity grid instability. Adding enough spinning inertia, energy storage and electricity transmission to make wind and solar generated electricity dependable is prohibitively expensive.

8) To achieve climate change mitigation there is no practical alternative but to immediately build about:

15,000 GWe - 3,000 GWe = 12,000 GWe

of new fuel sustainable nuclear power plant capacity.

9) According to the World Nuclear Association (world-nuclear.org), our world's total affordable natural uranium resource (under $260/kg, which is about 3 times uranium's current spot price) is 8.0 million tonnes. About 160 tonnes of natural uranium per GWe-year are required to fuel today's water moderated power reactors. Consequently, if people rely only on water moderated U-235 fueled power reactors to generate the required ~ 12,000 GWe, 100% of the world's affordable uranium would be consumed within:

[8.0 X 10^6 tonnes] / [(160 tonnes / GWe-year) X (12,000 GWe)] = 4.17 years.

Hence it is essential to shift to a much more efficient nuclear fuel cycle.

10) Fast Neutron Reactors (FNRs) with appropriate fuel cycles can provide sufficient energy to meet mankind's needs for thousands of years.

11) In the near term we can use a Uranium-Neptunium-Plutonium fuel cycle:

Pu-239 + n = 3.1 n + fission products + 200 MeV (energy)

n + U-238 = U-239 = Np-239 + e = Pu-239 + 2 e

12) In the future we can use a Thorium-Protactinium-Uranium fuel cycle:

U-233 + n = 2.2 n + fission products + 200 MeV (energy)

n + Th-232 = Th-233 = Pa-233 + e = U-233 + 2 e

This fuel cycle is more difficult to implement than the previous fuel cycle due to a hidden requirement for continuous selective extraction of Protactinium (Pa-233) as fast as it is produced. However, Thorium (Th-232) has the advantage that it is naturally 3X more abundant than Uranium (U-238).

13) At least half of the 12,000 GWe of new FNR capacity must be installed in low latitude countries that today can barely finance coal based electricity generation. These countries need economic support that is dedicated to deployment of FNRs. The other half of this 12,000 GWe must be installed in or near cities in higher latitude industrialized countries. To allow efficient deployment of district heating each FNR should have a full load capacity of about 300 MWe. The required number of such reactors sited in cities in industrialized countries is about:

6000 GWe / (300 MWe / FNR) = 20,000 FNRs.

Each such 300 MWe FNR can meet the reasonable total energy needs of about 100,000 people. In the near term Canada will need about 320 such FNRs.

14) A FNR, if attacked by a large armor piercing missile with a time delay warhead, might potentially become neutron prompt critical and explode. Hence, irresponsible aggressors must be defeated before they can inflict damage to the fleet of FNRs.

15) The risk to the public presented by a nearby power FNR is comparable to the risk of living downstream from a large hydroelectric dam. Either means of electric power generation is a threat to human life if it is subject to a determined military attack.

16) In circumpolar countries, where sufficient thermal capacity for winter space heating is essential, a three fold energy system cost saving can potentially be realized by locating FNRs within cities so that the

low grade heat rejected by thermal electricity generation can be used for district heating. However, urban FNR siting is only viable if the city residents are confident that the FNR will never be subject to a determined military attack. Hence, the public acceptability of urban siting of FNRs will likely become a local ballot box issue.

17) At the present FNRs provide the only practical and affordable means for sustainably halting further fossil CO_2 injection into the atmosphere. The sooner people grasp this engineering fact, the better. They may not like dependence on FNRs, especially FNRs installed within cities, but the alternative is progressive CO_2 driven thermal extinction of all of Earth's large land animals, including