Addendum:

How the Different Parts of the U.S. Government and the Private Sector Can Help with Using Enhanced Weathering, OAE, eOAE and eOAE2 to Combat Global Warming

In this addendum, page numbers and the "***document***" refer to the ***How to Combat Global Warming*** article.

The following is a summary of the most important parts of the *document.*

To combat global warming in time to avoid many trillions of dollars of damage to the world, will require the removal of 10 to 20 gigatons of CO_2 per year from the atmosphere (National Academies Press, 2018).

Techniques to remove CO_2 from the atmosphere are called Negative Emission Technologies (NETs) and Carbon Dioxide Removal (CDR). Direct Air Capture with Sequestration is termed DACS. It utilizes several different million-dollar commercial machines such as Climeworks, Carbon Engineering and Global Thermostat, to extract CO_2 from the atmosphere, after which it is buried.

The current emphasis is on DACS. The Department of Energy has allotted 3.7 billion dollars to test this technology in several hubs. In DACS atmospheric CO_2 is captured onto various materials and terawatts of electricity are then needed to release the captured CO_2.

The many potential problems with DACS are reviewed on pages 23 - 26 of the *document.* The two major problems are high energy cost to release the bound CO_2 and safety issues. At gigaton levels of storage concern is that a leak or an earthquake could release megatons of CO_2 and kill thousands of people.

The National Academies Press review (2018) proposed the removal of 10 gigatons per year till mid-century and then 20 gigatons/year. With DACS alone this would be a total of 1,280,000 one megaton burials by the end of the century. To think that none of these would ever leak is unrealistic. The eruption of tons of CO_2 killing a thousand of people and thousands of cattle from Lake Nyos in 1986, is an example of how deadly such leaks can be. One accident killing thousands of people would probably be a death knell to DACS similar to the effect of Chernobyl, 3-Mile Island and Fukushima on the nuclear power industry. Having safe backup NETs is critical.

Enhanced Weathering (EW) and Ocean Alkalinity Enhancement (OAE) avoid this issue because the mineralized CO_2 is placed above ground or in the ocean. There is far more room above ground than there are suitable places underground.

OAE using olivine can be accelerated by electrolysis (pages 158 - 165). We term this eOAE.

The potential danger of a leak of CO_2 with DACS can also be avoided with *in situ* sequestration of CO_2 because the CO_2 is chemically attached (mineralized) to the rocks. As such it is immune to release by earthquakes, accidents, and other problems. However, it is also expensive requiring terawatts of electricity and has problems with elevation of the ground with gigatons are buried. It was estimated that the *in-situ* burial of one gigaton would increase the volume over the area by the equivalent of 35 Empire State Buildings.

Both EW, OAE and eOAE use ultramafic rocks. EW can also use mafic rocks such as basalt. We call them Climate Rocks. Both are very common, and deposits are present in many countries. Mafic rocks have high levels of silicon, ultramafic rocks less so.

One of the most effective of the ultramafic rocks is olivine. Its most common variety is a magnesium form, Mg_2SiO_4 called forsterite. The most common mafic rock is basalt.

The reaction for Enhanced Weathering occurs on the surface of land and is called *ex situ* sequestration. It is very safe and permanent.

The critical equation is: $Mg_2SiO_4 + 4CO_2 + 4H_2O \Rightarrow 2Mg_2^{++} 4HCO_3^- + H_4SiO_4$

or olivine + CO_2 + water => carbonates + silicates

The carbonates are the mineralized form of CO_2 resulting in safe, permeant, above ground or ocean sequestration of CO_2.

This combination of olivine and related minerals, + CO_2 + water is what saved the earth from being an oven like Venus. Venus had no water, and its atmosphere is 96.5% CO_2 and mean temperature is 875°F. The earth had plenty of water and its atmosphere is 0.04% CO_2 but climbing. Its mean temperature is 59°F, also climbing.

<u>99.94% of all carbon on earth is stored in mineral form, while only 0.06% is stored in the ocean, the atmosphere, and in all life.</u> This equation and these rocks can once again save the earth from what humans are doing to it.

In nature, the above equation took place over thousands of years. This reaction takes place on the surface of the rocks. To maximize the rate of mineralization the rocks need to be finely ground to a 1 um size. This can speed up the reaction to as little as several weeks. Multiple parts of the *document* address this issue.

For example, a 5 cm diameter piece of olivine has a surface area of 78.5 cm^2. When ground into 1um pieces the surface area is increased 250,873 times markedly increasing the weathering rate.

Combating ocean acidification, warming and deoxygenation is also critical since billions of people rely on the oceans for their livelihoods, the vast majority in developing

countries. In addition, the corals, critical for the health of marine life, are currently dying, and the warm oceans are generating devastating hurricanes. It has been said "If the oceans die, we die."

To sequester gigatons of CO_2 using EW and OAE/eOAE it will be necessary to mine, grind and spread gigatons of climate rocks. The grinding can be performed using renewable energy.

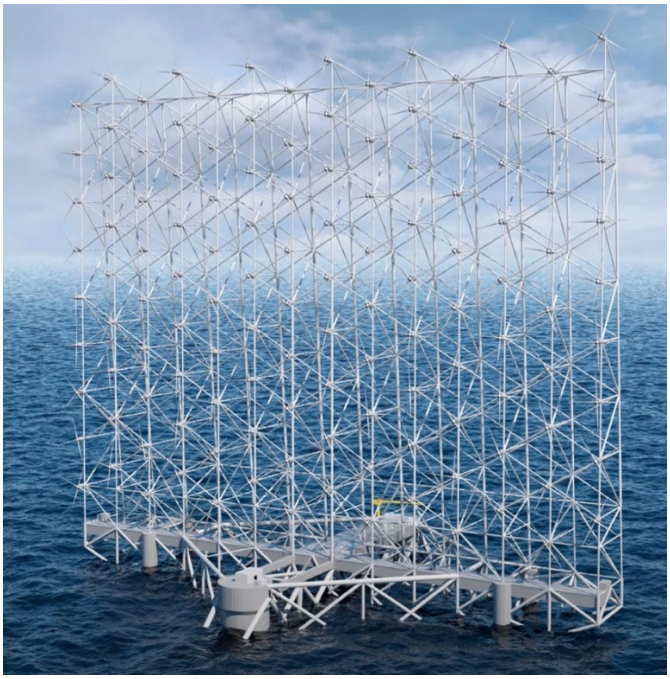
In addition to needing to mine gigatons of climate rocks a potential downside of using ultramafic rocks is that they contain nickel and chromium. We show (pages 234-246) that this is largely a manageable issue.

eOAE2. An exciting alternative to OAE using climate rocks is a form of OAE using electrolysis that directly removes CO_2 from sea water and converts it to carbonates without the need for climate rocks. We term this eOAE2 or e2 for short.

One of the most promising eOAE2 techniques is a hybrid of two electrolysis procedures, one that removes CO_2 from the ocean and converts it to mineralized carbonates (La Plante et al, 2021,2023) and a second that produces an alkali such as NaOH to alkalinize the seawater that is returned to the ocean. It requires large amounts of electrical energy. However, both reactions produce hydrogen that can be used in fuel cells to partially mitigate the electrical needs.

We propose that eOAE and eOAE2 units can be placed on ships. This would have many advantages (p 215).

We also propose that the electricity needed for eOAE2 could be supplied by islands of floating solar panel islands and/or floating wind turbines. The field of floating wind turbines is rich with innovative ideas. For example, a company called Windcatching proposes the follow design.



Utilizing the full energy of higher wind speeds in the open ocean and their multi-rotor design, the Windcatcher can generate 5x the annual energy production of a conventional 15 MW wind turbine. This would thus produce 75 MW. Since this is more than required smaller versions could be used. Clearly they would need to avoid hurricane allley.

Placing the solar islands with docked eOAE2 ships or barges, within areas of ocean currents, would allow the ocean to be brought to the ships instead of the ships moving in the ocean.

Once the eOAE2 ships and solar or wind turbine islands are paid for the ongoing expenses would be minimal allowing continued yearly sequestration of CO_2 at low cost. No reqirement to bury gigatons of CO_2. No requirement to mine and process gigatons of ultramafic rocks.

Thus, the most effective alternatives to DACS for gigaton levels of CO_2 sequestration are:

1. **EW. Enhanced weathering (EW) *ex-situ* sequestration in mineral form on land surfaces.**
2. **OAE Ocean Alkalinity Enhancement (OAE) using CaO, MgO and $Mg(OH)_2$. Mg(OH)2 can be derived from olivine.**
3. **eOAE Electrolysis enhanced OAE using olivine.**
4. **eOAE2 with the direct removal of CO_2 from seawater and storage in the ocean as carbonates without using olivine.**

EW and the 3 OAEs satisfy the following essential features:

1. **Capable of sequestering 10 - 20 gigatons of CO_2 each year.**
2. **The sequestering is safe and permanent.**
3. **No dangerous burial of gigatons of CO_2 is involved.**
4. **When EW is done on cropland it improves rather than removes cropland.**
5. **The OAEs combat ocean acidification, deoxygenation and warming.**
6. **Combat land and ocean release of N_2O.**
7. **Help reverse the destruction of coral reefs.**

To give an appreciation of the magnitude of the problem - to sequester 10 gigatons of CO_2 using EW it will be necessary to mine at least 10 gigatons of climate rocks. The total amount of coal mined worldwide averages 7.9 gigatons. Clearly, to obtain the necessary scale, this task needs to be shared by all countries that have suitable deposits. It would require a global Manhattan Project type effort.

Multiple terawatts of electricity are NOT needed using Enhanced Weathering and OAE since the reaction is exothermic. Grinding does require energy but that can be supplied by solar or wind energy and potentially modular nuclear energy and/or molten salt reactors (see MSRs and Terrestrial Energy pages 74, 139, 263).

The worldwide storage capacity of *in situ* sequestration is estimated to be trillions of tons of CO_2 (Fox 2021, page 47-48). **The limiting factor is that this still requires CO_2 capture and high energy is required for its release. There can be some mechanical problems with sequestration of this amount of CO_2 (page 48).**

While the largest of the suitable sites for *in situ* storage are in Oman, large sites are also in New Caledonia, and New Guinea and the U.S. The CO_2 to be injected would come from the DACS machines.

The Columbia River Basalt Group in the US has a total mass of over 300,000 km^3, more than enough for massive CO_2 *in situ* sequestration. There are smaller basalt deposits at other locations.

There are huge deposits of ultramafic rocks in New Caledonia. We should explore working with that country to develop their potential for both *in situ* and *ex situ* CO_2 sequestration.

<u>Currently, none of the mined climate rocks in the world are used for EW/OAE/eOAE.</u>

<u>To activate EW and OAE/eOAE we need to initiate the mining and processing of climate rocks in the U.S. and world-wide.</u>

One issue in national politics has been saving the jobs of Appalachian area coal miners. In addition to coal this area has large deposits of climate rocks. As coal is phased out those miners and coal companies could be re-positioned to mine climate rocks.

As with wind and solar, initiating large scale mining of climate rocks will produce many new jobs in the U.S. and worldwide.

The *document* and this Addendum also outlines how the private sector consisting of wealthy philanthropists, Non-government Organizations (NGOs) and hundreds of non-profit climate clubs, can play an important role in utilizing EW and the 3 OAEs to combat climate change.

We list five companies that have commercialized Enhanced Weathering. This is a way that venture capitalists could help to initiate the mining and use of climate rocks.

While there are some sorbents that may cut the cost of DACS (Jain and Lemcoff (2022) this would still be expensive. Other approaches (Prajapati, A et al (2022) may decrease costs still further. However, lowering the cost of DACS does not solve the potential danger of leaks.

Part of the Bipartisan Infrastructure Law included $2.1 billion for a Carbon Dioxide Transportation Infrastructure Finance and Innovation Program. None of these funds would be necessary with EW/OAE/eOAE/eOAE2 since no transportation of CO_2 is required. At least some of these funds could be used to develop EW/OAE/eOAE/eOAE2.

It has been suggested that we cannot remove gigatons of carbon without a price on carbon. This may be true, however, that comes with a lot of economic and political problems. It is possible that the costs of EW/OAE/eOAE/eOAE2 could be funded by all the governments of the world. In the long run they would be saving money since trillions of dollars in mitigations and damage would be avoided.

EW/OAE/eOAE/eOAE2 will be important, critical, and safe parts of the solution to global warming. The more widespread their use by other countries, the more effective they will become.

Even when the reduction of emissions is maximized, there is a residual portion of emissions that will be resistant to all efforts, such as the emissions by airplanes, agriculture, cement, the continued release by forest fires, and some land sites and ocean locations that put out gigatons of CO_2. The EW/OAE/eOAE/eOAE2 programs will need to be in place long term to sequester the CO_2 produced by those resistant sources.

It is estimated that Airlines will have to "solve" their CO_2 problem with offsets which could each 1.7 billion tons/year by 2035 (Kallbekken and Victor 2022). This clearly indicates a need for continued EW/OAE/eOAE/eOAE2.

Global wood harvests. In near future the cutting of forests will be driven by a 130% increase in demand for paper products and increase in demand for furniture, flooring, and other timber products. The demand for wood that can be burned for fuel is by far the most popular use and is poised to increase by 22%. As a result, emissions from global wood consumption is likely to **average 3.5-4.2 billion tons per year of CO_2 for next three decades**. This **equals 10% of annual CO_2** emissions and approaches estimates of annual emissions from land-use change due to agricultural expansion and is **three times more than that emitted annually by the global aviation industry.** This is an additional source of CO_2 resistant to the push for negative emission and an additional need for continued removal of CO_2 from the atmosphere (Peng et al, 2023).

The mining, processing, distributing, and selling of climate rocks could become the next Exxon Mobiles, and unlike the demise of fossil fuels they would be needed very long term.

The billions of dollars used in subsidies to support the fossil fuel industry could be shifted to supporting the climate rock mining industry. Since the same companies currently extracting fossil fuels could shift to extracting climate rocks, there would not be a reason for them to oppose this shift of federal subsidies. The current fossil fuel companies could easily switch from removing fossil fuels from the ground to removing climate rocks from the ground.

In addition to the above, there are other creative ways to enhance the effectiveness of EW. These are:

Explore the possibly of using vertical farming techniques (p 274-277) to produce artificial weathering hot spots located anywhere and especially located close to where the rocks are mined. This would avoid the costs of transportation and maximize weathering rates.

Explore the use of biocatalysts using fungi and other vehicles in conjunction with vertical farming, to accelerate the rate of weathering (see page 142).

Explore the possibility of developing a Drone Program in which the many thousands of members of the hundreds of NGOs and non-profit climate clubs could use inexpensive drones to spread finely ground climate rocks on huge expanses of mountains, forests, scrubland, pastureland, and croplands in the U.S., thus avoiding the high cost of using airplanes.

However, before any of this can happen, it will be necessary to begin mining and grinding climate rocks worldwide. This needs to start as quickly as possible. While The U.S. Government and the UN need to lead in this effort private enterprise could play an important role.

Use of eOAE/eOA2 on inexpensive catamarans using renewable energy could be purchased and crewed by the hundreds of NGOs and non-profits involved in combating climate change.

<u>An advantage of non-profits and philanthropists.</u> While a number of companies using various CDR technologies have been set up based on profits from selling carbon credits, this is inherently counterproductive since it simply gives CO_2 emitters an excuse to continue to emit. Non-profit organizations and organizations financed by philanthropy avoid this problem.

The proposed eOAE2 ships could also use nuclear power. The U.S. Navy is uniquely positioned to develop such ships. If some of the current fleet of 10 nuclear powered aircraft carriers and 71 nuclear submarines were retrofitted with eOAE2 machines, this could, over the rest of the century sequester up to 38 gigatons of CO_2 at relatively little cost. This is equivalent to 38,000 one megaton burials of CO_2 using DACS. Since we are not currently fighting any shooting wars, these ships can be used to fight the worldwide war against global warming.

One of the outstanding advantages of U.S. Navy nuclear fleet based eOAE is that once the eOAE ships are retrofitted the subsequent yearly costs would be minimal since these ships are used and their staff and expenses paid primarily for defense purposes. This could save many billions of dollars when compared to DACS, *in situ,* and even EW.

The following section presents suggestions on how to enlist many branches of the U.S. government and the private sector to bring about this critical addition to controlling global warming.

How the Different Parts of the U.S. Government and the Private Sector can help with Using Enhanced Weathering and OAE to Rapidly Combat Global Warming

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Notes:

• While this addendum discusses Departments in the U.S., most other countries have somewhat similar departments.

• Much of the following would cost very little since the tasks could be covered by the normal operating budgets of the respective departments. In addition, the funds for combating climate change in the Inflation Reduction Act could be used to carry out many of the following suggestions.

Shortly after he took office, President Biden asked all the different branches of the government to draw up plans to combat climate change. These focused primarily on reducing emissions. The problem was that most had timelines of 20 to 50 years to approach zero emissions and that, of course, related only to government facilities. Unprecedented heat waves and forest fires are already causing many billions in losses annually and thousands of deaths.

We cannot wait two to five decades. In addition, to reducing emissions, we also need to remove CO_2 from the atmosphere. The administration recognized this and has devoted $3.7 billion to various DACS (Direct Air Capture and Sequestration) hubs. As outlined on pages 23 to 26 in the document, there are serious problems with the underground storage of gigatons of CO_2. **Enhanced Weathering and 3 OAEs avoid those problems since the products produced by the mineralization of CO_2 are placed above ground or in the ocean.**

eOAF2 (pages 202 - 220) is the best and potentially the least expensive of all NET solutions since after the initial setup costs to allow it to run renewable energy, the yearly ongoing costs would be minimal.

This proposal in no way reduces the need to cut emissions. While many think that cutting emissions hurts the economy, two books*, Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming* by Paul Hawken and Tom Steyer and *Speed & Scale: A Global Action Plan for Solving Our Climate Crisis Now* by John Doerr, show there are many different ways to cut emissions, **most of which aid rather than hurt the economy.** However, **even if we reach close to zero emissions the CO_2 in the atmosphere will remain there for many hundreds of years, all the while continuing to devastate the earth**. **To avoid this and a cascade of tipping points** (p 285-295) there is universal agreement that in addition to cutting emissions we must also remove CO_2 from the atmosphere. We need action in 5 to 10 years, not 20 to 50 years.

The U.S. Needs to Mine and Stockpile Ultramafic Rocks

There are currently virtually no mining companies that mine ultramafic rocks just for use in EW/OAE/eOAE projects. Given the U.S. government's agreement that climate change is a critical issue for our national security, and given the reality that prevention is cheaper and better than endless mitigation, we have a pressing reason utilize the help of the many government agencies that could be involved. The following sections propose some programs and suggest how different government agencies might be involved.

What is needed now is a second round of presidential directives to the various branches of the U.S. Government, this time **to draw up plans to activate the EW/OAE/eOAE/eOAE2** NETs. There are thousands of individuals in these different departments of the government and marshalling them toward a well-defined goal, as happened with the Manhattan Project and Apollo Project, could accomplish the goal of halting the U.S contribution to global warming in years rather than many decades.

DOE - The Department of Energy

Recognizing the need to remove CO_2 from the atmosphere, the DOE has devoted $3.5 billion to fund regional Air CO_2 Capture hubs that will each capture at least 1,000,000 metric tons of CO_2 from the atmosphere. However, because of the potential problems with the underground storage of gigatons of CO_2 (p 23-26) we believe EW, OAE, eOAE and eOAE2 are a much safer and more permanent methods of sequestering CO_2. Thus, it would be helpful if the DOE also funded different aspects of the EW/OAE/eOAE/eOA2 technologies.

The DOE has initiated *Energy Earthshots - Carbon Negative*. They hosted its first-ever *Carbon Negative Shot Summit* in July 2022. With more than 1,700 people from 39 countries in attendance, and 39 total speakers across the keynote sessions and panel discussions, the day brought together leading innovators, advocates, stakeholders, and policymakers to discuss how to

advance commercially viable, just, and sustainable carbon dioxide removal (CDR) in the United States. One theme emphasized repeatedly throughout the day was how the push to advance CDR will not be limited to a single approach.

The DOE has two new resources—the *Carbon Matchmaker Tool* and *Carbon Management Interactive Diagram*—to learn about new carbon management provisions and funding opportunities.

Dr. Jennifer Wilcox, Principal Deputy Assistant Secretary for Fossil Energy and Carbon Management (FECM) in the DOE has developed numerous programs and workshops relevant to Carbon Removal and Storage and the entire DOD under the leadership of Jennifer M. Granholm Secretary, U.S. Department of Energy is devoted to research and development of Carbon Capture Technology.

We would urge this outstanding team to explore and fund EW,OAE,eOAE and eOAE2 and help to initiate the mining of Climate Rocks and the building of eOAE/eOAE2 ships in the US and rest of the world.

The National Energy Technology Laboratory (NETL)

The NETL is part of the U.S. Department of Energy national laboratory system and is owned and operated by the DOE. It supports the DOE mission to advance the energy security of the United States. It is committed to helping develop methods of CO_2 sequestration as indicated by its recent sponsoring of a Mineral Carbonation Workshop.

Importantly, the NETL publishes a great newsletter entitled, *Carbon Capture Newsletter* keeping readers up to date on all aspects of Carbon Capture. This newsletter needs to discuss the advantages of EW, OAE, eOAE and eOAE2.

National Renewable Energy Laboratory (NREL)

The NREL is transforming energy through research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. To help combat climate change NREL engages with a variety of organizations such as the United Nations' Intergovernmental Panel on Climate Change, Future Earth, and the World Climate Research Program to investigate and report on climate change impacts and mitigation strategies in urban areas. It is an ideal Laboratory to assist in research into EW, OAE, eOAE and eOAE2.

National Carbon Capture Center lead by John Northington, needs to add EW/OAE/eOAE/eOAE2 to the technologies they are exploring.

The Geophysical Fluid Dynamics Lab (GFDL) When the Intergovernmental Panel on Climate Change (IPCC) released its Sixth Assessment Report, Vaishali Naik and many of her colleagues at the GFDL contributed to the scientific results. As a physical scientist at GFDL, she is a part of the biogeochemistry, atmospheric chemistry, and climate division for the NOAA laboratory in Princeton, New Jersey. She is a coordinating lead author of the chapter on "Short-lived Climate Forcers," contained within the Working Group I Sixth Assessment Report.

National Ocean Service should also be interested in EW, OAE, eOAE and eOAE2.

DARPA Defense Advanced Research Projects Agency and ARPA-E

For sixty years, DARPA has held to a singular and enduring mission: to make pivotal investments in breakthrough technologies for national security. Nothing could be more relevant to our national security than controlling global warming.

DARPA History and Mission The genesis of that mission and of DARPA itself dates to the launch of Sputnik in 1957, and a commitment by the United States that, from that time forward, it would be the initiator and not the victim of strategic technological surprises. Working with innovators inside and outside of government, DARPA has repeatedly delivered on that mission, transforming revolutionary concepts, and even seeming impossibilities into practical capabilities. The ultimate results have included not only game-changing military capabilities such as precision weapons and stealth technology, but also such icons of modern civilian society such as the Internet, automated voice recognition and language translation, and Global Positioning System receivers small enough to embed in myriad consumer devices.

DARPA explicitly reaches for **transformational change** instead of incremental advances. It works within an innovation ecosystem that includes academic, corporate, and governmental partners, with a constant focus on the Nation's military Services, which work with DARPA to create new strategic opportunities and novel tactical options. For decades, this vibrant, interlocking ecosystem of diverse collaborators has proven to be a nurturing environment for the intense creativity that DARPA is designed to cultivate.

DARPA comprises approximately 220 government employees in six technical offices, including nearly 100 program managers, who together oversee about 250 research and development programs.

DARPA goes to great lengths to identify, recruit, and support excellent program managers—extraordinary individuals who are at the top of their fields and are hungry for the opportunity to push the limits of their disciplines. These leaders, who are at the very heart of DARPA's history of success, come from academia, industry, and government agencies for limited stints, generally three to five years. That deadline fuels the signature DARPA urgency to achieve success in less time than might be considered reasonable in a conventional setting.

Program managers address challenges broadly, spanning the spectrum from deep science to systems to capabilities, but ultimately, they are driven by the desire to make a difference. They define their programs, set milestones, meet with their performers, and assiduously track progress. But they are also constantly probing for the next big thing in their fields, communicating with leaders in the scientific and engineering community to identify new challenges and potential solutions.

Program managers report to DARPA's office directors and their deputies, who are responsible for charting their offices' technical directions, hiring program managers, and overseeing program execution. The technical staff is also supported by experts in security, legal and contracting issues, finance, human resources, and communications. These are the people who make it possible for program managers to achieve big things during their relatively short tenures.

At the Agency level, the DARPA Director and Deputy Director approve each new program and review ongoing programs, while setting Agency-wide priorities and ensuring a balanced investment portfolio.

DARPA benefits greatly from special statutory hiring authorities and alternative contracting vehicles that allow the Agency to take quick advantage of opportunities to advance its mission. These legislated capabilities have helped DARPA continue to execute its mission effectively.

ARPA-E The **Advanced Research Projects Agency-Energy** advances high-potential, high-impact energy technologies that are too early for private-sector investment. ARPA-E awardees are unique because they are developing entirely new ways to generate, store, and use energy.

Given its history and mission, as outlined above ARPA-E is in a unique position to tackle some of the more difficult scientific aspects of EW/OAE/eOAE/eOAE2. These would include:

- Appoint a team of scientists to focus on EW/OAE/eOAE/eOAE2.
- Develop catalysts that could accelerate the rate of the reaction of climate rocks + CO_2 + water ➞ Mg and Ca carbonates.
- Develop technologies that could also remove methane and N_2O from the atmosphere in addition to CO_2.
- Identify the most energy efficient methods of grinding climate rocks to 1 um size or smaller.
- Identify the best solar, wind, fuel cell and battery technologies for zero carbon OAE/eOAE/eOA2 ships.
- Identify the best fuel cells to provide power for zero carbon eOAE/eOA2 ships, especially those that can use the products of electrolysis. These would be most likely to use H_2.`
- Validate whether carbonic anhydrase can cheaply convert CO_2 from eOAE2 ships into carbonates.
- **Identify the best hybrid electrolysis techniques for eOAE2.**
- Identify the most effective electrolysis technique for eOAE with climate rocks.
- Identify the best modular nuclear reactors for producing electricity for grinding climate rocks and releasing captured carbon dioxide.
- Identify the best drone technology for spreading climate rocks in the mountains.
- Identify the most efficient methods of dispersing finely ground climate rocks on croplands and non-croplands. Can drones do the job?
- Examine the potential of different plants, or other technologies, to remove nickel and other heavy metals from soils (Rylett and Bruce, 2022; van der Ent et al (2021). However, as reviewed in the document, Nickel and Chromium may not always be a problem.
- Investigate the validity of using vertical "farming" techniques to develop weathering hot spots anywhere in the world (p 274-277).
- Help to design vertical farming plants suitable for EW.
- Contribute to the design of a carbon free ships for eOAE and eOAE2.
- Determine if an organic catalyst would help increase the efficiency of eOAE2.
- Work with the U.S. Navy to examine the possibility of using the Navy's fleet of nuclear ships for eOAE2.
- Explore the use of floating solar and wind turbine islands to power eOAE2.

Since DARPA-E works closely with industry it, along with other agencies, could play an important role in recruiting the industrial mining of climate rocks in the U.S. and other countries.

The Commerce Department

Carbon Offsets There is a billion-dollar carbon offset industry. Carbon offsets, purchased by many major companies, produce the illusion their companies are carbon neutral

(green washing). A significant percent of these offsets (up to 50 percent) involve trees or planting trees. The problem here is that the CO_2 these companies emit stay in the atmosphere for many hundreds of years while the trees provide a very temporary storage for the carbon. For example, a large proportion of the trees in Oregon, sold for carbon offsets by Green Diamond, recently burned down, releasing many tons of supposedly permanent offsets. A list of the many additional problems with tree planting for carbon offsets is provided by the David Suzuki Foundation www.davidsuzuki.org/Climate_Change/ What_You_Can_Do/ trees3.asp One of the problems he did not list is the potential shift of trees from photosynthesis to respiration, as temperatures increase (p 285).

A solution to the temporary nature of most carbon offsets This problem could be solved by having companies buy and spread many tons of climate rocks. Such a program could be administered and monitored by the Commerce Departments of the world and would provide offsets that really do have permanent CO_2 storage. Given the number of companies around the world that need carbon offsets, this could approach gigaton levels. This, of course is dependent on a significant world-wide increase in the mining of climate rocks.

Assisting NPOs and Non-profits. On many pages of this Addendum, we outline how individuals, NPOs and non-profit climate clubs can contribute to the fight against global warming by spreading ground climate rocks on their own gardens, lawns, and other areas and in other ways. The following are some of the things the Department of Commerce could do in this regard:

• Aid in the distribution of bags of ground climate rocks. This could be done through giant retailers such as Amazon, Walmart, Target, Garden Supply Stores, and others. These outlets would also make available Climate Rock Kits consisting of tools for spreading the ground rocks, safety masks, a set of core samplers, directions for their use.

• Individuals would need tools to spread the rock powder. The DOC could contract companies that manufacture garden and farm equipment, such as Stihl, John Deer, Garden Tool Suppliers, Hofmann Industries, Inc., and many others, to design, develop and manufacture the appropriate tools for this purpose.

• Individuals spreading the finely ground rocks will need suitable protective masks since 1 um (micrometer) particles can enter the lungs. It will be necessary to test the masks for effectiveness and make them available.

• Set up the centralized laboratory for core sample analysis. This would likely involve mass spectroscopy analysis, pH, moisture, metagenomics, and other variables.

• Work with other countries to develop the same programs.

• Launch TV, radio and newspapers ads promoting this program, emphasizing how individual citizens can help. Perhaps draw an analogy to the patriotic Victory Gardens of WWII. Contests and prizes could award those who spread the greatest amount climate rocks. These could take place at the level of the climate change club.

On pages 30-32 of this document, I discuss the **Drone Program** - a method of massively increasing the role of individuals helping to combat global warming. Now much larger amounts of climate rocks are needed, and it may be more effective for cities, counties, and states to assist in receiving and distributing many tons of climate rocks. The federal government's role would be to ensure an adequate supply of price subsidized ground climate rocks.

The Commerce Department and the Air Force could also assist in coordinating this program.

USGS - The U.S. Geological Survey

The USGS can play an important role in three ways.

1. If one does not already exist, develop a complete data base on the sites of mafic, ultramafic, and tailing deposits in the U.S. Table 2 of Krevor et al, (2009) and Dickerson et al, (1996), provide a good start. Evaluate **those deposits that are most suitable for mining** and explore methods of rapidly increasing the amount of ultramafic and mafic rocks mined. Also aid the developing solar and wind farms to supply the energy needed to finely grind the rocks to 1 um size.

2. Identify which sites would be suitable for *in situ* sequestration of gigatons of CO_2. Develop sites for the placement DACS machines.

3. Working with Dr. Jill Rolland, the regional director of the Pacific Islands, to determine if the U.S. can work with the governments of New Caledonia and New Guinea to utilize their deposits of ultramafic rocks for both *in situ* and *ex situ* sequestration of CO_2. The FECM division of DOE is already cooperating with the USGS on carbon storage worldwide.

4. **Help to identify the most optimal sites to begin mining and processing ultramafic rocks in the Western states of Washington, Oregon, and California**. These sites should also include areas for solar panels or wind turbines to supply the energy for grinding, and access to transportation of the ground rocks.

The DOD (Department of Defense) and Department of Homeland Security

In his book, *All Hell Breaking Loose*. *The Pentagon's Perspective on Climate Change,* Michael Klare documents in detail the **US Military's deep concern about how climate change is impacting the security of the United States**. He stated, **"Top military officials perceive climate change as a secondary but insidious threat, capable of aggravating foreign conflicts, provoking regional instability, endangering American communities, and impairing the military's own response capabilities. Worse yet, warming's impacts are expected to grow increasingly severe, complicating the Pentagon's ability to address what it views as its more critical tasks."**

The DOD has also stated, **"Climate change is an existential threat to our nation's security, and we must act swiftly and boldly to take on this challenge."** For these reasons, the DOD and the Department of Homeland Security need to be intimately involved in the actuation of Enhanced Weathering and OAE.

The risks to the military were felt to occur on two fronts.

1. The risk to military installations world-wide.

2. **The risk that droughts, desertification, excessive heat, rising seas, hurricanes, floods, and forest fires will cause instability of some nations resulting in mass starvation, mass migrations, disputes, and wars. These mass migrations from Central America to the U.S. and in Sudan due to climate change, are already occurring.**

Regarding the first, Congress directed the Department of Defense to conduct a full-scale assessment of climate-related threats to all US military bases – a total of 3,500 installations. An interim report Climate-Related Risk to DOD Infrastructure: Initial Vulnerability Assessment Survey was released January 2018. The greatest reported impact was from **drought** with 782 facilities (22% of all bases) experiencing some drought conditions, 763 bases reported impacts

from **strong winds**, 706 from **severe flooding**, and 210 from **wildfires**. It was stated that these bases are launch platforms and "**You can't fight a war unless you have a place to leave from**."

As if to emphasize the danger, a few months after the report was released Hurricane Micheal inflicted catastrophic damage on Tyndall Air Force Base in the Florida Panhandle, home of the super-sophisticated F-22 Raptor fighter planes, each costing $339 million. Senior military officials agree that **climate change is not some far off future problem, it is happening now**.

Regarding the second, "Pentagon analysists highlight the deleterious effect of climate change on vulnerable populations, fragile states, and brittle institutions around the world. **They see climate change as ratcheting up global chaos, which in turn means greater likelihood of U.S. involvement in ugly foreign wars." Such wars would cost us billions to trillions of dollars.**

Rear Admiral David Titley, former chief oceanographer of the U.S. Navy, noted that this, "can exacerbate or inflame tensions within or between states. **These problems can lead to state failure, uncontrolled migration, ungoverned spaces…and terrorist activity."**

Climate change will produce an increased call on U.S. Forces to provide humanitarian aid and security services known as "stability operations."

The collapse of economic and governmental institutions in numerous areas of the globe would disrupt vital trading networks and help foster deadly pandemics. In worst case scenarios, the major powers will fight over water and other vital resources, producing new global rifts and potentially involving the United States in full-scale ward with nuclear armed belligerents.

The American military will lose its capacity to defend the nation from multiple foreign perils, while the homeland itself will be ravaged by storms, floods, droughts, fires, and epidemics.

And this was only the first few pages of the book!

In the most recent report by the DOD (2021) includes the following statement, **"There is little about what the Department does to defend the American people that is not affected by climate change."**

Klare stated, **"As we write this, in September 2021, all of the above is already happening."**

Clearly the DOD has a vested interest in rapidly bring global warming to a halt. We believe the EW/OAE/eOAE/eOAE2 NETs are an effective way to do this.

The Army Corps of Engineers

The Army Corps of Engineers could be the ideal department to work with the **Olivine Corp** in Washington, or buy them out, and **dramatically accelerate the mining of climate rocks at the Twin Sisters site in Washington State.** In addition, they could build the solar or windmill farms or modular nuclear power, for the grinding of the rocks. They could also develop the modes of transportation to nearby ports for both eOAE ships and to distribute the ground rocks to other parts of the country or other countries.

The same approach could be taken with **Unimin (Covia)** for the ultramafic deposits in the Appalachian Mountains. The ultramafic deposits in California and Oregon (p 59-66, 291-295) are other potential mining sites in the U.S.

The Air Force

The air force could also play a significant role. As outlined in the section below, entitled **A Role for the Private Sector - NGOs and Non-profits,** we envision a very large role for them in a **Drone Program.** While the inexpensive drones discussed could easily handle spreading climate rocks in most of the land areas in the US, they probably would not be powerful enough to reach the higher reaches of the mountains. The Air Force could play an important role in modifying some of their drones to serve this purpose. The Air Force could do the mountain spreading themselves or train some members of the involved NGOs and non-profits in their use.

In addition, the map on page 78 of *the document*, shows the massive areas of non-cropland in the arctic and sub-arctic regions and deserts of Africa. While not as ideal as tropical hot spots, the massive areas could be used for depositing climate rocks. Some of these areas would require drones that were more powerful than the inexpensive commercial drones.

The Navy

The Navy could play a central and very critical role. The conclusion of the *document* is that one of the very best approaches to sequestering gigatons of CO_2 would be the development of a fleet of nuclear powered eOAE2 ships. If some of the current fleet of 10 nuclear powered aircraft carriers and 72 nuclear powered submarines were retrofitted with eOAE2, over the rest of the century this could sequester up to 38 gigatons of CO_2/yr at very little cost. Once the retrofitting was complete the yearly cost of sequestering the CO_2 would be minimal potentially making this the cheapest NET. See **Thinking Out of the Box** (p 219-220).

The Navy could also play a major role in OAE by developing a new **OAE Corps** that would oversee the building and staffing of **a fleet of OAE/eOAE/eOA2 vessels, some nuclear powered**. The **staffing would involve a corps of sailors, officers and scientists trained in the use of OAE/eOAE/eOAE2 technology**.

The U.S. Navy and Marine Corps announced the release of its climate strategy, *Climate Action 2030,* setting the Department of the Navy on a path to achieve the Nation's commitment to net-zero greenhouse gas emissions by 2050, while becoming a more capable, agile, and lethal fighting force.

"Climate change is one of the most destabilizing forces of our time, exacerbating other national security concerns and posing serious readiness challenges," said the Honorable Carlos Del Toro, Secretary of the Navy. "Our naval and amphibious forces are in the crosshairs of the climate crisis and this strategy provides the framework to empower us to meaningfully reduce the threat of climate change."

Climate change is expected to intensify the rate of threats the Department of the Navy will need to meet. These conditions require the Navy and Marine Corps to adapt to meet new operational requirements, respond to increasingly common humanitarian response missions, promote regional stability, and address risks to installations and defense communities. **"To remain the world's dominant maritime force, the Department of the Navy must adapt to climate change: we must build resilience and reduce the threat."**

The Navy is committing to draw down an additional five-million metric tons of CO_2 or equivalent pollution per year by 2027 – roughly the equivalent of removing one million cars off the road. The Navy will also deploy cyber-secure microgrids or comparable technology to leverage carbon pollution-free power at our bases and installations to support critical missions. The Navy also has a vested interest in stopping global warming and developing ships that run on renewable emery.

NOAA - National Oceanic and Atmospheric Administration

Regarding aiding with OAE/eOAE/eOA2, NOAA already has a robust program the **Ocean Acidification Program.**

This Program supports a wide variety of projects both within NOAA and cooperative academic institutions. These research projects examine specific themes aimed to determine our nation's vulnerability to ocean acidification. Their goals include determining our nation's vulnerability to ocean acidification which demands a trifecta of:

1. Quantifying the environmental exposure of marine life to ocean acidification through monitoring and modeling of ocean chemistry,
2. Discerning the sensitivity of marine life to ocean acidification through biological response research and ecosystem models, and
3. Understanding the human dependence on organisms most impacted.

NOAA will be valuable in assisting and monitoring an OAE/eOAE effort. They are also combating climate change in other ways.

NOAA's Role in Combating Climate Change NOAA Climate.gov provides timely and authoritative information about climate. They promote public understanding of climate science and climate-related events through videos, stories, images, and data visualizations; make common data products and services easy to access and use; and provide tools and resources that help people make informed decisions about climate risks, vulnerability, and resilience.

NOAA Normals are critical for characterizing current weather and climate.

Some additional specific areas where NOAA might be of great assistance are:

- Help with the design and building of the OAE/eOAE/eOAE2 carbon free ships.
- Help with the governance and international laws, if any, involved with OAE/eOAE/eOA2.
- Help with the governance and international laws involved in spreading finely ground ultramafic or other minerals in the ocean.
- Help with the question of whether focusing OAE/eOAE/eOAE2 efforts to areas of CO_2 outgassing is reasonable (p 165-171).
- Help with the question of whether focusing on the great barrier reef would be worthwhile.
- Help with the on board mesocosms to monitor the effects of OAE/eOAE and eOAE2 on ocean chemistry and marine life. Consultation with Dr. Riedesell of the GEOMAR Helmholtz Center for Ocean Research in Kiel, Germany (p 200) would be of benefit since they are proposing the same type of studies off Norway.
- Help with identifying the best electrochemical techniques for eOAE.

The State Department

Since the proposals outlined in the accompanying document involve international **cooperation with all countries of the world**, the State Department would be the go-to organizations to organize this international cooperation and commitment.

They could also initiate a financial aid program for **New Caledonia** to develop the vast deposits of ultramafic rocks in that country (p 48). This would be an ideal location to supply OAE/eOAE ships in the South Pacific and in the areas such as the threatened Great Coral Reefs

off northern Australia, and areas of CO_2 outgassing such as along the equator of the coast of Ecuador (page 167, 176).

New Caledonia and New Guinea have ultramafic deposits comparable to those of Oman (p 48-53) but has a more assessable government. Like in Oman these deposits could be used in conjunction with Direct Air Capture installations, to safely sequester megatons to gigatons of CO_2 using *in situ* sequestration. The U.S. State Department, working with the governments of New Caledonia (and France) could help finance and develop such an operation.

The Department of State could also play a role in soliciting the help of Ecuador in the Equatorial Project (p 176).

The Department of Agriculture

Since placing ground climate rocks on cropland would constitute an important aspect of the Enhanced Weathering project the Department of Agriculture would need to be heavily involved. If the **Drone Program** becomes effective, the department could assist in that approach to spreading climate rocks on croplands and other lands. They could play a critical role in farmer education in the use of this NET.

The Department of Interior

Part of the Climate Action Plan of the Department of Interior includes the use of the Best-Available Science. Planning and decision making will use the best-available information that considers existing and projected climate change vulnerabilities, risks, and impacts. The most effective science will work in co-production with the management community to provide integrated multi-scale science outputs to inform decisions. Decision-making will rely on scientists across the government and beyond. This includes, but is not limited to, the science expertise of the U.S. Geological Survey (USGS), including its National and Regional Climate Adaptation Science Centers (CASCs), bureau science programs, and other resources such as the U.S. Global Change Research Program's (USGCRP) National Climate Assessment.

Since some of the ultramafic and mafic deposits are on federal land the Department of Interior can play an important role on these projects. In addition, if the vertical farming hot spot weathering site concept (p 274-278) works, the Department of Interior could play an important role in identifying appropriate sites.

BLM - The Bureau of Land Management

The BLM manages more than 245 million acres of public land located primarily in 12 western states, including Alaska, on behalf of the American people. The BLM also administers 700 million acres of sub-surface mineral estate throughout the nation. Their mission is to sustain the health, diversity, and productivity of America's public lands for the use and enjoyment of present and future generations.

Most BLM public lands are in these 12 western states: Alaska, Arizona, **California**, Colorado, Idaho, Montana, Nevada, New Mexico, **Oregon**, Utah, **Washington,** and Wyoming.

Given the BLMs mission it probably has a role to play in helping to manage the commercialization of deposits of mafic and ultramafic rocks in the Western States especially **Washington, Oregon, and California**. As shown in the following, its mission also covers issues related to geologic carbon storage.

The Bureau of Land Management Issues **Geologic Carbon Storage Policy for Public Lands**. As part of a comprehensive strategy to combat climate change and reduce carbon dioxide

levels in the atmosphere, the Bureau of Land Management has issued a new policy relating to geologic sequestration of carbon dioxide on public lands.

Geologic carbon sequestration is the process of safely injecting carbon dioxide—the most common greenhouse gas—deep underground, permanently preventing it from entering the atmosphere and contributing to the climate crisis. Carbon dioxide has been injected underground in the United States since the 1940s, but typically as a temporary measure to produce more oil. This is the first time BLM is issuing a policy to allow for the hopefully permanent underground storage of carbon dioxide.

"This policy is an important tool to help the BLM combat the climate crisis and supports the Biden-Harris Administration's goal of reaching net zero emissions economy-wide by no later than 2050," said BLM Director Tracy Stone-Manning.

The new instruction memorandum provides a path for geologic carbon sequestration projects on BLM-managed lands by providing direction for authorizing rights-of-way for site characterization, transportation, injection, capture, and permanent storage of carbon dioxide at appropriately classified injection well locations. A right-of-way grant authorizes rights and privileges for a specific use of the land for a specified period appropriate for the life of the project.

The instruction memorandum will help ensure consistent processing of right-of-way applications for carbon sequestration projects across all BLM-managed lands and provide guidance to BLM staff on how to address compliance with other applicable laws, environmental review, the term of the authorizations (a 30-year renewable term), rental payments, cost recovery, and adequate monitoring and long-term stewardship.

While presently there are no approved carbon sequestration projects on BLM-managed lands, the BLM is currently processing two applications, one in Wyoming and one in Montana, and has received inquiries related to other potential projects in several states.

Because of the wide range of different types of land use in the U.S. it is likely that the **The Bureau of Land Management** would be involved in granting the permissions to spread climate rocks in many locations.

EPA – Environmental Protection Agency

If there was ever an important issue related to environmental protection it is global warming, which is already devastating our environment. The EPA will also be involved in granting permissions to carry out OAE/eOAE in US areas and with US ships (NAS 2021).

NRC - Nuclear Regulatory Commission and Oak Ridge National Laboratory.

The U.S. Nuclear Regulatory Commission was created as an independent agency by Congress in 1974 to ensure the safe use of radioactive materials for beneficial civilian purposes while protecting people and the environment. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection, and enforcement of its requirements.

Because of some scary nuclear reactor accidents, such a Chernobyl, Three-mile Island and Fukushima-Daiichi, many people are justifiably afraid of nuclear power. This was such a problem for some governments that most of the nuclear power plants in Germany were shut down and the building of new reactors in the U.S., has virtually come to a stand-still.

Molten Salt Reactors In the 1960s Dr. Arvin Weinberg, then Director of the Oak Ridge National Laboratory, had an **operating MSR (Molten Salt Reactor) successfully running for**

two years. Ironically, President Nixon shut down this program because it did not produce the plutonium needed for bombs. **A Molten Salt Reactor is super safe and cannot suffer a melt down since it is in a constant melt down state,** which is an inherent part of its operation. If an earthquake or tsunami occurs, and all the operators die, and all the electricity stops, a freeze plug melts and the molten salt drains to underground holding tanks and the reactor stops. This is a proven technique since that was how the MSR was shut off over weekends in the 1960s. In addition, nuclear waste is a tiny fraction of that of Light Water Reactors (LWRs) and in fact **MSRs can use as fuel, the waste from LWRs**. Thus, instead of spending billions to store the huge amounts of LWR waste, it can be used to drive MSRs. MRSs can also use thorium which is far more common than uranium. For details on Dr. Weinberg and the MSR technology see www.thecomingsfoundation.org go to Molten Salt Reactors.

It could be argued that if MSRs rather than LWRs were used to produce electrical power, their inherent safety, lower cost, and modularity would have resulted in the rapid replacement of coal powered electricity and **the rapid accumulation of global warming CO_2 might have never happened.** It is not too late to resurrect this important technology.

If one were to fantasize about an ideal solution to replacing fossil fuels with renewable energy some of the requirements would be:

- zero carbon footprint,
- able to burn up waste from LWRs,
- can use common thorium rather than rare uranium,
- cheaper than coal,
- inexhaustible energy supply,
- minimal waste,
- capable of producing both electricity and fuel,
- relatively inexpensive and would not require the multiple billions and long building lead times typical of LWRs.
- no environmental impact – (no threat to birds as with wind turbines or the desert as with solar).
- modular (thus avoiding the gigantic gigawatt reactors).
- does not require long power lines as with wind and solar.
- very safe.
- resistant to earthquakes (i.e., Fukashima)
- resistant to meltdowns (i.e., Chernobyl, Three Mile Island)
- resistant to terrorism
- affordable to developing nations.

MSRs satisfy all these requirements. Ironically, several years ago **China downloaded all the information on MSRs publicly available at the Oak Ridge National Lab and committed five billion dollars to build their own. They recently announced the development of working MSRs. Thus, they are taking our technology and doing what we should have done decades ago.**

There are several companies that are currently developing Molten Salt Reactors. We believe that **Terrestrial Energy** is the furthest along. There are two parts of this company – **Terrestrial Energy Canada and Terrestrial Energy USA**. In personal communications the Canadian branch expects to be approved in 2025 and the U.S. branch in 2030. ARPA-E is supporting the Yellowstone Energy Molten Nitrate Salt Reactor development.

The US Government needs to do all it can to support and facilitate the development and approval of Molten Salt Reactors and the associated companies. They can solve all the needs for the energy of grinding to facilitate the dissolution of ultramafic rocks. In addition, it is obvious that this exciting technology can play a major role in replacing coal, oil and gas fired power plants with carbon zero plants.

Because of the many companies getting involved in developing fusion reactors. A breakthrough of obtaining ignition, with more energy out than in, by the Laurence Livermore Laboratory, was announced in December 2022. However, this technology will not be available for decades.

FEMA – Federal Emergency Management Agency

According to its director, Dianna Chriswell, The Federal Emergency Management Administration has placed fighting global warming as a goal. When funds become available a question for them is, how to help. We suggest that assisting in the projects outlined in this document would be a good place to start. They stockpile many items as part of their emergency management. We suggest that stockpiling and distributing finely ground ultramafic rocks to have them available for use on croplands and many other lands could become an important part of FEMA efforts.

CIA – Central Intelligence Agency

The CIA assessed that the effects of a changing climate and environmental degradation will create a mix of direct and indirect threats, including risks to the economy, heightened political volatility, human displacement, and new venues for geopolitical competition that will play out during the next decade and beyond. The degradation and depletion of soil, water, and biodiversity resources almost certainly will threaten infrastructure, health, water, food, and security, especially in many developing countries that lack the capacity to adapt quickly to change and increase the potential for conflict over competition for scarce natural resources.

Clearly the CIA should have an interest in these projects.

NASA – National Aeronautics and Space Administration

In the early 1980s, NASA began working on an expansive Earth science program plan called Global Habitability, and that eventually became the Mission to Planet Earth. At the same time, a multi-agency effort called the Global Change Research Program was also taking form. NASA's role in that larger U.S. program was the provision of global data from space. The resulting Earth Observing System would be the agency's primary contribution to American climate science. The polar ice-observing missions, GRACE, which accurately weighs the total amount of ice, have revealed the unexpectedly rapid changes in the Earth's great ice sheets. This system has effectively countered the climate deniers claim that ice sheets in the Antarctic are actually increasing.

By 2007 NASA had 17 space missions collecting climate data. Today, it runs programs to obtain and convert data from Defense Department and NOAA satellites as well as from certain European, Japanese, and Russian satellites. NASA also sponsors field experiments to provide "ground truth" data to check space instrument performance and to develop new measurement techniques.

Instruments on NASA's Terra and Aqua satellites have provided the first global measurements of aerosols in our atmosphere, which come from natural sources such as volcanoes, dust storms and man-made sources such as the burning of fossil fuels. Other instruments onboard the Aura satellite study the processes that regulate the abundance of ozone in the atmosphere. Data from the GRACE and ICES missions and from spaceborne radar show the unexpectedly rapid changes in the Earth's great ice sheets, while the Jason-3, OSTM/Jason-2 and Jason-1 missions have recorded a sea level rise of an average of 3 inches since 1992. NASA's Earth Observing System's weather instruments have demonstrated significant improvements in global forecast skill.

These capabilities -- nearly 30 years of satellite-based solar and atmospheric temperature data -- helped the Intergovernmental Panel on Climate Change conclude in 2007 that "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." But there's still a lot to learn about what the consequences will be. How much warmer will it get? How will sea level rise progress? NASA scientists and engineers will help answer these and other critical questions in the future.

The role that NASA might play in activating the Enhanced Weathering and the OAE NETs is unclear but given their significant past accomplishments they should be included in the effort. One clear possibility is the use of LANDSTAT data (p 77-78) to identify the different areas of land use. The map on page 78 shows the vast area of non-cropland in the Arctic regions of Canada and Russia-Siberia. While not as ideal and tropical hot spots, it is a huge area to spread climate rocks.

I would also argue that as exciting as returning to the moon and going to Mars are, **we first need to fix our own planet first**.

NASA and Nickel-hydrogen batteries. A powerful bank of batteries could play a major role is the development of ships carrying the hybrid electrolysis eOAE2 technology, and such batteries already exist. For years NASA has used nickel-hydrogen batteries in space craft. see https://youtu.be/2zG-ZrC4BO0.

They can last decades! They are temperature tolerant. Currently a disadvantage is the requirement for platinium and palladium. A company **evervenue** is developing Ni-H batteries that do not require these expensive metals. Ships have the advantage that they can be large enough to carry a large amount of these batteries.

The UN

A Need for Rapid Action UN Assessment Report - AR6 - Climate Change 2021 This scientific report, 3,000-plus-pages from 234 scientists, was released in August 2021 by the UN and Intergovernmental Panel on Climate Change (IPCC). They found that even if nations impose the strictest cuts to atmosphere-warming greenhouse gas emissions today, global warming is likely within the next two decades to surpass 1.5 degrees Celsius. There is wide agreement that the agreements at the COP 26 fall far short of what is needed.

"The recent changes in the climate are widespread, rapid, intensifying, and unprecedented in thousands of years," said IPCC Vice Chair Ko Barrett, senior climate advisor for the U.S. National Oceanic and Atmospheric Administration. "The changes we experience will increase with further warming."

The world has already warmed about 1.1 degrees Celsius, or roughly 2 degrees Fahrenheit since the 19th century. And the consequences are evident.

A previous U.N. climate report that examined the effects of surpassing 1.5 degrees of warming found that an additional half a degree would expose tens of millions more people to extreme heat, cause coral reefs to "mostly disappear" and result in greater habitat loss for animals that depend on Arctic summer sea ice.

While the UN is not a branch of the U.S. Government, our government could urge the UN to set up a World Enhanced Weathering Organization and OAE organization, analogous to the WHO, World Health Organization, to supply scientific and technical support to any country needing it and urge world-wide cooperation in the utilization of EW and the 3 OAEs to combat global warming.

Office of the President and The Biden Climate Team

It is clear from the above that the U.S. government has vast resources that can be tapped to activate Enhanced Weathering and OAE to control global warming. To maximize the speed and optimize the science involved in developing the Enhanced Weathering, OAE, eOAE and eOAE2 NETs as the best approach to halting global warming. We recommend distributing the task to the above departments is a reasonable path to follow.

1. As was done to cut emissions, have the President and the Biden Climate Team instruct all government agencies to do everything that can to activate the Enhanced Weathering, OAE, eOAE and eOAE2 NETs. This addendum offers some specific suggestions.

2. It will be critical to appoint a team of scientific EW/OAE/eOAE/eOAE2 experts for the US, the UN, and the world. They would help to monitor all aspects of the effort. It should include hard driving activists who will do their best to rapidly activate worldwide EW and the 3 OAEs and utilize the Drone Program to participate in the removal of CO_2 from the atmosphere.

The setting of hard targets can help drive progress. The hard targets of developing the atom bomb in four years and a man on the moon in 9 years drove the success of the Manhattan and Apollo Projects. Given a similar level of effort, a hard target of **minimizing the United States' contribution to global warming in 5 years and the entire world's contribution to global warming in 10 years, using EW and the 3 OAEs, may be doable.**

3. Explore the possibility that the Navy could retrofit its fleet of nuclear-powered ships with eOEA2 technology**.**

4. Develop Global Cooperation for Mining Ultramafics Here we would also ask the Biden Climate Team for assistance in following.

- Initiate an International EW/OAE/eOAE/eOAE2 Consortium.
- Identify the location of mineable mafic and ultramafic rock deposits in US and other countries. They are almost always close to the coast as in Norway, United States, Columbia, Australia, New Guinea, and New Caledonia. This is undoubtedly due to the

mechanism of how they are produced, i.e., by the movement of tectonic plates. This costal location is ideal for spreading such rocks in the ocean as well as supplying other countries.

- Initiate the mining of those rocks.
- Develop a source of clean energy for the crushing and grinding of the rocks.
- Develop suitable methods of storing and transporting the ground rocks.
- Identify suitable ports and techniques for placing the ground rocks on ships.
- Identify for a given country the most suitable use of this product – on cropland, non-cropland, in rivers, in the ocean, or simply supplying other countries.
- Those countries that have access to the ocean may prefer to put their ground rocks into the ocean. If so, the development, in conjunction with a Marine Engineering firm (SunReef?), of standardized plans for OAE/eOAE/eOAE2 ships using renewable energy to distribute rocks for alkalinization, would be very beneficial. Determine if the countries of the world are willing to purchase one or more of the above-described eOAE2 ships.
- Determine the amount of credit they each country can receive for these efforts.
- Develop techniques for monitoring the efficiency and long-term effectiveness of CO_2 sequestration and risk assessments including assessing trace metals.
- We would envision that each country put together a team consisting of geologists to identify the bests deposits of ultramafic rocks, mining engineers to determine the best approach to the mining, environmentalists to help minimize environmental impact, electrical engineers to set up the solar panels, mechanical engineers to determine the best methods of grinding, farmers to monitor to use of the rocks on farmland, economists to determine the amount of CO_2 emitted based on amount of gasoline, oil, natural gas and coal consumed, PR people to develop public support and politician's to ensure the smooth operation of the whole undertaking. If any of these specialists are not available, a UN Global EW Organization could supply them. eOAE2 would not require most of these individuals.

5. **Work with New Caledonia**. This nation could become a major supplier of ultramafic rocks in the Pacific Area including for combating equatorial CO_2 outgassing. It is also a potential site for storage of CO_2 by *in situ* hybridization. How do we get that started? It is a French Colony. Do we approach the President of France or the local government, or do we start with one of the authors who have published studies this area, such as Pierre Gautier? This is a task for the U.S. government, the State Department, and the Biden team.

6. **Set up a Department for Enhanced Weathering/OAE** We would also urge the Biden Climate Team to set up a department in one of the government agencies with a title, such as the DOE for EW/OAE, with a consulting staff consisting of many of the investigators listed in this document. This department would have a budget for initiating EW/OAE, eOAE and eOAE2 activities in the U.S. and possibly abroad.

Carbon Tax and Enhanced Weathering. There has been considerable discussion of instituting a carbon tax on all fossil fuel positioned to be used in the U.S. This has especially been advanced by the Citizen's Climate Lobby. The bills in congress to institute this have not yet been approved and may never be. They propose giving the resulting money back to U.S. Citizens. I have great concern about how long this approach would take to produce a significant

decrease in carbon emissions, probably many years if at all. We also have concerns that this taxed fuel would then be used anyway and would emit CO_2, the only difference being that the CO_2 was 'paid for.' CO_2 is still being emitted into the atmosphere.

We would suggest an alternative, that the funds received be given for the development of EW/OAE/eOAE/eOAE2. This would allow the sequestration of the amount of CO_2 equal or greater than what the taxed fuel would produce. It would be an instant result, not a hoped-for result after many years. An additional advantage of this approach is that any proposed bills incorporating this proposal might be far more acceptable to a wide range of liberal and conservative congressmen and get passed. If this approach were to result in a significant reduction in CO_2 emissions and in atmospheric CO_2, the economic benefit would be far greater than distributing the funds to U.S. citizens.

A Role for the Private Sector - Profits, NGOs, and Non-profits.

Lesions from the Tvind School

If NGOs and non-profits feel that because you are outside the power structure of your government, you have no way to set policy you are wrong. Just listen to the story of the Vwind School in Denmark. In 1975, after the first energy crisis, the Danish government concluded the answer was to build many nuclear power plants, despite strong public opposition.

An option was to use wind power instead since many parts of Denmark were very windy. However, some of the largest companies in the world, including Boeing, Westinghouse, General Electric, Hamilton Standard, and other giants had tried and failed to produce reliable large scale wind turbines. Then **a small continuation school in Denmark, consisting largely of teenagers**, set to work researching and designing a giant wind turbine blade **made of cantilevered fiberglass with a giant attachment site at its base**. The students were out to prove to the government that it did not need nuclear power plants. They felt that **if the Danish government would not act, they would take matters into their own hands**. The following is a famous photo of the giant blade they produced.

The 1978 photo of the giant wind turbine blade designed at the Tvind School. From Paul Gipe *Wind Energy for the Rest of Us*. 2016 wind-works.org. p58-68.

The following photo is the Wind Turbine they produced.

The megawatt wind turbine procuced by Twindkraft
of the Tvind School on Jutland, Denmark.
From Paul Gipe *Wind Energy for the Rest of Us*. 2016
wind-works.org. p58-68.

Not only did this wind turbine work, it revolutionized the field of wind energy and formed the basis of modern wind turbines.

So, what is the moral of this story? If your government shows no interest in activating a powerful second front in the fight against global warming, in the form of EW, OAE, eOAE and eOAE2, a grass roots push by NGOs and non-proficts could fill the gap. We present, in these documents, a number of options.

The following are areas where private citizens, NGOs and non-profits could greatly help.

A Role for Wealthy Philanthropists and Committed Companies

Given the increasing restrictions on U.S. government spending it will be increasingly important for the private sector to fill the gap.

• Set up a **Climate Rock Mining Consortium** to oversee and fund the required mining operations, handle the purchase of land (if required), buy out or merge with existing companies, obtain the required permits and work with the governors and governments of the respective states. **This consortium would be funded by wealthy individuals or foundations interested in combating global warming, or well-funded NGOs or non-profits.** This project could be aided by working with an international Geological and Mining Consulting firm such as SRK Consulting.

• Identify the exact location of deposits of climate rocks in the U.S. and determine which are most amenable to mining. These sites are outlined on pages 62-68, 251- 252, of the *document.* Those in **Washington, Oregon and California are of especial interest**. This could be done with the U.S. Geological Survey, or by a privately funded group of geologists (see Dickinson et al, 1996 for an extensive list of possibilities), mining engineers and environmentalists. They could also test for the levels of Ni and Cr in the samples obtained.

• Explore how to the obtain carbon neutral sources of energy (solar, wind, hydroelectric) required to grind the rocks.

• Help to identify the best methods of transporting the ground climate rocks to other parts of the country to support the **Drone Program**.

• Help facilitate the efforts of non-profits and individual citizens.

• Help to explore the potential value of vertical "farming" for EW.

• **Support ship based eOAE/eOAE2**.

• **Support the development of floating solar and wind turbine islands providing the power for eOAE2.**

• **Purchase catamarans containing eOAE2 hybrid technology and give them to climate change non-profits to allow them to participate in the removal of CO2 from the atmosphere and counter acting ocean acidification.**

Commercialization of Enhanced Weathering

The following companies have utilized Enhanced Weathering in their business plan.

The Future Forest Company is located on the Isle of Mull, off the west coast of Scotland**.** As the name implies, this company started out with reforestation. They quickly realized that restoring forests couldn't go far enough on its own to pull excess CO_2 out of the atmosphere. They decided to explore enhanced weathering as a way to help fill the gap. They utilized ground basalt which had the advantage that it did not contain nickel. Because of the area's heavy rainfall, weathering should happen quickly. It sells carbon credits.

Project Vista is in San Francisco, CA. Its ocean carbon capture process accelerates the natural chemical weathering of olivine minerals by spreading a large amount of olivine-containing rocks in and around coastlines.

Heirloom Carbon is also located in San Francisco, CA. It utilizes widely available, low-cost minerals to produce oxides that naturally bind to CO_2 at ambient conditions. It used a process called carbon looping (p 79) illustrated by the following three equations.

1. $CaCO_3$ + heat → CaO + CO_2 ΔHrxn = 178 kJ/mol
2. CaO + H_2O → Ca $(OH)_2$ ΔHrxn = -65 kJ/mol
3. Ca $(OH)_2$ + CO_2 → $CaCO_3$ ΔHrxn = -113 kJ/mol

The first reaction is endothermic, requires a lot of heat, and **produces CO_2 which must be sequestered**. Some of the lost heat is recovered in reactions 2 and 3 that are exothermic. The third reaction combines with atmospheric CO_2 to form a permanent mineral, $CaCO_3$.
To carbonate the material, Heirloom lays out thin layers of $Ca(OH)_2$ powder onto large area trays. The trays are then stacked into vertical, **tiered contactor structures** to minimize land area requirements, all whilst enabling maximum air-to-sorbent contact. This is the same concept we proposed for our **vertical farming to facilitate the olivine mineralization**. It seems counterproductive to produce CO_2 to sequester CO_2. But it seems to work.

44.01 is in the UK. It provides carbon mineralization as a service using direct air capture and other processes including the use of peridotite rocks to sequester CO_2 through mineralization.

Carbon Collect is in Ireland. Their Mechanical Trees technology requires no energy to capture CO_2 from the atmosphere since it functions passively using the wind, thereby reducing the cost of carbon capture. Mechanical Trees is a column that is ten meters tall when extended to capture CO_2 from the air and contains sorbent tiles that constantly expand and retract.

A potential downside of commercializing CDR technologies by selling carbon credits, is that it provides an excuse for companies to continue to emit CO_2 instead of finding ways to reduce emissions.

A Role for Fossil Fuel Companies

Fossil fuel companies across the globe are threatened with a pending reduction in demand for their products as the reduction in man-made CO_2 emissions takes hold. However, **there are many similarities between extracting fossil fuels from the earth and extracting climate rocks. Both require teams of expert geologists, technical expertise, research facilities, significant capital, ability to transport the product worldwide, a sales force and political influence with many countries. As the fossil fuel business decreases the mining of climate rocks can increase.**

An additional advantage is that Climate Rock mining will never become obsolete. Gigatons of emission of CO_2 resistant emission reduction is spewed into the atmosphere each year from agricultural and other land, ocean out-gassing, air travel, volcanoes, and other sources. There will always be an ongoing need to sequester this CO_2 safely and permanently.

This new business does not have to be limited to fossil fuel companies. Any enterprising entrepreneur can get involved.

A Role for NGOs, Non-profits, and Individual Citizens

There are well over **four hundred** non-profit organizations devoted to climate change (Climate Clubs) and NGOs (non-government organizations) devoted to combating climate change across the U.S. and the rest of the world. Many of them have hundreds of chapters and many thousands of members. To date, all they have been able to do is urge their respective governments to address the climate problem, focus on reducing emissions, and sit back in frustration as it becomes apparent that these efforts may be too little and too late.

In a short time, Greta Thunberg was able to marshal **7.5 million supporters for her foundation *Fridays for Future*. It now has 14 million members**. This suggests that given the chance to actively participate in removing CO_2 from the atmosphere, many millions of individuals across the world would be interested in purchasing, at a government subsidized price, finely ground climate rocks to spread on their own lawns, gardens, and other non-cropland areas. If just one of the over 400 climate change non-profits and NGOs can quickly attract 14 million followers, it is not beyond reason that 400 could marshal millions of individuals, to take part in the Drone Program or other tools to spread finely ground climate rocks on lawns, gardens, roadsides, riverbeds, grasslands, mountains, and other non-cropland areas. The individuals involved do not even have to be members of a climate club. Those in the general population can also get involved. They could get the satisfaction of actively doing something to curb global warming and of contributing to the science of enhanced weathering.

The U.S. land area totals 2.3 billion acres.

There are 40 million acres of lawn in the U.S. Climate Rocks can be mixed with the fertilizer normally used on these lawns.

In 2008 there were 45 million houses with gardens in the U.S. These can be liberally dusted with Climate Rocks

In 2012 there were 914 million acres of farmland in the US.

Of these 414 million acres were in permanent pasture, 389 million in cropland. (USDA). Climate Rocks can be spread on both the pastureland and cropland. In this addendum we discuss the development of a Drone Program to assist in this (see below).

For these clubs, instead of the slogan, “Let’s plant some trees” which could backfire if they burned up or if plants shifted from photosynthesis to respiration, the slogan should be **“let’s spread Climate Rocks everywhere we can think of and permanently sequester carbon dioxide.”** It is even possible that a tax break for each ton of climate rocks an individual used, could be used to stimulate this process. We would also change NIMBY (not in my back yard) to YIMBY (yes in my back yard).

If multiple millions of individuals across the U.S. and the world participated in the program, each a ton of climate rocks per year, the total could begin to approach useful levels of CO_2 sequestered (see below). In contrast to the current direct air capture methods, such as Chimeworks, the CO_2 would not have to be sequestered underground.

The following table shows the number of persons involved vs tons and megatons of CO_2 sequestered assuming each person, over year, using the Drone program or other methods, could spread one ton of climate rocks.

# Persons		Tons of CO_2 sequestered *
1	1	ton
10	10	tons
100	100	tons
1,000	1,000	tons
10,000	10,000	tons
100,000	100,000	tons
1,000,000	1,000,000	1 megaton
10,000,000	10,000,000	10 megatons
100,000,000	100,000,000	100 megatons

* Assuming 1 ton of climate rocks would sequester 1 ton of CO_2.

If either the pounds of climate rocks spread pe person, or the number of persons involved was increased, **much higher amounts of CO_2 could be sequestered.** In the U.S. alone, WWII, 20 million families had victory gardens. World-wide a figure 100 million individuals involved does not seem out of the realm of possibility, especially as the effects of climate change begin to affect every person on earth.

Thousands of Mini labs. All these participants should be supplied with a set of simple core samplers. Before any climate rocks are used, it will be necessary to take an initial sample to get background levels of weathering products and heavy metals. The parties could then periodically remove a core sample and send then to a central laboratory for analysis of the rate and effects of the weathering. This, combined with the individuals reporting how much they watered their lawns and gardens, and accessing weather reports about the humidity, temperature, and rainfall in the area where the sample came from, could result in thousands of mini-research plots throughout the world. This could provide a huge database to answer many questions about the rate of dissolution of climate rocks in relation to geographical location, rainfall, humidity, temperature, presence of nickel and chromium, type of rock and other factors.

This involvement by individuals would be valuable for several reasons.

1. These would give the many thousands of individuals in climate clubs worldwide, the satisfaction of being actively involved in the fight against global warming.
2. The numbers in terms of thousands of mini labs providing a large database about enhanced weathering would be huge.
3. The amount of CO_2 sequestered could exceed that of DACS and the sequestration above ground would be safe.

Use of Mountainous Regions

One of the non-cropland places where huge amounts of ground climate rocks could be spread is in mountainous areas. The following table shows the square miles of mountainous land in the US.

Mountain Ranges US	Square miles
Appalachian Mountains	737,000
Rocky Mountains	382,894
Cascade Mountains	200,000
Brooks Range	151,343
Alaska Range	55,889
Aleutian Range	48,143
Ozark Mountains	47,104
Blue Ridge Mountains	34,563
Sierra Nevada Mountains	24,370
Adirondack Mountains	18,702
Olympic Mountains	3,600
San Gabriel Mountains	970
Great Smoky Mountains	816
Total	**1,705,394**

Clearly there are many square miles of mountainous land in the US. In many ways this land is ideal for spreading ground climate rocks.

1. It is not used for agriculture or pastureland.
2. There would be minimal concerns about heavy metal contamination since the level of such metals is probably higher in the mountain land than in the climate rocks. Even if it was not, the effects would be minimal.
3. Rainfall in the mountains is generally adequate to satisfy the equation for weathering of climate rocks (see above).
4. One of the desired effects of EW is that the weathering products are washed into the sea where they help to combat ocean acidification. Most mountain areas feed rivers that discharge into the sea.

Independent of the mountains the following table shows the land use in the U.S.

Land type	Land use (%)	Land area
Forests	27%	842,400 mi²
Shrubland	24%	748,800 mi²
Agriculture	17%	530,400 mi²
Grasslands and Pasture	17%	530,400 mi²
Wetlands	5%	156,000 mi²
Other	5%	156,000 mi²
Open Space	3%	93,600 mi²
Urban Areas	2%	63,400 mi²
Total	**100%**	**3,120,000 mi²**

The Drone Program As shown above, exclusive of land for agriculture there are huge areas of other land including forests, shrubland, grasslands and pasture, wetlands, and other. The nature of both the mountains and these areas suggests that finely ground climate rocks would need to be spread by air. However, planes are very expensive, a trained crew is required, and the planes would themselves produce a lot of CO_2 exhaust, partially defeating the purpose. There is another option that **climate clubs could easily afford - drones**. Drones are not expensive, and they do not require a trained crew. Since they are electric, they do not spew CO_2 into the air. A special city, county, or state agencies could monitor the program to ensure permissions and parcel different areas to different groups to avoid duplication.

There are many companies making commercial drones for sale. Some even specialize in agriculture use for spraying or seeding. The following are three examples, all of which cost less than $25 thousand, well within the range of most NGOs and non-profits.

1. **HSE-UAV XAG P40** The following figure shows it in action.

The XAG's generator + charger combo produces true 240V output allowing the P40's large batteries to charge in just 12 minutes. It can spray **37 acres per hour** at 10 liters per minute with a 4-to-6-meter spray width and a 25 L or 55 lbs. capacity. With rice seeding the capacity is 2.4 tons/hr. It comes with a GC4000+ Auto Super Charge Station that can charge 24 batteries on 4 gallons of fuel. The drone is produced by HSE-UAV.com, 100% U.S. based. It costs $22,000.

2. DJI AGRAS Crop Sprayers. This company makes many models such as **AGRAS MG-1S, AGRAS T16 and AGRAS T30,** and others. They can cover **7 -10 acres per hour**, 40-60 times faster than manual spraying. The payload capacity is 10 kg or 22 lbs. It costs $11,000. All AGRAS have precision operation, able to pre-program the area to be sprayed.

AGRAS T16

3. AIRBORN AGRO A downward facing radar keeps the drone at the right height.

Note the large holding tank with a **60-liter capacity**. The finely ground rocks could be sprayed as a slurry.

Those Climate Clubs that wish to actively participate in the drone program can research the different models for themselves. It is anticipated that throughout the country **most of the areas listed in the above table of land use in the U.S. could be sprayed with finely ground climate rocks.** This would provide dramatically more area than gardens and lawns and only thousands as opposed to millions of volunteers need be involved. As a result, the **Drone Program**, run by many different NGOs and non-profits, **could reach gigaton levels of CO_2 sequestered.** If it proves successful, this program could also cover croplands, reliving the framers of that task.

A Zero Carbon Ship for eOAE2

While EW and OAE utilizing finely ground ultramafic rocks has many advantages over DACS, there are a few negative issues, including the ecological effects of mining, the cost of

mining and grinding, and the cost of transporting and spreading the rocks on land or ship based OAE. **Is it possible that there is an OAE technique that does not require ultramafic rocks?** The **answer is yes**. Pages 202-220 of *the document*, reviews this possibility.

In addition to avoiding the need to mine, grind and distribute ultramafic rocks, there are the following additional positive aspects of shipboard eOAE2.

1) It would avoid the NIMBY and governance issues as well as the costs of land-based operations.

2) It would avoid any concern about whether the massive deposition of ultramafic rock products in the ocean might pose problems with heavy metal contamination, since it simply uses electricity to rearrange the pre-existing chemistry of the ocean.

3. It would avoid the concerns voiced by Fakhraee et al (2022, 2023) (192-195).

4) Being ship based it could concentrate on specific areas of the ocean such as those involved in outgassing of large amounts of CO_2 and areas where corals are dying.

5) Being ship based it could concentrate on specific areas of the ocean where colder seawater temperature, such as the Southern Ocean, result in higher concentrations of CO_2. The higher the CO_2 concentration the more effective the eOAE2 would be.

We propose that the U.S. goverment (NAVY, NOAA) and private capital, invest in developing eOAE2 ship-based technology.

Catamarans and eOAE2

As described in various places in these documents, I have expressed the thought that the Hybrid Electrolysis Technology (HET) driving eOAE2, could be placed on catamarans with the electrolysis powered solely by onboard renewable energy, such as solar panels, horizontal axis wind turbines (HAWTs) and hydrogen fuel cells. However, calculations indicate that is an unrealistic dream. The solar cells and HAWTs combined, even for a 100-foot catamaran, were only able to provide 164 kW. La Plante et al (2021) stated that,

> "The energy requirements of electrolytic mineralization-based CO_2 removal (sCS^2) are formidable. For example, mineralizing 660 t of CO_2 per h would require 1,500 MW of power. It would be necessary to buildout 1,760 plants at this scale, around the world, each having 8410 mesh-electrode units, to annually mineralize 10 Gt of CO_2, while consuming more than 20 PWh of electricity."

And that was only half of the HET. Despite this, I believe there is still a place for catamarans and HET based eOAE2. The following caveats need to be considered.

1. It is not necessary for eOAE2 to carry the whole load of needing to sequester 10 to 20 gigatons of CO_2/yr. EW, the other two OAEs, DACS, and many other lesser NETs would be in the mix.

2. Instead of needing to use onboard renewable energy the required electricity can instead be supplied by multiple solar islands scattered around the oceans (see pages 212 of *the document*) or multiple floating wind turbine islands (see page 4 of *the addendum*). These sources of electrical power would be used in conjunction with the very powerful nickel-hydrogen batteries (see https://youtu.be/2zG-ZrC4BO0 and page 22 of the addendum) using alternatives to expensive rare metal Pt and Pd.

3. In striking contrast to solar and HAWTs, the amount of electricity that can be returned to the batteries by **hydrogen fuel cells** is itself formidable. For every ton of CO_2 sequestered a ton of H_2 is produced. **One ton of H_2 can produce 16.68 MWh of electricity**. For the second half of the HET for every ton of water processed, one ton of H_2 is produced. **Virtually half of the electrical energy required for eOAE2 can be recouped by the fuel cells**.

4. A new basic 50-foot catamaran costs between $750,000 and $1 million. Out fitting them with the HET technology would probably cost an additional $250,000. It is hoped that governments, philanthropists and billionaires will step up and help climate non-profits, NGOs and even individuals buy and utilize this HET based eOAE2 technology. These ships can be manned by a quite small crew. It is hoped that many hundreds of such catamarans will eventually plow the ocean to correct its destructive acidification and warming.

5. Once this HET based eOAE2 technology is set up and paid for, ongoing expenses for sequestering CO_2 would be quite low. As pointed out previously there would be no need to bury gigatons of CO_2 with its attendant safety issues (pages 23 - 25 of *the document*) and no need to mine and grind gigatons of ultramafic rocks as with EW and the La Plante et al (2021, 2023) arm of the HET technology. **Over the rest of the century, this would save many billions of dollars**.

In conclusion: The combined activation of EW, OAE using CaO, MgO, $Mg(OH)_2$, eOAE using olivine, and eOAE2 ships that do not use olivine, all using or running on renewable energy, could sequester a significant part of the needed 10 to 20 gigatons of CO_2 each year.

As Greta Thunberg said, "*we need a whole new way of thinking."*

Often the only thing halting progress on great national and global needs is a viable and specific plan involving a "whole new way of thinking." We suggest that the proposals listed in this *addendum*, and those outlined in the document *How to Stop Global Warming*, constitute just such a plan.

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