MITIGATION OF GLOBAL WARMING: April 4, 2023

By C. Rhodes P.Eng., Ph.D.

From an astrophysical perspective, CO2 induced climate change (also known as Global Warming) has been well understood since about 1970. The challenge of Global Warming is not caused by any lack of scientific knowledge, it is caused by public reluctance to face astrophysical reality.

Extraction and combustion of fossil fuels has caused increases in the atmospheric CO2 concentration, in ocean acidification and in both dry land and ocean temperatures. The increase in temperatures is causing droughts, sea level rise and increasingly more violent storms.

On the scale of a human lifetime the global warming process is irreversible. However, further increases in atmospheric CO2 concentration and the consequences thereof can be prevented by use of fuel sustainable Fast Neutron Reactors (FNRs) instead of fossil fuels to meet mankind's power and energy requirements.

For reasons related to electricity system stability, the maximum fraction of human prime energy requirements that can be met by wind and solar electricity generation is about 20%. The remaining prime energy must be supplied by hydro electricity and FNRs.

Thus far only a few countries have demonstrated the national resolve required to switch from fossil fuels to clean (non-fossil) energy. In this respect two of the worst performing countries are the USA and Canada. At the root of the problem is misinformation, promoted by vested fossil fuel interests, with respect to dependable power. Governments have irresponsibly funded wind and solar electricity generation, but at best these intermittent energy sources can only displace about 20% of the fossil fuel consumption. CO2 capture and storage, presently promoted by fossil fuel interests, is not a sustainable solution. The only economic and fuel sustainable solution is widespread deployment of liquid sodium cooled Fast Neutron Reactors (FNRs) with supporting used fuel reprocessing.

Formation of Planet Earth:

The elemental and isotopic composition of planet Earth indicates that planet Earth is an aggregation of atoms that were formed during a stellar supernova. Planet Earth is a dense rocky sphere covered by lower density gaseous atmosphere. This rocky sphere initially acquired heat from the gravitational potential energy of its constituent atoms and was further heated by radioactive atomic decay. Today there is continuing absorption of solar radiation and continuing heat loss to deep space by emission of thermal radiation.

Eventually this rocky sphere became captured in its present orbit around our sun. At the time of planet Earth's orbital capture planet Earth had a high surface temperature and a high atmospheric CO2 concentration. Due to the high surface temperature, initially carbonate rock (limestone) did not exist. However, over time near Earth's poles it gradually became cool enough for liquid water to exist, enabling biochemical reactions.

Natural Carbon Sequestration:

Over hundreds of millions of years solar energy driven biochemical reactions gradually sequestered most of the carbon in the atmospheric CO2 and ocean HCO3- ions into carbonate rock (limestone) and fossil fuels. As the atmospheric CO2 concentration gradually decreased Earth's average surface temperature also gradually decreased, which increased the stability of the carbonate rock.

Reversal of Carbon Flow:

Today, combustion of fossil fuels and production of Portland cement and steel together produce CO2 gas many times faster than CO2 is removed from the atmosphere and oceans by natural solar driven biochemical carbon sequestration. The net result is continuously increasing concentrations of atmospheric CO2 molecules and ocean HCO3- ions (ocean acidification).

Effects of Increasing Atmospheric CO2 Concentration:

The effect of increasing Earth's atmospheric CO2 concentration is to reduce Earth's thermal infrared emission which increases Earth's average surface temperature. This surface temperature increase is amplified by a decrease in Earth's 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 higher average wet bulb (humidity adjusted) temperature, a rise in sea level, increased storm violence and changes in atmospheric and ocean circulation.

The increase in wet bulb temperature is making the tropics uninhabitable for humans without electrically driven air conditioning. Part of the CO2 dissolves in ocean water causing ocean acidification that threatens much of the marine food chain.

The situation that the public must face is that continuing combustion of fossil fuels will further increase the atmospheric CO2 concentration making the CO2 driven climate change and ocean acidification problems progressively worse. To minimize further climate change and ocean acidification it is necessary to halt combustion of fossil fuels.

Mitigation of Global Warming:

The only source of dependable prime non-fossil power with sufficient capacity to sustainably fully displace fossil fuels is Fast Neutron Reactors (FNRs). FNRs together with appropriate fuel reprocessing are 100 fold more fuel efficient than today's water moderated nuclear power reactors and with suitable fuel reprocessing produce about 1000 fold less long lived nuclear fuel waste. However, deployment of a fleet of FNRs with sufficient capacity to stop the present ongoing rise in atmospheric CO2 concentration will likely take at least 50 years.

A practical problem is that consumers can not switch from consuming fossil fuels to new FNR supplied clean power until after the required FNRs and related services are constructed. Most present North American public utilities have no provision for funding FNR deployment. A fossil carbon tax levied by

a government will not solve this problem until the fossil carbon tax revenue is dedicated to funding new FNR capacity deployment.

Public Education:

There are a number of important quantitative issues that the public must grasp.

1) Even under the most favorable circumstances, due to intermittency, the maximum possible economic fraction of wind, solar and hydroelectric generated electricity to total world clean energy supply is about 25%.

2) The concept of CO2 capture and permanent CO2 storage underground as a high pressure liquid does not work. Carbon dioxide at ambient temperature and at a pressure greater than 73.8 bar (1085 psi) is a liquid with a density greater than the density of water. When this high pressure liquid CO2 is initially injected deep underground it sinks in ground water, giving the impression that the CO2 is trapped. However, over time the CO2 dissolves in the overhead ground water forming HCO3- ions which gradually migrate out to the atmosphere via diffusion through ground water to connected surface water bodies, water springs, water wells and inadequately sealed well boreholes. This CO2 leakage process is similar to the gradual release of CO2 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 such as Canada or the USA, 1 GWt meets the total energy and power needs of about 100,000 people.

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

5) The other (2 / 3) of the world population, who mainly live at lower latitudes, presently consume only a small fraction of the fossil fuels. However, the lives of these people are threatened by the increasing storm violence, the rising sea level and the increasing peak wet bulb temperatures. These people are being forced to either migrate to higher latitudes or to install continuous electric air conditioning. In either case, by 2070 the total world thermal heat demand is reasonably projected to be about 44,000 GWt.

6) In order to obtain world wide cooperation with respect to CO2 emission reduction, it is necessary to produce about 44,000 GWt of dependable and sustainable non-fossil (clean) heat. Of this amount about 11,000 GWt can be supplied by renewable energy leaving 33,000 GWt or its equivalent, about 11,000 GWe of dependable and sustainable nuclear electricity.

7) Renewable power of 11,000 GWt can come from wind, solar and hydroelectric generation. Hydroelectric power is limited by precipitation and available river geography. Wind and solar electricity generation vary both daily and seasonally 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 prevent further accumulation of CO2 in the atmosphere and oceans it is necessary to immediately build about:
11,000 GWe
of new fuel sustainable nuclear power plant capacity.

9) According to the World Nuclear Association (world-nuclear.org), Earth'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. If mankind relies only on water moderated (U-235 fueled) power reactors to generate the required ~ 11,000 GWe, 100% of the world's affordable natural uranium would be consumed within:
[8.0 X 10^6 tonnes] / [(160 tonnes / GWe-year) X (11,000 GWe)] = **4.54 years**.

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

10) Fast Neutron Reactors (FNRs) with appropriate fuel reprocessing can provide a 100X better fuel efficiency.

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 Uranium-Neptunium-Plutonium fuel cycle due to a hidden requirement for continuous selective chemical extraction of Protactinium (Pa-233) from the reactor neutron flux as fast as it is produced. However, Thorium (Th-232) has the advantage that it is naturally 3X more abundant than fertile Uranium (U-238).

13) At least half of the 11,000 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 11,000 GWe must be installed in or near cities in higher latitude industrialized countries. In order to allow efficient deployment of district heating each urban sited FNR should have a full load capacity in the range 200 MWe to 300 MWe. The minimum required number of such urban sited FNRs is about:
5500 GWe / (275 MWe / FNR) = 20,000 FNRs.
Each such 275 MWe FNR can meet the reasonable total energy needs of about 82,500 people in an industrialized country. In the near term Canada will need about 485 such FNRs.

14) A FNR, if attacked by a large armor piercing missile, might potentially become neutron prompt critical and explode. Hence, irresponsible aggressors must be defeated before they can inflict damage to 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 electricity generation is a serious 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 large electricity 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 acceptable if the city residents are confident that the FNR will never be subject to a determined military attack.

SUMMARY:

At this time fuel sustainable FNRs with supporting fuel reprocessing provide the only practical and affordable means for minimizing further CO2 driven climate change. 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 continuing sea level rise, increasing storm damage and ongoing extinction of Earth's major land animals and marine species.