Good Aerosols, Bad Aerosols: Mitigating Global Warming through Solar Geoengineering, Carbon Dioxide Removal and Ancient Vedic Methods

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Abstract: Our globe is threatened by the menace of global warming caused due to the excessive emission of greenhouse gases (GHG). Almost all the Governments and other organizations in the world are grappling to fight this problem. This includes multidimensional measures to reduce the emission of greenhouse gases caused due to pollution, dust, burning of fossil fuels, automobile exhausts, industrial exhausts, uncontrolled construction activities, and deforestation etc. But there is another school of thought comprising of scientists and planners who are engaged in partially counterbalancing the global warming process by spraying some chosen aerosols in the stratosphere which partially reflect the solar radiation back into space, thus causing a cooling effect on the planet Earth. Yet there is another method of geoengineering, called "Carbon Dioxide Removal (CDR)". Another exotic method to tackle this problem of pollution as well global warming, which we discuss in this paper, comes from the ancient Vedic wisdom from India by performing Yagnas (Havan) under controlled conditions by the trained people (priests). In this paper, we discuss all these approaches to tackle the global warming problem and give our recommendations.

Keywords: Aerosols, Global Warming, Solar Geoengineering, Solar Radiation Management (SRM), Carbon Dioxide Removal (CDR), Vedic Methods, Yagna, Yajna, Environment.

I.INTRODUCTION

The world is confronted these days with the menace of atmospheric pollution, its impact on the human heath as well as another equally scaring phenomenon, called "global warming". NASA data shows that the hottest year on record was 2016, and before that it was 2015, and before that it was 2014, and so on. The rise of global temperature in 2016 was 1.78^0 F higher than the mean of 20th century. Some of the most prevalent greenhouse gases (GHG), responsible for the global warming are: carbon dioxide, methane, ozone and nitrous oxide etc. An increase in temperature due to GHGs, if remains unchecked, can cause havoc to the human and animal life and to our future generations. It could cause glaciers to melt, the sea levels to raise, forest fires to erupt, soil fertility to decrease etc. The whole world is concerned about this. There have been numerous summits in the past to cut GHG (particularly carbon dioxide) emissions but we are not witnessing the effects as we would wish to. These layers of these gases absorb the solar radiation and also the radiation rerediated by the surface of the earth, thus warming the planet. Open burning or biomass burnt in cook-stoves (chullahs) produces particles with a higher proportion of organic carbon that scatters sunlight and results in net cooling of environment, emissions from fossil fuel have a higher proportion of black carbon, which absorbs light and forces heating. Seen this way, the use of low-sulfur diesel has the highest net positive radiative forcing—it warms the atmosphere.

On the other hand, it has been observed by some scientists that some aerosols can have a "direct" cooling effect by partially reflecting the radiation from the sun back to space. [1]. See Fig. 1, as an illustration. Thus the amount of solar radiation that reaches the surface of the earth is reduced.

This results into a cooling effect which mitigates the global warming caused by the greenhouse gases because of absorption of radiation by them. For example, after Mount Pinatubo in the Philippines erupted in 1991, the massive plume of ash it sent into the sky cooled global surface temperatures by about 1^0C for a year [2]. On the other hand, some scientists believe that by cleaning the environment with removal of the maximum amount of pollutants and aerosols, may lead to further rise in the temperatures of the atmosphere due to the unchecked release of greenhouse gases. So there are competing effects of the greenhouse gases and some of the aerosols in the atmosphere in determining its "warming or cooling". But all such aerosols, which produce the cooling effect, may not be good for the human health and for the environment. In fact majority of these may be bad aerosols, due to their micron-size ($PM_{1.0}$, $PM_{2.5}$ or PM_{10}, for example) and the chemical composition which may result into a severe impact on the human health. Many scientists term "bad aerosols" as those aerosols which cause "warming effect" instead of "cooling effect' [3]. But here we redefine "bad aerosols" as those aerosols which are bad for the human health independent of their warming or cooling effects. Aerosols vary in size and composition, they can be naturally or manmade generated. For example, there are a wide range of them, from flame synthesized nanoparticles and nanomaterials (good aerosols), with fundamentally new properties and functions because of their small size (<100 nm) to airborne particulate matter resulted from the industrial production of

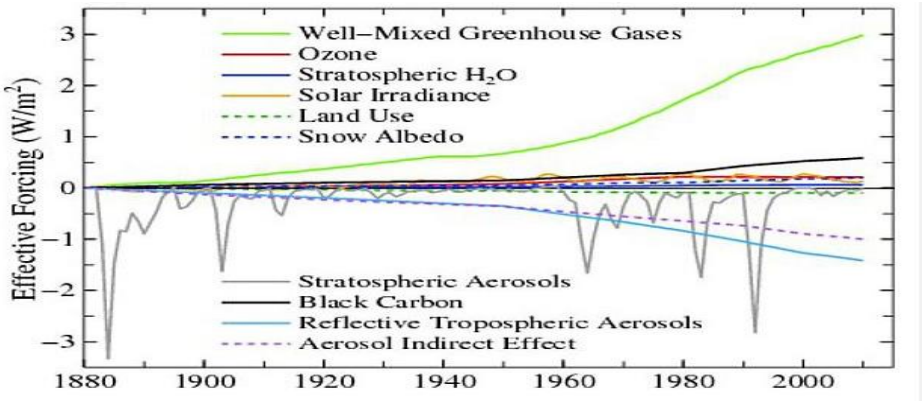
nanomaterials, and viruses that have a negative effect in visibility and human health (bad aerosols) [4]. Thus we are seized with the problem here about releasing some of the "good aerosols", which may not only decelerate the global warming effect to some extent, they should simultaneously cause little harm to the planet Earth and to human health, or preferably may be good for the human health.

But does that mean that we should, without analyzing the other consequences, find some "good aerosols", release them into the atmosphere to counterbalance the global warming and provide desirable effects to the human health? Should we resort to this kind "geoengineering" of the atmosphere? Here geoengineering means any attempt to rebalance Earth's climate budget through direct, large-scale, human intervention to the planet's land, oceans, or atmosphere. It is the deliberate manipulation physical, chemical, or biological aspects of the Earth system to counter global warming. As an example, solar geoengineering is the process of deliberately releasing aerosols into the atmosphere to mitigate the effects of global warming [5, 6]. Solar reengineering is also referred by some as Solar Radiation Management (SRM).

There are alternative techniques of geoengineering, which are called "Carbon Dioxide Removal (CDR)" [6, 7]. Why does CO_2 get most of the attention when there are so many other heat-trapping gases (greenhouse gases) like methane, ozone and nitrous oxide etc.? It is because [8]: (i) CO_2 has caused most of the warming and its influence is expected to continue; (ii) CO_2 remains in the atmosphere longer than all other heat-trapping gases; (iii) Antarctic ice core records illustrate that CO_2 levels have risen by 36% in the last 250 years, with half of that occurring only in the last three decades. CDR techniques aim to remove carbon dioxide from the atmosphere, directly countering the increased greenhouse effect (global warming) and ocean acidification. These techniques would have to be implemented on a global scale in order to have a significant impact of carbon dioxide levels in the atmosphere.

Another exotic proposal which will be discussed in this paper is to exploit our ancient Vedic system, which is thousands of years old and still practiced by a large majority of Indians, for mitigating the problem of "global warming" besides purifying the environment and reducing the concentration of pollutants in the atmosphere.

Fig. 1 Radiative Forcing Curve [Ref 1]



II. HOW TO GENERATE "GOOD AEROSOLS" IN THE ATMOSPHERE?

There have been attempts in the past to spray sulfate aerosols to create this kind of cooling effect on the planet earth [5]. This layer of aerosols in the atmosphere significantly reflects in the incident solar radiation back into the space, thereby producing a cooling effect in the atmosphere or which partially counterbalances the rising temperature caused due to the greenhouse gases. Injecting sulfate aerosols into the atmosphere for this purpose has the following repercussions [5]: (i) Continued ocean acidification: If we use sulfate aerosols as a solution to global warming without imposing any restrictions on continued carbon emissions, the ocean would continue to become more acidic which threatens marine life. (ii) Less sun for solar power: The reduction in incoming solar radiation due to aerosols reflecting them back to space would have a significant impact in the radiation available for solar power systems generating clean energy; (iii Depletion of Ozone Layer: Sulfate aerosols deplete the ozone layer in the atmosphere which allows harmful UV radiation to reach the planet earth; and finally (iv) Unexpected consequences: Scientists cannot possibly account for the entire complex climate interactions or predict all of the impacts of geoengineering. So there are potential side effects of the scheme of spraying sulfate aerosols, however, such as regional precipitation changes, ozone depletion and acid rain. In the light of this, we term sulfate aerosols as "bad aerosols" in spite of the fact that they could cause a cooling effect.

In the light of these discussions, we should search for some kind of "good aerosols", (i) which produce the cooling of planet through a partially reflecting layer by the sun, thus partially decelerating the global warming effect, (ii) which does not deplete ozone layer, (iii) which does not acidify the ocean, (iv) which is not harmful to human health, and (v) which does not disturb the radiational equilibrium significantly etc. With this aim in mind, the following schemes have been suggested for generating "good aerosols" in the atmosphere.

2(a) Calcite as "Good Aerosols" for Solar Geoengineering

Researchers from a Harvard School have identified a "good aerosol" for solar reengineering that may be able to cool the atmosphere with very little adverse effects caused by sulfate aerosols [9, 10]. They found that "calcite", an alkaline material and a constituent of limestone could counter ozone loss, prevent acidity of oceans, while simultaneously cooling the planet. The researchers at this School mentioned that very small amount of calcite, one of the common compounds found in the earth's crust, will be required for the purpose of solar reengineering. These authors have calculated that the injection of calcite ($CaCO_3$) aerosol particles might reduce net radiative forcing while simultaneously increasing column ozone concentration to the desired level [10]. The following chemical reactions are expected to take place between calcite ($CaCO_3$) and acids like HCL, HBR, HNO_3 and H_2SO_4 [10]:

$$2HCl + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O$$

$$2HBr + CaCO_3 \rightarrow CaBr_2 + CO_2 + H_2O$$

$$2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$$

$$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 [+ CO_2 + H_2O$$

These reactions result in HCl, HBr, HNO_3 and H_2SO_4 being removed from the stratosphere, thus decreasing their concentrations, which otherwise would have been responsible for the depletion of ozone layer. Injecting calcite particles into the aerosols thus could repair the ozone hole while simultaneously counterbalance the global warming [11]. Since cutting GHG emissions doesn't cut the risk of global warming; there combining it with solar geoengineering may work better.

These climate researchers (Keith et al) from Harvard now intend to launch a high-altitude balloon, tethered to a gondola that would spray a small quantity of calcite and other aerosols into the stratosphere [12]. In a recent article published in the Guardian [13], it was mentioned that even if the world were to cut GHG emissions to zero tomorrow, it will take decades before the global temperatures would stop rising. Therefore the simultaneous use of solar geoengineering is important today. Evidence suggests that the Solar Radiation Management (SRM) or Solar Geoengineering could be possible as a quick-fix option to tackle global warming if the ramifications of the climate change continue to worsen [14].

2(b) Solar Geoengineering through Iron Salt Aerosols (ISA)

There is a recent proposal for solar geoengineering of using iron salt aerosols as which exert a cooling effect on the climate [15]. It looks into a proposal to enhance the cooling effects ISA in order to reach the optimist target of Paris climate agreement (2016) to limit the global temperature increase between 1.5 and 2^0 C. It has been shown [15] that the ISA method has the potential to cut back on the rise of CO_2 and CH_4. This review paper demonstrates the cooling effects of atmospheric iron dusts in the tropospheric aerosol particles composed partly of iron and chloride (iron salt aerosols, ISAs).

2(c) Geoengineering through Carbon Dioxide Removal (CDR)

Carbon Dioxide Removal (CDR) techniques reduce the CO_2 concentration in the atmosphere by locking away carbon in places where it cannot contribute to global warming [6]. Afforestation is the best solution for CDR, but it is becoming very difficult to implement it at the desirable scale due to various social, economic and political reasons as well as the availability of land for this purpose. Another proposal is to build large machines which can suck and remove CO_2 directly from the ambient air and store it elsewhere [7]. Another more easily implantable method of CDR is through ocean fertilsation where one can transfer carbon from the atmosphere to the deep ocean. This technique focuses on accelerating the growth of algae at the ocean surface. Algae are simple plants that can convert CO_2 into organic carbon, using energy from the sun. A lot of carbon absorbed this way is soon converted back to CO_2 through the process called respiration, and is released back to the atmosphere. However, some of the carbon (in the cells of dead algae and other particles) can sink to the deep ocean where it may remain for a very long period (more than a hundred years or so), thus not contributing to the global warming. However, a limitation of this ocean-fertilisation method is that this would have to be continued indefinitely to achieve the ongoing CO_2 removal. Further, another side effect of this technique is that the marine life, like fish, cannot survive in the deep ocean due to the lack of oxygen at that level. Lately people have devised and designed some chambers that suck the CO_2 gas directly from the atmosphere [16], store this gas and use it elsewhere. Such a plant uses its gigantic fans to push air through the towers containing KOH which reacts with CO_2 gas to form potassium carbonate. The remaining air, now containing less CO_2 gas is released back into the atmosphere. But such an

effort has not been found commercially viable for the desired scale though many countries, including China have bought these CO_2-sucking chambers and installed these at some selected places like parks in Beijing.

2(d) Ancient wisdom of Vedic Methods (Performing Yagnas)

'Yagna' or "Yajna" or "Yagya" or 'Havan" means sacrifice, worship, devotion to anything, prayer, praise, and offering. Normally this process is done in front of a scared fire with simultaneous offerings of cow's ghee (butter), wood, samagri (material) and chanting of 'Mantras' (recitations in Sanskrit language) by a trained and learned priest. Yagna has been an ancient Vedic tradition in India which is more than two thousands of years old. There are various kinds of Yagnas suiting to several occasions but "Agnihotra" is the most popular among them which can be performed daily, preferably in the morning and also in the evening. Here 'Agni' means fire and "hotra" means healing; that means "agnihotra" means: healing through fire. Yagya basically purifies the atmosphere and the improved atmosphere is good for one's physical and mental health [17].

In performing yagna, the heat energy from yagna's fire and the simultaneous sound energy created by chanting of mantras are blended together to achieve the desired physical, chemical, medicinal and psychological benefits [18]. The fumigation and vaporization of substances in the yagna-fire constitute a verifiable scientific method of sublimation of matter and expansion of its colloidal state generates ions and energy with positive effects in the surroundings through the specific sonic waves of the mantras. Wood (called samidha), used in yagna has to be dry and free from dust, insects and worms and is from specific trees like sandal, mango etc. Wood is cut into small pieces according to the size of havan kund (an inverted metallic pyramid where all this stuff is put and burnt). The havan samagri (material) (material) consists of various odoriferous, healing, sweet and medicinal-value substances. Ghee (purified butter) is used made from cow's milk. The temperature attained in the havan kund varies between 250^0 C and 600^0 C, while in the actual flame it can rise as high as 1200^0 C to 1300^0 C.

The fatty substances used in yagna are mainly ghee. The hydrocarbons produced in the reactions undergo slow combustion and, as a result, methyl and ethyl alcohols, formaldehyde, acetaldehyde, formic acid and acetic acid are formed. The vaporized products diffused in the atmosphere are subjected to photochemical reactions in the presence of sunlight. The carbon dioxide produced in this process is also reduced to formaldehyde as in the following chemical reaction [18]:

$$CO_2 + H_2O + 112000 \text{ calories of heat} \rightarrow HCHO + O_2.$$

The formaldehyde thus produced functions the role of disinfectant for removing harmful bacteria. From an environmental angle, the reduction of CO_2, produced by Yagna, and the liberation of oxygen cannot be overemphasized. Similar kinds of other useful reactions take place in the presence of specific radiations from the sunlight. This may be the reason why it has been recommended that yagna should be performed during sunlight.

With the advent of spectrographic techniques it is now possible to study the sound effects of mantras in relation to yagna. The chanting of these mantras produces sound vibrations at specific frequencies, which are beneficial to human mind, heath and all plants and animal life. These vibrations also help in spreading specific energy waves in the surrounding atmosphere with purification effects.

The gases created by Yagna fire help in removing foul odours, removal of bacteria, removal of insects and produces positive effects on the plants and vegetation. Even the burnt ash produced after yagna has been found to increase the fertility of soil and purification of water.

The wood and fossil burning in the environment is always controversial because of the generation of CO and CO_2. The yagna also produces these gases but it should be noted here that the way in which samidhas (wood) are burnt in yagna is a process of slow combustion. It is different from the burning of coal in the factories or household fires where oxygen is sucked in large quantities and CO_2 is emitted likewise. In the slow combustion process that takes place in Yagna, a small quantity of oxygen is utilized and CO_2 is produced in a very small quantity most of which gets converted to formaldehyde though the photochemical process, the rest of $CO_2$is absorbed by the surrounding plants and the CO_2 cycle is strengthened. Some part of CO_2 full of aroma goes very high in the atmosphere which rids it from the pollutants and other ozone depleting substances.

Agnihotra yagya was performed in 2014 [19] and the concentration of certain pollutants and other products was measured after this performance. It was noticed that SO_x and NO_x were reduced by 51% to 60%, respectively as compared these contents before the yagya. RSPM and SPM concentrations were also found to be reduced because of yagya. Some more experiments on Agnihotra yagya were performed in 2015 [20] with identical results. In that it was found that SO_x level reduced by 89.37% and NO_x reduced by 25%.

III. DISCUSSIONS, RECOMMENDATIONS AND CONCLUSIONS

The four solutions for global warming proposed in this paper are: (i) solar geoengineering or solar radiation management (SRM) through calcite aerosols to be sprayed in the troposphere, (ii) solar geoengineering through iron salt aerosols (ISA), (iii) geoengineering through carbon dioxide removal (CDR), and finally (iv) through ancient

Vedic methods by performing yagnas. These methods may counter global warming to some extent, but they do not mitigate the underlying causes, namely, the excessive greenhouse emissions. A lot of research is still required in the area of material science, for example, to search for those "good" SRM aerosols which not only cause minimum harm to the human, plant, animal and environmental health but simultaneously have high reflectance for the uv radiation (to protect human beings from uv) , an adequate reflectance for the infrared radiation (to cool the atmosphere), and a negligible reflectance and high transmittance for the visible radiation; the last characteristic is required for the healthy growth of plants in the presence of adequate sunlight and for the efficient generation of solar energy on the earth. These aerosols should not harm the oceans' marine life, the fertility of land and other related issues. Further, it is apprehended that these aerosols may introduce their own risks and uncertainties for the future which might have escaped the attention, imagination and comprehension of the scientists of today. In fact there are some people who term this experiment of SRM as "planet hacking". The geoengineering solution proposed through the carbon dioxide removal (CDR) method amounts to postponing the problem to a distant future date because we remove CO_2 gas from the atmosphere at one place and dump it elsewhere because it does not threaten us in the near future. The Vedic (Yagna or Agnihotra) methods proposed in this paper might reduce the concentration of GHGs, particularly the CO_2 gas to some extent, near the earth's atmosphere before these gases escape to higher levels; but these yagnas have most of the times been performed in the past more as rituals, occasion-specific events or for religious purposes rather than with the scientific investigations as aim in mind. It is strongly recommended that this ancient Vedic wisdom from India, should be investigated more thoroughly and scientifically with the help of modern measuring equipment in scientific and systemic ways by performing yagnas at a large number of places by the trained and learned priests in collaboration with the concerned scientists and environmentalists before we are a position to contribute to the mankind in an unbiased way about this 'wonderful' solution. The scale of performing can neither be very miniscule otherwise the desired effects may not be visible. Nor it should be too large otherwise there might be a danger of too much carbon dioxide being produced near the surface of the earth. Whatever method we adopt as a solution to global warming, we must keep in mind that if you tinker with the nature too much, the nature might punish you back sooner or later. The UN Convention on Biological Diversity called for the governments to ensure that "no climate-related geoengineering activities that may affect the biodiversity, take place, until there is adequate scientific evidence on which to justify such activities…with the exception of small scale scientific research studies." [6]. In conclusion, we sincerely feel that a lot of research and small-scale validation of these concepts is needed before reaching certain decisions for the future. The entire idea has repercussions at social, economic, political, ethical and religious levels. A healthy and unbiased global debate is needed every time the scientists and environmentalists claim to have come out with a panacea or "silver bullet" to tackle the global warming problem. Till such time we should vigorously continue our campaign to cut down the GHG emissions through proven methods.

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