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Review

Avoiding the "Great Filter": An Assessment of Climate Change Solutions and Combinations for Effective Implementation

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Abstract: Climate change is the long-term shift in global weather patterns, largely caused by anthropogenic activity of greenhouse gas emissions. Global climate temperatures have unmistakably risen and naturally-occurring climate variability alone cannot account for this trend. Human activities are estimated to have caused about 1.0 °C of global warming above the pre-industrial baseline and if left unchecked, will continue to drastically damage the Earth and its inhabitants. Globally, natural disasters and subsequent economic losses have become increasingly impactful as a result of climate change. Both wildlife ecosystems and human habitats have been negatively impacted, from rising sea levels to alarming frequency of severe weather events around the world. Attempts towards alleviating the effects of global warming have often been at odds and remain divided among a multitude of strategies, reducing the overall effectiveness of these efforts. It is evident that collaborative action is required for avoiding the most severe consequences of climate change. This paper evaluates the main strategies (industrial/energy, political, economic, agricultural, atmospheric, geological, coastal, and social) towards both mitigating and adapting to climate change. As well, it provides an optimal combination of seven solutions which can be implemented simultaneously, working in tandem to limit and otherwise accommodate the harmful effects of climate change. Previous legislation and deployment techniques are also discussed as guides for future endeavors.

Keywords: Great Filter; Climate Change; Earth; Humanity

1. Introduction

In the 1960s, researchers calculated that the average temperature of the Earth would rise substantially during the next century. However, since said century was viewed as still very far off, the concern was dismissed and public attention quickly returned to more immediate issues such as the Vietnam War and the Civil Rights movement. A decade later, with environmentalism on the rise and evidence of a relationship between human actions and global warming becoming apparent, climate change gradually became an anxious public concern again. Such fear was justified: potential hazards resulting from global warming included droughts, floods, hurricanes, severe storms, heatwaves, wildfires, cold spells, and landslides. Constant threats such as temperature shifts, precipitation variability, changing seasonal patterns, changes in disease distribution, desertification, ocean-related impacts, and soil and coastal degradation contribute to vulnerability across multiple sectors in many countries [1]. It was later reported that the failure to reduce emissions from such hazards will cost the world at least $2 billion per day in economic losses. For instance, the economic losses attributed to wildfires in 2018 alone are approximately equal to the collective losses from wildfires incurred over the past decade [2]. Eventually, politicians began focusing on the emergence of a serious new public issue.

After the realities of climate change were first officially recognized by the political world during the late 20th century when the first world climate conference was held in Geneva, the Intergovernmental Panel on Climate Change (IPCC) was established under the United Nations in 1989 to review further political and economic consequences of global warming. Since that time, countries and committees around the world have taken various actions to combat the situation, ranging from political contracts and agreements on such issues as ocean alkalinity enhancement to introducing and expanding carbon taxes. Though multiple world leaders claimed their countries have been continuing to put in their best efforts and pledging to reach their stated goals, objective data shows that many such efforts were, however, far from sufficient, resulting from a lack of legislation and agreements being passed and how those that did pass were sometimes never met, according to the 2018 Emissions Gap Report from the United Nation Environment Programme.

On November 4, 2016, the Paris Agreement went into force as an internationally recognized treaty. The Agreement requires all states to align their efforts with their "nationally determined contributions" (NDCs) that they determined themselves and to report regularly on these efforts. Yet 5 years later, as pointed out by Sir Robert Watson, former chair of the IPCC, most countries still need to triple their 2030 reduction commitments to be aligned with their own Paris Agreement target, and they all currently have the technology and resources to do so. An analysis of the pledges for the 184 signatory countries found that almost 75% were insufficient. The analysis concludes that most countries who took those pledges, like China and India, will have even higher emissions at the end of the decade while others, such as the US and Russia, either pledged substantially low or never pledged at all. Only some, like the European Union, actually modeled reasonable and efficient goals for themselves [2]. The Parties of the Paris Agreement promised to uphold their standards through "appropriate mobilization and provision of financial resources, new technology framework and enhanced capacity-building…[supporting] developing countries and the most vulnerable countries" [3] and maintain their NDCs. However, individual solutions, although recommended, were not specified. For instance, Pakistan has not included a single measurable target in its contribution to a UN climate deal. At 350 words, the final document is slashed from drafts seen by civil society observers. It says Pakistan will need affordable sources of power generation to develop, but has insufficient data to set specific goals. Governments around the globe are still debating which solutions to use and how much time, effort, money, and other resources should be put into each.

Numerous solutions exist and have been proposed, and some complement each other better if implemented together as opposed to utilizing a single solution or a different combination. The purpose of this paper is to evaluate all aspects of these solutions and to devise the optimal combinations that are the most cost-effective, easiest to implement and would benefit humanity the most from the devastating impact of global climate variability.

Integrating different solutions that complement each other limits the negative effects and consequences of others while boosting their combined benefits simultaneously. For instance, a carbon tax proposal by Professor Gilbert E. Metcalf of Tufts University not only included a straightforward tax of $15 per metric ton of CO_2, but he also proposed three different forms of tax credits that would benefit the employers and employees in the factories and other facilities that produce carbon. By this innovative approach, manufacturers would not be incentivized to increase the market price level of their goods, which would be increased if tax credits or other types of subsidies were not given. The revenue to the government from the carbon tax – estimated to be $90.1 billion – would be reinvested in other solutions such as bioenergy development, carbon capture and storage, or new plans for more renewable plants [4]. Another example of complementary solutions includes industrial enhancements in plants along with additional funding and research to maximize the efficiency of industrial capital in production. Historical precedence has proven as well the effectiveness of integrating multiple ones simultaneously. As an example, large scale stationary sources of SOx & NOx dramatically reduced those emissions by installing SCRs (selective catalytic reduction) equipment on furnace stacks in the 1990s, which resulted in a landmark victory in combating smog, particulates and acid rain [5].

Recently, the international community has categorized all climate change solutions into two broad areas: mitigation and adaptation. Mitigation focuses on limiting the number of greenhouse gasses that foster climate change from being emitted into the atmosphere and decreasing the concentrations of existing gasses from the atmosphere. This is done by either regulating emission sources like gas-powered vehicles and industrial factories or enhancing Negative Emissions Technologies (NETs). These solutions "enable economic development to proceed in a sustainable manner" [6]. Adaptation strategies stress the importance of helping countries, especially developing nations and those who face more danger from climate change due to their geographical location, to cope with any potential hazards and consequences. These include managing increasingly extreme disasters and their associated risks, protecting coastlines from rising sea levels, managing ecosystems, dealing with reduced water availability, developing resilient crop varieties, and protecting energy and public infrastructure [7]. A blend of mitigative and adaptive solutions are needed to address the risks of climate change; mitigation solutions lessen the efforts needed for adaptation, and in turn, adaptation decreases the target intensity of mitigation. If combined, vast amounts of efforts and resources will be saved, further proving the value of integrating multiple policies. Suggested combinations in this paper will include both adaptation and mitigation strategies.

This paper first contains a thorough evaluation and assessment for 23 different solutions proposed to combat climate change. The solutions are separated into eight categories based on their fields or sectors of technologies. Each evaluation of the solution covers a general description of their operating process and results of past efforts; if any. The efficiency of each solution is also included and used for comparison. The efficiency of a solution is usually determined by the estimated metric tons of greenhouse gasses (GHG) reduced over a controlled variable of resources (capital, time, physical efforts, funding) for mitigation solutions while adaptation solutions are measured from the risk reductions in disasters (number of lives, amount of property, stability lost). In addition, the assessment presents the solutions' unique advantages and disadvantages comparatively. Finally, the current viability and technological readiness of the strategy will also be given to show when a solution should be implemented to achieve its maximum potential. For better comparison, compiling tables are constructed to weigh the data as well. Based on the evaluations, the paper suggests an ideal combination of the assessed strategies for implementation at the international level. A 2017 UN report estimated that keeping the planet from heating past 2 ˚C above the pre-industrial baseline will require removing 10 billion tons of GHG annually by 2050 and 20 billion per year by 2100. These combinations have their targets set to meet this goal with the most efficacy in effort, time, and money.

2. Mitigation and Adaptation Solutions

Energy

Nuclear:

Nuclear energy and renewable energy are currently the two pillars of clean energy. While the use of renewable energy is steadily climbing, the future of nuclear energy is much less optimistic, contributing 18% of global energy in 1996 and only 11% today. This decline in energy production is a result of increasing competition with renewable energy and low natural gas prices [8]. In addition, fear of nuclear accidents and the possibility of countries transforming nuclear power plants to develop nuclear weapons also limits the support and funding for nuclear energy.

The main advantage of nuclear energy production is a nuclear reactor's high-capacity (i.e., operational) factor. In 2021, this value was estimated to be around 92%, suggesting that each nuclear unit produces energy around 92% of the time on average. This generates nearly 800 billion kWh of nuclear energy in the United States annually, avoiding more than 470 million tonnes of carbon emissions each year. Most recently, nuclear energy produced in 2020 surpassed coal electricity production [9]; however, this trend is not expected to continue as the EIA suggests that coal-fired electricity generation is expected to increase as nuclear-powered electricity generation decreases due to reasons previously listed. Nuclear energy production will also lead to substantial economic benefits; some estimate that current nuclear units located in the United States generate approximately $40-50 billion each year, providing a wide range of job opportunities with stability. Furthermore, land requirements for nuclear energy production are notably lower than other clean-energy sources. According to the Nuclear Energy Institute (NEI), wind farms require 360 times more land area to produce an equal amount of electricity as a nuclear facility requires.

While nuclear plants are relatively simple and inexpensive to maintain over long periods of time, capital costs for nuclear power plants are extremely expensive, ranging from $6,500-$12,250 per kilowatt for a 2,200 MW plant, and levelized cost of energy (LCOE) ranging from $112-$189 per MWh generated. Simply, the high up-front cost of building each nuclear unit deters many investors and companies. In addition, false associations of nuclear power plants with nuclear weapons also contribute to the lack of funding and support for this type of energy resource. Although rare, nuclear accidents in the past have instilled fear among the public, causing nuclear energy to be further cast in a disapproving light. A fair depiction of nuclear power plants to the public is vital for widespread support of nuclear energy, as with many other mitigation strategies.

Nuclear energy is one of the few energy sources that can provide extensive amounts of energy without damaging the environment. Accurate, unbiased data must be available to the public for support towards this energy source. Indeed, the need for energy source education as a necessary topic in school and integration directly into students' science curriculum, becomes increasingly relevant for study as GHG content increases in the atmosphere. Among other strategies to combat global warming, utilizing nuclear energy to replace natural gasses and fossil fuels is among the most critical for study. Media misinterpretation of scientific investigations have led to a rapid decline in nuclear energy support, and a deficient supply chain and workforce have led the cost of nuclear generated energy to be the most expensive source. Reversal of this reality requires improved education and the development of a larger market.

Table 1: Nuclear Energy Data Analysis

Source	LCOE[a]	Cost ($ per kWH)[b]	Energy required	Land required
Nuclear [10]	$148 (+20% from 2009)	Capital costs: $6,500 - $12,250 LCOE: $112 - $189	0.1 - 0.3 kWh of energy input required	Around 1 square mile for a 1,000-megawatt facility

a: Levelized cost of electricity (total cost of building and operating over an assumed lifetime)
b: Kilowatt hours (3,600 kilojoules)

Renewable:

Renewable energy can be defined as originating from sources naturally restored or regenerated and regarded as zero, low or neutral in GHG emission during energy production. This energy type has been receiving the most positive attention as the use of fossil fuels is being challenged, encouraging the growth of renewable energy with support from a developing market and leading renewable energy to become the fastest-growing energy source globally. The future development and deployment of renewable energy sources depends heavily on both international and domestic policies and goals. Market conditions, such as resource availability, cost, demand, and regulations, also determine the growth of renewable energies.

The main sources of renewable energy (in order from greatest least) are hydroelectric, biomass/biofuels, geothermal, wind, and solar. Each type of renewable energy encompasses its distinct set of benefits and disadvantages, and it is difficult to list out a detailed description of all commonalities between the types. However, it can be said that all of these renewable energy types generally increase job opportunities and efficiently use secure energy sources. The costs and land requirements for each of the renewable energy types are listed in the table below, but the land requirement and cost for wind energy is notably low. In addition, wind turbines are easy to maintain and can be sold off for fixed prices over long periods of time, enabling a steady income. However, geographical limitations and wind availability cause wind energy to be not as effective and thus less popular among the renewable energy types.

Renewable energies have much lower energy capacity factors compared to nuclear power or fossil fuels. Some renewable energy sources are also largely intermittent, and wind turbines and solar panels cannot produce electricity in the absence of the necessary ambient conditions. While battery storage of wind and solar-derived power has been proposed as one way to mitigate the effects of these limitations on consumers, this option adds an additional layer of thermodynamic inefficiency while increasing capital cost. In addition, effective installation of wind turbines and solar panels requires large amounts of land and may distress local populations. Situating wind farms away from cities would significantly lower its cost and reduce adverse consequences. However, transmission lines must then be built to deliver wind energy to population centers, further driving up cost and reducing efficiency. Moreover, wind energy development may not be the most profitable use of land and would need to compete with other high-value uses.

Historically, biomass/biofuels regularly demand substantial amounts of energy to operate, and unsustainable bioenergy practices could eventually lead to deforestation and damage natural habitats of various wildlife. Bioenergy utilization also requires considerable space, as companies need to situate production plants close to sources of biomass to reduce transportation costs. Additionally, biomass companies should be encouraged to use agricultural waste instead of growing separate organic matter to reduce their land footprint. Hydroelectric energy production is similarly restricted in establishment areas due to its necessity to be located near bodies of flowing water. Without careful planning, this can disrupt the natural flows of rivers, disrupt animal migration paths, increase water toxicity, and generally displaced both humans and animals from their local environments. While hydroelectricity can be produced for relatively low costs decades after construction, the initial financial investment remains significantly large, and large-scale construction of hydroelectric plant costs may steadily increase as land areas for reservoirs are declining. Local environments must be suited for long-term energy production and precipitation trends must be favorable in order for hydroelectric facilities to function properly and effectively. As well, much of the easily accessible locations for building hydroelectric facilities have already been developed, leaving few new opportunities for additional plants.

Table 2: Renewable Energy Data Analysis

[10]	LCOE[a]	Cost ($ per kWH)[b]	Land required (square feet per kWH)
Hydroelectric	--	$0.04	13,700
Biomass/biofuels	$85	$0.09	152
Geothermal	$97	$0.04	196
Wind	$45 (-67% from 2009)	$0.07	43.6 (direct land use only)

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Solar	$50 (-86% from 2009)	$0.10	100

a: Levelized cost of electricity (total cost of building and operating over an assumed lifetime)
b: Kilowatt hour (3,600 kilojoules)

Currently, Iceland is completely independent of fossil fuels and other nonrenewable energy sources, producing electricity only from hydropower and geothermal facilities, specifically generating 75% and 25% of its total electricity consumption, respectively. In addition, the country has taken advantage of domestic volcanic activity and geothermal energy to obtain hot water and heat. Interestingly, the country only shifted to renewable energy because of economic reasons as opposed to environmental concerns, because the country could not continue to sustain expensive oil importation prices and required a stable energy source. This transition suggests that reprioritized economic policies could be significantly more effective compared to prolonged discussions about global warming consequences, placing an emphasis on political and economic solutions that favor carbon taxation and discourage pollution. Another lesson that can be obtained from this example is to utilize regional environmental advantages, such as Iceland's abundance of naturally occurring geothermal energy. For instance, Rock Port, Missouri exploits its wind resources and produces 125% of the town's energy consumption, and the unused energy can then be sold to other areas as a source of income. While some areas are more suitable for the installation of solar panels, others may instead be incentivized to build geothermal plants due to local characteristics. Thus, each region should be responsible for procuring the maximum benefit based on their own natural atmospheric and geological advantages.

Economic/Political

Carbon Tax:

By definition, under a carbon tax, the government sets a price that emitters must pay for each standardized quantity of greenhouse gasses they emit. Sweden, Finland, and the Netherlands have already adopted such taxes. The desired result is that businesses will take steps to reduce their emissions to avoid paying the tax. However, setting the exact price of the tax often poses a considerable challenge for politicians as too high or too low of a tax usually backfires, and an equilibrium is hard to find in a dynamic economic environment. The effects of the hypothetical tax on emissions will be dependent on the market itself because, due to self-interests and the theory of rational choice, businesses will most likely only reduce their emissions if switching to these reduction activities is cheaper than accepting the actual tax, rendering no effect if the tax is too low. However, setting a price too high on the tax would also be devastating as businesses will impose a higher price level on their goods in order to maintain profit margin, hurting the consuming public. For instance, since most businesses lack direct participation and significant influence in government decisions taken by Congress, a high tax would cause a high level of dissatisfaction among businesses. Hypothetically, once a corporation believes that the tax is taking away from their bottom line, they will raise the prices of consumer goods in order to reestablish profit margin. For instance, a tax of $40 per ton would add about 36 cents to the price of a gallon of gasoline, or about 2 cents to the average price of a kilowatt-hour of electricity [11]. In addition, the negative burdens of the carbon taxes will not be distributed proportionally across all income levels, becoming regressive towards the lower end of the economic spectrum with the poor being impacted almost 5 times as much compared to the top income decile [4]. International actions have been largely set back as well. If the tax rate is high enough to significantly reduce emissions, few, if any, countries will allow an international agency to collect the taxes. If the tax rate is low enough to make an international agency operational, however, it is unlikely to discourage significant cuts in fossil fuel usage [12]. Thus, political actions have usually been hindered and the opinions on an appropriate amount for a carbon tax have often fluctuated amid vigorous debate. For example, there have been several proposed implementations in the US

Congress such as H.R. 2069, introduced by Representative Stark in 2007, which included tax proposals of $15.00/ton on coal, $3.25/barrel on oil, and $7.30/t on natural gas, but it eventually failed. However, other indirect taxes and subsidies are imposed on carbon-emitting factories. Ultimately, the goal is to design a carbon tax to best internalize the effects of emissions and to adjust the income or payroll tax for any distributive effects [4], and be successfully implemented.

Academic papers abroad do not provide a consensus view on the marginal damages of GHG emissions and the optimal tax rate for the US either. For instance, the IPCC reports that $12 dollars per ton would be sufficient, Stern Review reports that at least $85 is needed to implement an efficient carbon tax [13], while MIT researchers proposed an $18 solution with an increase of 4% per year. Others suggest setting a direct price signal through a tax at a modest level initially and increasing it over time. Some also include a tax on GHG emissions at an initial rate of $15 per metric ton of CO_2 that gradually increases over time. A carbon tax levied on all energy-related carbon emissions at a rate of $50 per metric ton and an annual growth rate of 5 percent would generate $1.87 trillion in additional federal revenue over the next 10 years [14]. CO2 emissions will reduce by 8.4% while total greenhouse gasses would be reduced by 14%. Reductions in coal consumption would be 59%, petroleum 34%, and natural gas by 8%. Simulations show that the carbon tax revenue for the United States stays constant after 3 or 4 decades at around 1.2% of the US GDP, which is equivalent to roughly 300 billion dollars currently [4].

Another estimation predicts that a carbon tax starting at $25 per ton and rising at 2% over inflation annually would have raised $1 trillion over its first decade [15]. The U.S. currently raises a similar amount with all of its other excise taxes. However, the impact of the tax on societies as a whole would ultimately depend on how exactly these revenues are used. For example, rebating the revenues directly back to households in poor economic conditions, using them to aid and improve the welfare in low-income communities, or compensating workers in carbon-intensive industries are some applications of the carbon tax revenue by the government [16]. Carbon tax revenues should be used to reduce other taxes in a way that maintains progressivity [4].

Comprehensive carbon policy packages have been proposed by various professionals and credited sources, all of which would include other policies that would complement the carbon tax and contribute to reductions in carbon emissions in the United States at the same time. Increased spending on energy-related research and development, providing energy production subsidies that contribute to a continuing reliance on US fossil fuels, and implementing tax credits are all solid suggestions for complementary implementation [17]. These subsidies are often justified on the basis of encouraging energy independence in the United States since they replace imported fuels with domestic fuels, increase energy security, along with enhancing support for energy efficiency investments in order to contribute to a reduction in energy consumption and carbon emissions. This includes the action of improving current production technology and funding capital investment in factories and other production facilities.

Cap & Trade:

Cap-and-trade is a term that represents a system of solutions which include an implemented “cap” or limit on GHG emissions while simultaneously encouraging actions of “trade” or exchange of quantities of emissions between producers. The cap represents the ceiling in which individual firms and factories are allowed to emit their greenhouse gasses, usually measured by weight or volume of gas emitted. The limit would decrease over time and companies who exceed this limit during this period would be financially penalized. For example, the Arizona Council of Engineering and Scientific Associations sets U.S. emission goals for 2020 and 2050 that are 17% and 83%, respectively, below 2005 levels. The cap is thus relatively rigid and strict as imposed by the government. The trading aspect, however, accommodates these limits and makes the overall system uniquely flexible. The trading system essentially allows firms to buy and sell the government caps with one another, meaning companies could conduct trade in their own favor to

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either profit or avoid more expensive fines from the government. California began operating a cap-and-trade program in 2013, and it is linked with a program in Quebec, Canada. The program was one of the first in the world, and is among the largest. California's greenhouse gas production has fallen 5.3% between 2013 when the state launched its own cap-and-trade policy, and 2017, as California targets economy-wide carbon neutrality by 2045. This improvement has not come at the expense of industrial output either, with the economic output of the state's manufacturing industry increasing from $250 billion to $299 billion over the same period. However, the system has struggled in recent months as the Covid-19 pandemic triggered a downturn in global energy demand. In turn, this reduced the need for allowances as the state's largest GHG intensive facilities have been producing fewer emissions.

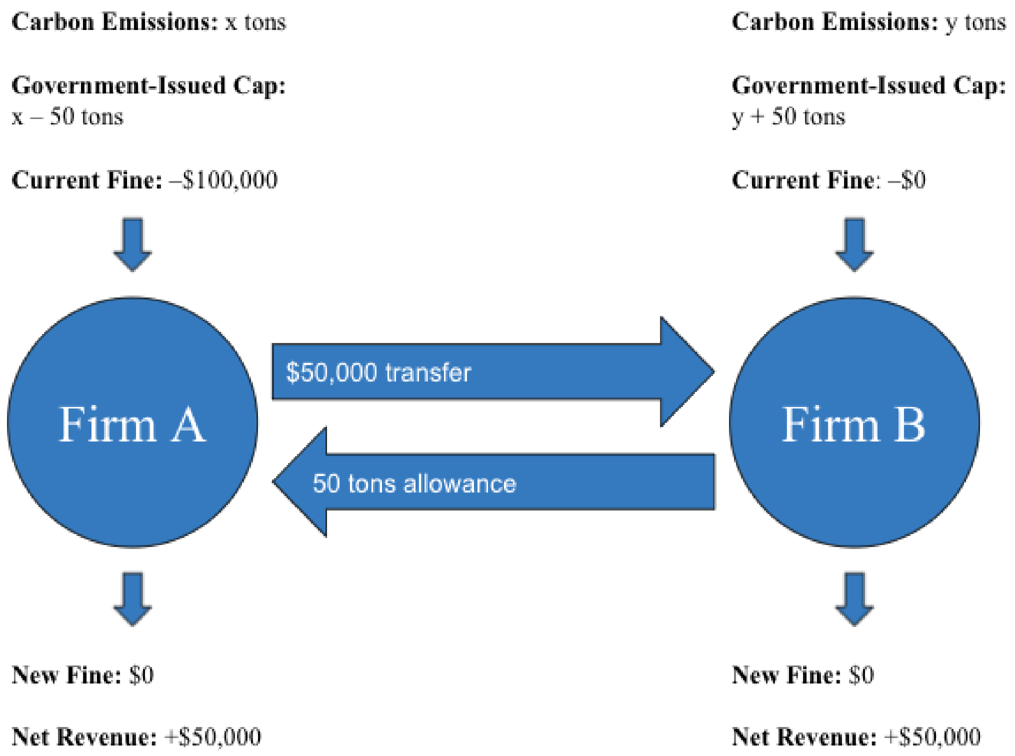

Figure 1 - Demonstrated hypothetical diagram of emission allowances between industry firms. This shows the trading system of carbon allowances and how they may mitigate fines via the cap-and-trade system.

As shown in Figure 1, we can conduct a hypothetical scenario of two companies, Firm A and Firm B. They exist such that Firm A has an emission record of x tons per year while Firm B emits y tons of greenhouse gasses per year. Due to their status as carbon-emitting producers, the firms have had "caps" imposed upon them by the government, thus constituting their GHG emission allowance, based on their production amounts and efficiencies. In this scenario, Firm A receives an allowance of x-50 tons, meaning Firm A has been over-emitting by 50 tons; Firm B receives y+50 tons, meaning it has 50 tons of allowance left for utilization. Further, we assume the potential fine Firm A will receive is $100,000 for exceeding its cap, but Firm B is in a better position as it does not have to pay a fine due to it being well below its cap. Under a cap-and-trade system, however, the firms can form a pact that will result in mutual benefit. For instance, Firm A could purchase 50 tons of allowance from Firm B for $50,000 so that Firm A's emissions would not exceed its new, upwardly adjusted "cap'' and wouldn't have to pay the $100,000 fine, resulting in a net expenditure avoidance of $50,000. Firm B would also benefit from the direct sale of its unused extra allowance, resulting in a revenue gain of the same amount – $50,000. Thus, both firms not only keep their emissions under their respective caps but also add to their bottom line from this exchange simultaneously. In comparison to the carbon tax, under cap-and-trade businesses have options to avoid (or mitigate) being fined for emissions unless they exceed their allowances whereas a carbon tax mandates a set rate for every ton of CO_2 emitted.

Cap-and-trade systems are flexible because they incentivize businesses to choose the most cost-effective ways to stay under the cap while keeping compliance costs low. Additionally, they promote technological innovation in areas such as carbon capture by folding in a valuation dimension to GHG emissions. However, the cap-and-trade system also comes with its own drawbacks. When the government forces a complementary solution like renewable energy to the businesses instead of letting businesses choose for their own interests, those effects won't be as efficient and is difficult to enforce both simultaneously. Nevertheless, it is still crucial to consider complementary policies where a systematic market approach fails, preventing emitters subject to a cap-and-trade system from choosing the lowest-cost compliance options. Thus, there exists a trade-off between the freedom of the market and an increase in cost-efficiency against government objectives and intervention. As Ann Carlson explains, if no market failure exists, policymakers should recognize the trade-off inherent in limiting the market mechanisms cap-and-trade is designed to promote and evaluate whether ancillary benefits justify the reduction in market flexibility and the potentially higher costs [18]. Essentially, if the government is looking for a long-term, cost-effective approach, it would simply allow cap-and-trade to function where it is applicable. On the other hand, if the government wants quick, short-termed changes, then complementary solutions may be added to force businesses to take a specific approach. Note that this method will likely frustrate many corporations and should be avoided if possible. Additional components are necessary to consider in cap-and-trade implementation that have the potential to enable high impact results. For instance, according to Richard Schmalensee of MIT and Robert N. Stavins of Harvard, "in several systems, the ability to bank allowances for later use has been an important source of cost savings. The ability to bank provides a margin of intertemporal flexibility with positive economic and environmental consequences. Changes in economic conditions can render caps non-binding (reducing incentives to invest in innovation) or drive prices to intolerable levels. These problems can be mitigated by adding price floors and ceilings. The result is a hybrid, combining features of cap-and-trade and carbon tax systems" [19]. Other components to consider besides allowance banking include the policy's scope, target, allowance allocation, offset, compliance periods, and market integrity (C2ES).

Higher overall real (inflation-adjusted) price levels depress the returns on working and investing by shrinking the basket of goods people can buy with their earnings. Thus, higher prices act analogously to an income tax. Because income is already taxed such as through payroll and capital taxes, the cap-and-trade system introduces another layer, or distortion, on top of those already present. This piling on of distortions, known as the "tax interaction effect", can be even more costly than the direct abatement costs. The revenue the government can raise from auctioning allowances can offset this, however, the tax interaction effect enables reduction of other taxes. The most efficient form of revenue recycling would offset the most distortionary taxes, meaning the ones that have the highest marginal deadweight loss [20]. A number of scholars have examined this, but the tax system is so complex that economists have not identified one definite optimal policy. Analyzing a 15% cut in emissions, the Congressional Budget Office (CBO) estimates that the downward hit to GDP could be reduced by more than half if the government sold allowances and used the revenues to lower corporate income taxes rather than to provide lump-sum rebates to households or to give the allowances away [20].

Research and Investment:

In August 2007, the Secretariat of the U.N. Framework Convention on Climate Change published a technical paper, *Investment and Financial Flows to Address Climate Change*, estimating that approximately $205 billion dollars in additional investment will be required annually by 2030 to meet the target of global greenhouse gas emissions reduction. All climate change investment, whether public or private, can be categorized into three different types: environmental, social, and governance (ESG) investing, which basically is for the use of adaptation infrastructure, based on the investments' intentions, purposes, and/or amount. Asset managers from each institution have, in effect, created a boundary line for investors who seek more ethical ways to profit. For instance, instead of plain investing in the stock market, by investing in efforts to resolve climate change, these people will have made a positive humanitarian impact as they are saving the earth from climate change, an existential threat to humanity [21].

There have been many efforts in climate investing, but they are still minuscule compared to the amount that was used in other programs. One such effort was from the World Bank Group, the world's largest contributor to climate investment for developing countries and accounts for $26 billion in 2021, which is over two-thirds of adaptation finance. Another of the current investment programs in place is the Climate Investment Funds (CIF), which includes $8.5 billion dollars in total, and who describes its goal "to accelerate climate action by empowering transformations in clean technology, energy access, climate resilience, and sustainable forests in developing and middle-income countries" [22]. The less expensive yet large-scale financing planned by the CIF for long-term implementation would lower the probability of risks and reduce the general cost of financing climate change programs. However, looking at the big picture, Bank of America has estimated that in the next 20 years, there will be more than $20 trillion of material and financial growth in governance funding from investors, equal to about half of the current total market capitalization of the S&P 500, meaning, current funding is far from sufficient. Starting twenty years ago, there have been approaches towards a carbon price in order to underpin a move to low carbon energy sources and with that, much academic literature explores the possible impact of such a price [23][24]. However, since a global carbon price is obviously absent, over the years various technologies have been supported by specific policies and public-private cooperation globally [25]. For example, in the 1990s, there has been an effort to reduce SOx & NOx emissions from major stationary sources (e.g., refineries, petrochemical, HC-powered cogeneration plants, etc.) by retrofitting their furnace stacks with SCR (selective catalytic reduction) units. This was expensive per high up-front capital cost and additional ongoing operational costs (e.g., general maintenance, catalyst replacements, supplying near reagent grade aqueous or anhydrous ammonia to the inflow grids), all of which hit the bottom line financially but in the long run produced outweighing benefits. GHG emission reduction technology, like the Negative Emissions Technologies mentioned in this paper, will be directionally similar and also a challenge financially, but like the SCRs of 25+ years ago, is doable and will ultimately have massive paybacks. Thus, investment and research efforts are crucial in supporting these frameworks.

Similar to other economic solutions, social and political barriers exist which hinder investing as well. Examples include the immaturity of climate change policy frameworks and absence of policies that are stable, constraints on decision making within investor companies' fiduciary duties, perceptions of investors that returns of renewable infrastructure investments are too low and initial capital investment requirements too high, a requirement that projects need a certain minimal credit rating so that it is possible to invest, technology-risk associated with uncertain and unproven technologies, transparency on climate-related disclosure and data, limited projects with acceptable risk-return profiles' liquidity, lack of suitable financial vehicles/financial instruments, high transaction costs or fees transaction costs, and lack of proven knowledge/technical advisement on green infrastructure investment. These are all amongst the many reasons why a single investment may fall behind [26]. In addition, the most outstanding reason why we do not have hundreds of billions or even trillions of dollars invested in climate change addressing projects at this time is disinterest from politicians, who most likely understand the severity of the issue but continue to be fearful of losing support from, for example, automobile corporations and votes from the many of the middle to lower income customers of that entire industry who tend to favor lower gasoline prices and more affordable vehicles.

A number of policies and government interventions are now being developed to reduce or manage barriers to investment [27]. These include the use of regulatory measures as well as public finance mechanisms (PFMs) and public-private partnerships (PPPs). Nonetheless, although such governmental policies do aid in investing efforts, most of the funding has to come from the private sector and public taxes [28]. The mandates and targets set for renewables, such as the European Union's 20% of final energy from renewable sources by 2020 goal, have also shown to be to a somewhat positive result. Several other approaches have been utilized including subsidies or stricter government regulation [25].

In his *Perceived Barriers and Policy Solutions in Clean Energy Infrastructure Investment*, Aled W. Jones classified many distinct barriers which hinder research and usage of clean energy. These included the risk of backfire from implementing low-carbon policies and issues on the deal flow of the investments. Other barriers pose more general dangers that negatively affect investors such as notable currency risk, breaches of contract, and civil disturbance. The low-carbon policies risk is associated with the possibility of a change in targeted policy support which in turn results in lower-than-expected returns on investment. The deal flow problems are caused by a lack of flexibility to change in the investment market as investors tend not to switch projects from their current one to one which better addresses climate change concerns [29]. An interesting take on investing in climate change suggested by researchers Blyth, Bunn, and others is to invest in retrofitting carbon capture, utilization, and storage (CCUS) technology to coal plants. However, the chief problem in doing so is that coal has the possibility of raising carbon prices to unexpected higher levels. As one proposal to solve this problem, the government can add the CCUS component after the expected carbon price is up [30].

When designing climate-sensitive investments, we are accustomed to using historical weather and climate data. Engineers use it in the design of infrastructure and buildings, the insurance industry to calculate premiums and capital needs, and farmers depend on it to choose types of crops and scheduling. Even national governments base their assessments of energy security requirements on such data. With the projected changes in climate, however, historical data is no longer as useful for planning. Ideally, we would by now have highly accurate climate models that allow us to produce reliable climate statistics for the future. Current models are unable to reconcile differences that lead to large uncertainties and disagreement. Thus, it is wise to favor strategies that are reversible and flexible over irreversible choices. The aim is to keep the ramifications of being wrong about future climate change as low as possible. Among these examples, one can mention insurance and early warning systems that can be adjusted every year in response to the arrival of new information on risks. Another example is restrictive urban planning. When deciding whether to allow the urbanization of an area potentially at risk of flooding if climate change increases, the decision-maker must be aware of the fact that one answer is reversible while the other is not. Refusing to urbanize, indeed, has a well-known short-term cost, but if new information shows in the future that the area is safe, urbanization can be allowed virtually overnight. This option, therefore, is highly reversible, even though it is not costless since it may prevent profitable investments from being realized [31].

Government Subsidies:

In the United States, the federal government has paid $145 billion for energy subsidies to support R&D for nuclear power ($85 billion) and fossil fuels ($60 billion) from 1950 to 2016. During this same timeframe, renewable energy technologies received a total of $34 billion [32]. The federal government has made investments in energy for more than a century, such as by granting access to resources on public lands, helping build railroads and waterways to transport fuel, building dams to provide electricity, subsidizing exploration and extraction of fossil fuels, and providing financing to electrify rural areas. Subsidies are the most common and important policy to stimulate the development of the renewable energy industry [33]. Several federal government tax credits, grants, and loan programs are available for qualifying renewable energy technologies and projects. In addition, most states have some financial incentives available to support or subsidize the installation of renewable energy equipment [34]. Generally speaking, three types of subsidies are used in practice, and almost all countries in the world that expand renewable energy formulate and implement at least one of these subsidies. However, the implementation results in many countries present different policy effects from a theoretical point of view, based on the differences of the price level, output level, and social welfare by comparison. On such a basis, the American Progress research team found that under the premise that social welfare maximization is the goal of the government, no matter what the situation is, mixed subsidy policy can bring forth the highest level of social welfare. However, when the negative externality coefficient of the environment is small, that is to say when the environmental protection problem goes unheeded, a mixed subsidy policy will bring relatively higher prices for energy products without accompanying higher social welfare outcomes [35].

Many different types of subsidies have been implemented in the past, especially in European countries. The main policies used by European governments are the Feed-in Tariff (FiT), the Feed-in Premium, and the Green Certificate (GC). To be successful, these policies usually include three key provisions: (1) guaranteed access to the grid; (2) stable, long-term purchase agreements (typically, about 15-20 years); and (3) payment levels based on the costs of renewable energy generation. The FiT is also known as fixed-price policy as it includes a premium payment and a constant over-the-spot market electricity price. It provides a fixed amount of money to be paid for renewable electricity production and an additional premium on top of the electricity market price [36]. The implementation of such policies can also be seen in other European countries: In Italy, the Gestore dei Servizi Energetici published some reports on renewable energy support policies. The Spanish authority, Comisión Nacional de Energía (CNE), produces information on energy policies and the British Office of Gas and Electricity Markets (OFGEM) and publishes an annual report [37].

Though effective, government subsidies come with one negative aspect–its high cost. Government subsidies can be of significant financial burden as the increase in the degree of attention to the environment can not only increase the price of energy products, it can also bring about the decline in output level of renewable energy enterprise, following from the premise that the size of the market remains unchanged in the short term [38]. The output of conventional energy enterprises is bound to increase per gains in population, standards of living and modernization which, while not conducive to the development of renewable energy, also causes greater pressure for environmental protection. From the perspective of promoting the development of renewable energy, when the environmental pollution caused by energy enterprises is slight, mixed forms of subsidy policy appear to provide the optimal path forward. In the case of mixed subsidies, renewable energy can have a higher level of production and the level of social welfare elevation it brings is also higher than the other two types of single subsidies. However, although the level of social welfare is the highest under the mixed subsidy policy when the negative externality coefficient of energy enterprises is very high, this policy will bring the reduction of production of renewable energy enterprises [39]. Different subsidy policies have their own advantages and there are also relevant limitations in some aspects. Hence, policymakers should make and implement reasonable policies to fit their own needs according to their own carefully considered situations and targets [40].

Direct/Indirect Aid to Other Countries:

Aiding third-world countries is an absolutely critical economic policy in dealing with climate change because even if the United States were to keep our emissions way down, if relatively undeveloped countries are still mass emitting carbon dioxide, then there is still not going to be any big impacts on the net harm of climate change on Earth. And thus, by providing aid in the form of finance (direct) or invests, political and economic actions, or otherwise (indirect), we can ensure third-world countries take the necessary steps to also combat climate change. As recently reported, during the COVID pandemic, the United States is rejoining international efforts against climate change in 2021. All members of the Paris Agreement were obliged to submit updated pledges for emissions reductions prior to a global climate meeting in November 2021. President Joe Biden has publicly stated he wants to re-establish U.S. leadership on climate.

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Doing so will require the United States to make an ambitious but achievable pledge and to assist other nations in doing the same. Nathan Hultman, a nonresident senior fellow in the Global Economy and Development program at Brookings, suggests that these subnational actors can share their skills and ambition with their counterparts abroad. Hultman also sees for the United States an opportunity to lead through its outsized role in the global financial sector. It can encourage greener investing by requiring disclosure of climate risks and support global efforts to finance emissions reduction and climate adaptation in developing countries. Four years of U.S. absence from the global climate community, including global climate negotiations and international efforts to reduce greenhouse gas emissions, have left a gap in international leadership and credibility. After whipsawing through political positions on climate change, the United States must advance a credible strategy for robust and continued climate action at home that is seen as reliable and not subject to reversals over time [41].

Aid and interactions do not have to come directly from a given nation's political leadership. In fact, subnational actors with significant climate commitments represent roughly 70% of the U.S.'s GDP, which is equivalent to the world's second largest economy - roughly the size of China's [42]. Using policy authorities at their disposal, many of which are significant, these actors have advanced climate action across multiple sectors and types of emission, including electricity, clean transportation, land use, methane, Chlorofluorocarbons, and more. Even outside of federal regulation and legislation, such policies are already driving significant reductions in U.S. emissions and could do more if expanded in line with recent trends [44]. As another example, over 600 local governments in the United States have developed climate action plans. While the majority of these municipalities are lagging in their efforts to meet their targets, some large cities (Los Angeles, New York City, and Durham, North Carolina, for example) have achieved significant reductions and have highly qualified organizations to demonstrate how such reductions can be achieved [43]. Thus, while not all countries are structured like the United States, bottom-up leadership and implementation are central to success in some form in all countries. The United States can use its non-federal actors in its diplomatic efforts to support and bolster climate action around the world. For this, U.S. cities, states, and businesses can collaborate with their counterparts in other countries to discuss opportunities and strategies, supported by the U.S. diplomatic effort. Such efforts could take place through a U.S. State Department Office of Subnational Diplomacy, as recommended by Anthony F. Pipa, a senior fellow in the Center for Sustainable Development, housed in the Global Economy and Development program at Brookings, and Max Bouchet, a project manager and senior policy analyst in the Center for Sustainable Development, housed in the Global Economy and Development program, in their brief for this series [41].

Financial assistance for vulnerable countries is one of the most powerful tools available to the international community in reducing the risks posed by severe weather disruptions connected to drought, flooding, and food insecurity, among others. Given the global role of the United States in delivering humanitarian aid and responding to crises, equipping countries to be more self-sufficient and resilient in the face of the growing pressures from climate change would save taxpayer dollars, while strengthening America's diplomatic standing and national security [45].

Lastly, international perception of the U.S. domestic commitment is also important; the commitment must be seen as sufficiently ambitious to unlock other diplomatic opportunities available to the United States. The goal of achieving emissions reductions of approximately 50% below 2005 levels by 2030 is receiving a great deal of attention, but is highly ambitious for the United States. Attaining such a target would be a challenge, but the whole-of-society approach described above could improve the probability of reaching such a goal [41].

Agricultural/Agroforestry

Afforestation/Reforestation:

The Green Belt Movement (GBM), founded in 1977 by Wangari Maathai, planted 51 million trees in Kenya [46] and in 2018, 850 hectares of the countryside were restored by this movement [47]. GBM is essentially one of the many practices of afforestation and reforestation, a mitigation strategy by way of land use management. They serve as reversal processes to forest and soil degradation, and in turn, reduce the negative impacts on the hydrological systems, aiming to capture carbon dioxide (CO_2) in Earth's atmosphere and store it in the soil through photosynthesis. Afforestation is the introduction of trees and plants to clearings, wastelands, and arid, barren areas to carry out the creation of forests. Reforestation is the restoration of forests which have become thinned out or are experiencing a significant decrease in tree population due to deforestation, wildfire, or other natural/man-made disasters. These mitigation strategies not only contribute to enhancing global atmosphere, environment, and natural habitats, but their byproduct of refining soil conditions is also an important component to helping lead the majority of the forest-dependent residents out of their extreme poverty as well.

Afforestation and deforestation have comparably low costs with high carbon removal rates and capacities that enable them to cover larger landmasses and extract abundant amounts of CO_2 with a minimalist budget. To put in perspective, an acre of matured trees absorbs 9.2 metric tons of CO_2 per year, where one matured tree is able to consume approximately 48 pounds of CO_2 per year [48]. By introducing additional new trees and plants into this area, afforestation and reforestation help to prevent topsoil runoff and erosion as increasing the quantity of trees in near-barren lands pins down the soil with their interconnecting network of roots. With increasing soil stability, water absorption and storage capacity of the soil increases consequently. Through transpiration, torrential rainfall, and sturdy underground watersheds and water tables are realized. An improved, cleaner environment assists in preserving endangered organisms and increasing the biodiversity of that area by providing a more supportive natural habitat, and with new plants and trees introduced, the positive effects of photosynthesis on the land and environment increases correspondingly: the growth of photosynthesis processes promote fresher, much more oxygenated air. This stands as a top priority in today's society for it can lower peoples' and other organisms' chances of contracting different respiratory diseases. In addition, cleaner air, by definition, provides people with an environment with less air pollution and therefore helps to shield society from the otherwise avoidable illness and discomfort that can be acquired through breathing polluted air. Other benefits such as social cohesion, leisure activities, and the raising of awareness and education for future generations can all be observed through the implementation of afforestation and reforestation [49].

On the contrary, the negative effects of afforestation and reforestation are much less in magnitude than the benefits they bring. Forest management, especially the creation of new forests on existing lands, can lead to the loss of land for urban development, habitat, biodiversity, agriculture, housing, and other public infrastructure. In addition, eco-tourism may also become a problematic unintended consequence of afforestation. Afforestation and reforestation implemented solely for economic benefits and entertainment can, if not managed well, bring more litter and destruction into the forests and the habitats those forests host rather than preserving them. Additionally, expanded forestlands pose higher chances of wildfire and pests being spread in that area, which in turn demands higher levels of maintenance to avoid than what was needed before in a sparser landscape. Apart from natural disasters, expanding forest landmass decreases the land value and increases scarcity which then contributes to a surging escalation of property prices and rents for the public [49].

Table 3: Afforestation/Reforestation and Forest Managements Data Analysis

Work Cited: [50]	Approximate time span (#/yr^a)	Global annual CO_2 removal Potential	Global total CO_2 removal capacity	Global land mass required	Total cost for implementation of practice

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[51]		($GtCO_2$[b])	($GtCO_2$)	(Mha[c])	(\$/tCO_2[d])
Afforestation/ Reforestation + Forest managements	1.9 billion	≈ 3.6 (2050) ≈ 7 (2100)	[80, 260][e]	[70, 90] ∪[f] [350, 500]	[0, 50]

a: Number of trees annually
b: Gigatons of CO_2 mitigated
c: Million hectare
d: Cost in United States Dollars (USD) for every ton of CO_2
e: "[x,y]" represents the domain and limitation of the variable from x to y
f: "[w,x] ∪ [y,z]" represents the conjunction of two (or more) domains, where it stands for "the limit is from w to x, and the limitation is also from y to z"

Afforestation and reforestation are currently being widely executed by many states and regions. For example, the Republic of Korea (South Korea) has been conducting national reforestation program since 1961 [46], and the Korea Forest Service (KFS) has been intensively planting trees in the 1970s and 1980s, and by 2008, 2,960 million trees are planted in 1,080 thousand hectares of South Korean land with more to come, bringing an alliance between the South and North Korea on this matter. This suggests this strategy is ready to be put into large-scale carbon removal practice immediately with public and political approvals. However, due to the beneficial environmental and social impacts of afforestation and reforestation being strongly dependent on the specifics of the actions which put these strategies into practice, an adequate administration and governance are suggested to maximize the gains brought by this approach and to distribute benefits fairly among the people.

Bioenergy Carbon Capture and Storage (BECCS):

Due to the efforts of combating climate change, a total of 23 bioenergy carbon capture and storage (BECCS) projects have been executed globally, with a major amount of BECCS being located in Europe and North America. Currently, merely 6 of the 23 remain continuously operated, "capturing CO_2 from ethanol bio-refinery plants and MSW (Municipal Solid Waste) recycling centers," and in 2019, 5 facilities are actively capturing ≈1.5 million tCO_2/y worldwide through BECCS technologies [52]. BECCS is one of the negative emissions technologies (NETs), which, in turn, is a mitigation strategy. This technology entails a large demand of biomass (plant matter that was once alive) for capturing and storing the CO_2 emitted by the burning of other biomasses such as forest woods and fast-growing energy crops (e.g., barley, wheat, corn, sugarcane, rice, and willow trees) into a long-term underground storage. As well, it allows the industry to use the bioenergy (Ex: heat and generated electricity) created through the same process while emitting little to no CO_2 into the atmosphere [53].

Naturally, the CO_2 emitted by the burning biomass is eventually reabsorbed by the regrowth of these trees and plants, creating a cycle that results in a carbon-neutral process. Thus, by seizing the escaping CO_2 before it reaches the atmosphere, the net CO_2 emission can then be negative, a process that extracts CO_2 from the atmosphere rather than merely preventing further emissions. Furthermore, the bioenergy produced through BECCS can provide supplemental fuels for sectors of soils that are difficult to decarbonize. Setting these benefits aside, BECCS is mainly limited by its high cost (\$100 - \$200 per tCO_2) and biomass availability. Because BECCS requires the planting of special bioenergy

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crops specifically for this use, it would therefore require contributing nearly 50% of Earth's agricultural landmass toward BECCS. This will lead to decreasing land for housing and crops, increased utilization of water, fertilizers, damage to local habitats, CO_2 released from the soil and re-entering the atmosphere, and the prospect of pipeline-related concerns due to CO_2 injection into geological reservoirs. These factors may lead to an increase in food insecurities, displacements, biodiversity loss, shortage of water, soil carbon loss and leakage, seismic activities, and air/water pollution [51].

Table 4: Bioenergy Carbon Capture and Storage (BECCS) Data Analysis

Work Cited: [54] [51] [50]	Approximate biomass/ bioenergy productivity (t/ha[a])	Global annual CO_2 removal Potential ($GtCO_2$[b])	Global total CO_2 removal capacity ($GtCO_2$)	Global land mass required ($Mha/GtCO_2$)	Total cost for implementation of practice ($\$/tCO_2$[c])
Bioenergy Carbon Capture and Storage (BECCS)	[1.8, 25.1][d]	[0.5, 5] (2050)[e] [5, 10] (2100)	[0, 1191]	[31.7, 58.3]	[20, 100]

a: Tons per hectare
b: Gigaton of CO_2
c: Cost in United State Dollars (USD) per tons of CO_2
d: "[x,y]" represents the domain and limitation of the variable from x to y
e: "(z)" represents the year said goal should be achieved

Similar to afforestation and reforestation, BECCS implementation is also distributed worldwide. Due to its potential risks to the environment and civilians, BECCS is better to be put in practice with a combination of one or more other NET technologies, such as carbon capture and sequestration, which can enhance its benefits while reducing its negative effects overall. In addition, governments should take into consideration that research, development, and demonstration (RD&D), life cycle analysis, agricultural policies, finance mechanisms, and cross-cutting considerations should be promoted and implemented for maximized benefits to be received from this program.

Bioengineering (BE) of Crops/Genetically Modified Organisms (GMOs):

With limited water and the degrading soil health caused by climate change, food insecurity has been and will continue to increase if no actions are taken. One of the possible adaptation strategies to climate change is the bioengineering of crops, whereby alteration of crop DNA, genes, and alleles, allows farmers to yield crop productivity with smaller land areas. Different methods of bioengineering crops in agricultural practices are available according to current technology: traditional breeding, mutagenesis, RNA interference, transgenesis, and gene editing.

Traditional breeding, established by Gregor Mendel in the 1860s, focuses on the selection of desirable alleles and cross-breeding these selected crops together to produce offspring that combines both beneficial traits or has a minimized disadvantage against its environment. This method, dated back approximately 9,000 to 11,000 years, does not require further research and testing for large-scale implementation/organic use, and it can affect up to 10,000-300,000 genes in total. *Mutagenesis*, invented in 1983 by Kary B. Mullis, is a technique using chemicals and radiation that efficiently detects and escalates a targeted genome/DNA sequence, amplifying the desired genes without cloning. Although mutagenesis does not require testing for implementation and is approved for organic uses, it remains extremely unpredictable, therefore creating uncertainty on the number of genes it can affect during its process. *RNA interference*, discovered by Andrew Fire and Craig Mello in 1998, presents itself as a mechanism that can inhibit certain gene expressions by degrading mRNA from that specifically chosen gene and neutralizing the mRNA. Yet it can only be conducted under the condition that the RNA molecules appear as double-stranded pairs. With future testing required for application and the ability to affect 1 to 2 genes, this method is not well-established for organic use, though RNA interference may be able to reduce certain traits of the crop in the future effectively. *Transgenesis*, developed in 1973 by Herbert Boyer and Stanley Cohen, involves the practice of transferring a section of the desired gene(s) from one organism to another in a specific location to promote chosen traits. This method requires further testing for implementation outside of organic use, it can affect approximately 1 to 3 genes during each transferring process, and with more technological development, transgenesis would allow crops that had been genetically modified to pass on their altered traits to future generations. Ultimately, there are *gene-editing* techniques such as those established by Emmanuelle Charpentier and Jennifer Doudna in the early 2010s which include the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) that alters the genes through identification of the "problematic" genes and conduct "operations" to alter those genes to the desired form and script. Even with testing required and an unknown certainty of organic utilization, it can accurately affect at least 1 to 3 genes when applied, ending with a result that is more specific, controlled, and predictable [55].

With the bioengineering of crops, production by farmers can now be made more resistant to the degrading environment on Earth caused by climate change, maintaining, if not yielding, increases in overall output. Furthermore, with genetically modified crops stronger protection against extreme weather conditions (e.g., drought, flood, storm, strong wind, etc.) the biochemical make-up of the crops allow for more resiliency. As a result, a greater portion of these crops will be saved from these unpredictable natural disasters, expanding the suitable soil range for the crops to be planted (i.e., ~10% increase of global arable land), and reducing the use of chemicals/fertilizers (e.g., pesticides) and tillage (i.e., the process of turning the soil in the field), which in turn improves soil preparation efficiency and reduces greenhouse gas emissions. With better security, larger agricultural land dedication, and higher production, food security can increase dramatically, supporting the growing global population and leaving fewer people dependent on insufficient amounts of food each day. To gain maximum benefit, a much deeper level of genetically modified crops will be needed to give crops the ability to shield themselves from natural disasters like drought and flood. However, even without these higher developing technologies, the investment in GMOs is still considerable. Not only will developing the altered seeds require large monetary investments, but unpredictability in seed qualities raises the investment rate further, along with the complicating factor of often being mixed with regular seeds that do not match pricewise [56].

This adaptation technology has already been implemented by some countries and regions. Besides being adopted quickly by farmers to ensure the stability and protection of their crops, companies are also participating eagerly in this economic opportunity. Likewise, and similarly to many other technologies listed, the bioengineering of crops still requires much more research to decrease the unpredictability of the genes that are being modified and increase the effectiveness of the modified genes in order to maximize the advantages brought by the GMOs. In addition, better education and regulations for the farmers that utilize these GMOs should be established to raise awareness of the negative effects of all aspects brought by climate change and address the concerning factors following the plantation of GMOs [56].

Irrigation Systems:

Worldwide, average agricultural water utilization practices equate to more than 70% of global freshwater consumption annually [57], while approximately 40% of that water consumption is wasted through primitive irrigation practices and failure of resource management (i.e., "poor irrigation systems[/transportation], evaporation, [water runoff,] and overall poor water management") [58]. Correspondingly, some fruits and vegetables require more water usage than others. To put in perspective, to grow one pound of wheat uses 130 gallons of water while the same quantity of coffee requires 2,500 gallons of water. In many cases, the 40% of water not actually used for its intended task was returned to the environment rather than being used elsewhere, resulting in more input of money, time, and energy consumption to re-acquire and redistribute this water [58]. Therefore, to better manage water distribution overall, better irrigation systems are needed for large-scale implementation.

Similar to the bioengineering of crops, there are many methods for this adaptation strategy from surface irrigation (i.e., traditional water delivery systems) and sprinkler irrigation to drip and airdrop irrigation systems. *Surface irrigation* (e.g., level basin irrigation, furrow irrigation, and border strip irrigation), first implemented more than 6,000 years ago [59], is a system of irrigation that takes advantage of gravity where water is carried through the field and overland by flowing from higher to lower elevations. By feeding water in dug furrows and basins with siphons, gated pipes, and turnout structures, water can easily flow from one side of the field to the other, improving efficiency (e.g., "provides 60% water-use efficiency" [56] and management, bringing larger benefits with small sections of land, including slop/long fields, and requiring minimum financial, technological, energy consumption, and water resources (not excluding the use of rainwater) support. However, not only does the limited space of surface irrigation cover plants with water outside of their necessary quantity and timing needs, but many limitations are also associated with surface irrigation systems such as leveled land, large fields, soil with high filtration (high interception of water of soil demands more water to water the crops thoroughly), and the need for drainage outlets, all of which bring disadvantages to the farmers when utilized and ultimately restrict this practice. Sprinkler irrigation systems, widely adopted in the Americas, Europe, Asia, Africa, and the Oceania region, are a water-emitting technology that uses an overhead mechanical and hydraulic simulation (e.g., "high-pressure sprinklers, sprays, and guns" [56] of rainfall in the air to water the soil and the crops. These mechanical irrigation systems can be permanently or temporarily situated, and they can travel across the field via wheel roll, linear movement, or central pivoting. Piping and pumping units are usually required in the sprinkler irrigation system, applying necessary hydraulic pressure and delivering the pressurized water according to soil and crop needs. With the shift from surface irrigation to sprinkler irrigation systems, the water is distributed more efficiently and effectively (e.g., 75% water-use efficiency), results in a decreasing trend of water consumption, for example: 56% of barley, 46% of potato, and 41% of maize's irrigation water usage saved when compared to traditional gravity irrigation (ref). Additionally, less time is needed for watering and fertilizer application, mitigation of uneven water/fertilizer distribution, resulting in more crops being grown on agricultural lands of lesser areas [56]. Except for soils having high clay content, the sprinkler irrigation system has proven to be suitable for all kinds of arable land and provides a shield of protection against lower temperature/climate conditions, promoting higher crop yields of 50% for cotton, 40% for groundnut, and 36% for maize of improvement over traditional gravity irrigation. In turn, resident income, employment opportunities, and food security are increased. However, because the sprinkler irrigation system is highly dependent on the prevailing climate and temperature, it can become extremely unpredictable under certain circumstances which can easily result in excessive evaporation of water. Sprinkler irrigation systems waste up to 30% - 50% of water due to evaporation, run-off, etc. Therefore, as the temperature becomes higher (i.e., lower latitude and desert conditions), farming irrigation efficiency drops by almost 15% as compared to cooler and more moderate climate conditions. Consequently, due to the number of pipes, sprinklers, and laborers needed for this technology's

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implementation, the economic input and energy demand are relatively high ($600 to $2,500/hectare). Moreover, because this method is a simulation of natural rainfall, regions with unpredictable rainfall are not as suitable as others.

The drip irrigation system (i.e. micro/low-flow/low-volume/trickle irrigation system), first introduced by Simcha Blass and Kibbutz Hatzerim in 1959, creates a "dripping" system that maintains the soil moisture at a fixed level through water-emitting technologies applying droplets and small streams of water to the soil surface/plant roots, tightly controlling the water consumption up to 90% water-use efficiency, and providing a much more effective and efficient way of applying chemicals and fertilizers to the soil. One example of the drip irrigation system is subsurface irrigation (SDI), which similarly irrigates the crop as the drip irrigation system from underground and within the plant root zone for better water delivery accuracy and overall management. With the more developed technologies (e.g., "pumps/pressurized water system, filtration systems, nutrients application system, backwash controllers, pressure control valves (i.e., pressure regulators), pipes (including main pipelines and branching tubes), control/safety valves, poly fittings, accessories, and emitters" [56], the accuracy of water usage can be greatly improved. By reducing deep percolation/evaporation water run-off to near zero decreases in production input, diseases, and the unpredictability of crop growth result while increasing the yield and quality of the finished crops. Furthermore, the drip irrigation systems can be automated and applied across many climates, conditions, and soils (e.g., salinity, sandy, drought, terrains) that other irrigation systems may not adapt to, supporting a wider variety of permanent/non-permanent crops, fruits, and vegetables. The biggest concern regarding the drip irrigation system is the cost. Due to the many instruments needed for this practice, the initial cost of implementation ($800 to $2,500/hectare) can be considerably high. However, in maintaining the practice, fluctuations of the cost may be affected by unpredictable rainfall, climate/soil conditions, damage to wildlife, and the shifting of piping/instrumentation positions.

The most recent irrigation system, invented in 2011 by Edward Linacre, is the airdrop irrigation system. This technology essentially harvests H_2O molecules or moisture droplets from the air through a turbine that drives and cools the air to that of the underground space during the condensation process until it reaches 100% humidity, resulting in condensate formation. The produced water, stored in an underground tank, is then pumped to the roots of the plants during the watering process. Because "the airdrop irrigation system is a low-tech, self-sufficient solar-powered solution," [60] it is suitable for arid and semi-arid land where water shortage presents as a recurring problem, so less water can be used in a more cost-effective system.

Most irrigation system types are currently widely implemented. However, with better economic management and public awareness, better and more developed technologies and instruments can be applied to integrate the overall benefits provided by these systems. By implementing systems such as the drip and airdrop irrigation systems, water usage can be substantially decreased, while the creation of artificial ponds, lakes, and reservoirs can supply farmers with a constant water supply, relieving otherwise persistent water shortage pressures in some regions.

Atmospheric/Astronomical

Carbon Capture, Utilization, and Storage:

While technologies to decrease greenhouse gas emissions are vital to meeting climate goals, negative emission technologies must also be analyzed and considered to formulate the most optimal combination of strategies. Carbon capture, utilization, and storage (CCUS) is a type of negative emission technology (NET) designed to chemically capture CO_2 from the atmosphere, concentrate it, and inject it underground or into a storage reservoir.

CCUS systems capture CO_2 from either the source of emission, such as furnace flue gas stacks in fossil-fuel power plants, or directly from the atmosphere via direct air capture, (DAC) and permanently stores the greenhouse gas, typically underground. Globally, 1 - 13 approximately 8 gigatonnes of CO_2 must be removed annually to stay within

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the goals mentioned previously corresponding to a relatively safe range of increasing temperature, and at an annual expense of $100 billion to $1.3 trillion assuming the low-end price of $100 per metric ton of CO_2 captured and stored. This cost is higher than most other mitigation technologies and that is mainly due to the high levels of energy needed to separate CO_2 from the solutes or sorbents used in the capture of the GHG during the chemical process. In addition, captured CO_2 as a commodity does not attract a large market. However, there have been recent technological developments such as enhanced oil recovery and synthetic aggregates that could provide a large enough market to lower the cost of CCUS. This negative emission technology requires very little land overall and does not require such land to be arable - one of its major advantages compared to other mitigation technologies. The water usage associated with CCUS depends on the humidity and ambient temperature of the environment [61]. Designating CCUS plants in cooler, more humid climates can minimize the amount of water lost due to evaporation, and thus reduce the amount of water needed in the process.

As greenhouse gas emissions rapidly increase, it becomes clear that simply reducing emissions will not be enough to reduce the effects of global warming; instead, climate change will only be fully moderated by removing CO_2 directly from the atmosphere in combination with converting to renewable energy. In fact, the IPCC states that “all pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal” [62], emphasizing the importance of implementing carbon capture, utilization, and storage. One of the major benefits of CCUS is its practical land requirements for the system, which would lessen negative impacts on local food production or other land uses. Compared with other mitigation technologies, CCUS plants require much less space. In contrast, capturing a million tonnes of CO_2 by way of forests would require nearly 849 km^2 more land than from CCUS technologies. In addition, CCUS plants can be built close to storage reservoirs to eliminate the need for transportation pipelines, reducing CO_2 leakage. Captured CO_2 can also be sold or recycled to bring in revenue and lessen the cost of carbon capture such as being integrated into synthetic fuels or building insulation.

However, carbon capture, utilization, and storage systems require substantial amounts of energy to power equipment and regulate the rate of carbon capture. One study found that the energy needed to provide enough power and heat to the process in order to meet the Paris Agreement objectives was approximately a quarter of global energy supplies by 2100 [63]. Moreover, the process of CCUS is very expensive, this due to the low concentration levels of CO_2 in some of the feed sources to the process and corresponding high energy consumption. As previously stated, the cost of adhering to the 1.5°C pathway would cost trillions of dollars. Thus, while CCUS is crucial to implement, it should not be heavily relied on. Depending on CCUS as a means to combat climate change can also lead to the misguided belief that emissions from burning fossil fuels can be offset with GHG removal technologies, when in reality CCUS is expensive and consumes an enormous amount of energy. This circumstance creates a challenging GHG balance and would demand non, or at least low, GHG emitting energy sources to be employed in powering CCUS facilities.

As of 2021, Climeworks – a notable company specializing in carbon air capture technology – operates three CCUS plants that capture approximately 1,100 tonnes of CO_2 per year. Climeworks plants are 90% efficient and emit ≈10 kg for every 100 kg of CO_2 removed from the atmosphere. After capturing CO_2, Climeworks either sequesters the collected greenhouse gas underground or sells it for commercial purposes. Although Climeworks has yet to reach profitability, there is still much reason to believe that they, along with many other similar for-profit businesses or even government-owned plants, can pull vast amounts of CO_2 out of the atmosphere and bury it underground while selling enough CO_2 to provide an offset to their operational costs to continue. The most optimistic scenario is one in which a virtuous circle occurs: when copious amounts of CO_2 is produced and attracts a larger market that can leverage the economics of scale, thus driving the cycle.

Table 5: Carbon Capture, Utilization, and Storage Data Analysis

Global land mass required (km²)	Cost for implementation of practice ($/tonne removed)	Total cost for implementation to remove 10 gigatonnes CO_2 per year (see Introduction)	Energy consumption (kWh[a]/tonne removed)	Water usage (tonne/tonne removed)
400 km^2 to 24,700 km^2 per Gt (non-arable)	$100 - $1,000/tonne removed	$1 trillion - $10 trillion/year	2,000 kWh/tonne of CO_2 removed	1 - 7 tonnes/tonne of CO_2 removed

a: Kilowatt hour (3,600 kilojoules)

Stratospheric Aerosol Injection:

In June 1991, a volcano located in the Philippines (Mount Pinatubo) erupted, explosively ejecting about 20 million tons of sulfur dioxide into the atmosphere which, after forming particulates, reflected substantial amounts of sunlight back into space that would have otherwise reached the Earth's surface. As the contents of Pinatubo volcanic plumes became distributed across the planet, major cooling effects resulted. This eruption lowered the global temperature by nearly 0.6 °C. Stratospheric aerosol injection (SAI) aims to mimic this cooling effect by spraying large quantities of reflective particles into the stratosphere. Because aerosol particles scatter and absorb sunlight, they can greatly influence plans to cool the climate. However, due to its many shortcomings, this proposed type of climate engineering is currently only theoretical.

Chiefly, the obvious benefit of SAI methodology involves the rapid cooling of Earth. The amount of cooling and the duration of its effects depend on the type, amount, and duration of the aerosols. Possible particle types range from sulfur dioxide (commonly used as sprayed reflective particles) to finely powdered salt or calcium. Unlike marine sky brightening (discussed later in this section), SAI is not deployed in the atmosphere but rather in the stratosphere, which does not contain heavy rain clouds that could quickly disperse the pollutants. Thus, it is likely that heavy influxes of aerosol particles could remain in the stratosphere for a longer amount of time until natural chemical processes and atmospheric circulation washes them away. If efforts are implemented successfully, a majority of climate change mitigation success reactions would follow, including the reduction or reversal of land/sea ice sheet melting, an increase in plant productivity, reduction/reversal of sea-level rise, and an increase in terrestrial CO_2 sink from enhanced sequestration in soil and oceans.

On the contrary, SAI is dismissed by many members of the scientific community because of a large number of potential consequences upon implementation. While SAI would lower global temperatures, droughts in certain continents would still likely ensue, if not worsen. According to the Geoengineering Model Intercomparison Project, temperatures in tropical areas would cool, yet areas with higher latitudes would warm, as well as cause increased extreme climates and ice sheet melting. Additionally, climate change-related problems such as ocean acidification from CO_2 forming carbonic acid would not be addressed and resolved by SAI since this technique can only mitigate surface climate issues. A variety of atmospheric impediments would also arise from SAI, for example, solar power and ground-based optical astronomy would be greatly hindered by the use of this mitigation strategy. Commercial/military control of this technology should also be mentioned as possible consequences of SAI. In addition, international conflicts would be extremely difficult to avoid because the implementation of SAI would require the agreement of each and every country, and withdrawal from the agreement at any time could cause the entire operation to fail. This could lead to the termination effect, which would have disastrous consequences once this grand-scale geoengineering strategy is paused. "If geoengineering were halted all at once, there would be rapid temperature and precipitation increases at 5–10 times the rates from gradual global warming" [64]. Lastly, just as other mitigation strategies such as space-based mirrors and direct air capture can introduce a moral hazard, success with SAI may cause global populations and governments to increase support towards these temporary technologies and reduce funds for permanent solutions such as renewable energy and better agricultural practices. Thus, it is vital for government leaders and policymakers to acknowledge that these solutions are short-term, flawed, and only considered as temporary relief from the repercussions of global warming.

After examination of its many disadvantages in practice, SAI is suggested to be best regarded as only a theory rather than having real application potential. Other solutions that are more long-term and do not involve nearly so many negative consequences should be evaluated further and considered instead. If SAI is implemented, policymakers must remember that SAI is not and cannot be a substitute for permanent mitigation strategies.

Marine Sky Brightening:

The basic idea of marine sky/cloud brightening (MSB) is to enhance cloud reflectivity by cloud seeding with seawater particles or with other synthesized chemicals. Seawater is sprayed into the air to inject salt into the clouds, increasing albedo (sunlight reflection back into space), thereby aiming to offset climate change. This type of solar radiation management (SRM) would require a sufficient amount of salt crystals to ensure an effective reflection rate while also being small enough in size to not promote precipitation. If implemented successfully, cooling effects would promptly follow and could be fairly effective in mitigating global warming.

The impacts of marine sky brightening would be immediate and reversible in the short term. Compared to other SRM techniques, marine sky brightening is considerably more financially feasible. According to a report published in 2008, in addition to approximately £50 million for research, development, and tooling, "50 spray vessels costing approximately £1–2 million [$2 million] each could cancel the thermal effects of a 1-year increase in world CO_2", adding up to nearly £50-110 million to offset the thermal damage done by 1 year of CO_2 increase [65]. By comparison, space-based mirrors require between one to ten trillion dollars for effectiveness. Furthermore, MSB also allows for the localization of solar radiation protection. This technology can be directed to shield specific areas such as areas with ice sheets that are at greater risk due to global warming.

Similar to deploying sunshade configurations in the atmosphere, MSB also concerns international law and politics. In particular, the United Nations Convention on the Law of the Sea (UNCLOS) states that parties are obligated to "protect and preserve the marine environment" from any polluting source. Whether MSB particles would be considered a polluting source remains unclear, and any negative effects of MSB could lead to immediate violation of the law. Moreover, a limited understanding of the complex nature of clouds could lead to unexpected consequences. Large-scale climate patterns and precipitation could be greatly affected, though climate experts suggest that SAI technology and usual climate change patterns would result in more drastic weather changes.

Enhancing cloud reflectivity has the most impact (both beneficial and detrimental) on local and regional precipitation, temperatures, and run-off. Thus, compared to SAI technology, MSB is able to localize its reflective effects and is roughly less expensive. While both should be considered as temporary fixes, MSB may be more moderate for known adverse effects and SAI involves several unknown effects. The brightness of clouds and reflectivity rates drop

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dramatically after a few days of cessation of the technology; therefore, MSB is easily controllable, making it an ideal temporary relief solution. It is important to note, however, that a sharp halt of activity could lead to the termination effect, and the reduced carbon sink could lead to significantly warmer temperatures, similar to the usage of SAI. Marine cloud brightening, although able to produce a reductive effect on both regional and global warming, will likely cause its own changes to climate, and constant cloud assessments and modifications will be required to ensure there are no serious adverse effects of MSB.

Space-Based Mirrors:

In addition to efforts for reducing GHG emissions and storing away GHG, alternative methods to counteract global warming have been theorized and researched for potential deployment. Among these include a newly developed yet promising field: space-based mirrors. Similar to the concepts of stratospheric aerosol injection and marine sky brightening, this idea aims to reflect solar energy away from Earth. Optimal placement of these large reflective sun shades is near the Sun-Earth L1 Lagrange equilibrium point, where the Earth and Sun's gravity are in balance, thus ensuring the mirrors remain stationary with only minor attitude adjustments required. It is important to note that this strategy, along with other solar radiation management techniques, should be viewed as a last resort rather than a continuously implemented policy. This is due, in part, to some of the disadvantages regarding these rapid GHG reduction processes that will be discussed later.

Although the deployment of large-scale space-based mirrors may pose too monumental a task to be practical, sunshade configurations have been viewed to be one of the most efficient methods in solving climate change [66]. Deploying large orbital sunshades allows for the concentration of specific areas that are most directly impacted by the effects of climate change. Examples of such regions include the North and South poles, as well as African countries and clusters of small islands. By erecting shields to prevent overheating in those areas, local and regional environments that face the greatest dangers can be temporarily rescued until other, more permanent solutions are implemented.

However, only by reducing GHG emissions and addressing the excess GHG already existing in our atmosphere and oceans can a permanently stable state of life on Earth be achieved. Future generations cannot rely on simply resisting climate change without addressing its root causes, and future implementation of space shades followed by their success might lead the public to demand more of the same, eventually resulting in the dependence of these short-term, "back end of the pipe" relief measures. Ocean acidification, among other internal environmental issues caused by excessive GHGs in the atmosphere, remains entirely unsolved by the blockage of sunlight, whether via mirrors or reflective particles. In addition, the present economic feasibility of this solution is low unless stronger motivations and funding for SAI emerges. Some estimations value the cost of space transportation and construction to be between one and ten trillion dollars. Lastly, adverse effects such as unintended influences on Earth's various natural cycles and cultivation of crops are also shortcomings to carefully consider.

While computer simulations have demonstrated that space-based mirrors are theoretically successful, uncertainty will always remain until experiments have been conducted at a scale large enough to ensure the safety and effectiveness of this mitigation strategy in the real world. In addition, global consensus must be achieved before implementation, otherwise negative results occurring in some countries while success in others may prompt political blame and, in the worst case, global warfare. As per the general view of the scientific community, it would be most optimal to continue regarding solar radiation management techniques (SRM) as a last resort and undertake extreme caution during any implementation efforts.

Geological

Geologic Reservoir Sequestration:

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Geologic reservoir sequestration, or geological sequestration, is a mitigation strategy used after CO_2 is captured "at the point of emission" from industrial capturing methods. This is done by storing captured CO_2 "in deep underground geological formations" through physical or chemical implementations. Similar to the storing process in the Bioenergy Carbon Capture and Storage (BECCS) solution, the CO_2 captured is physically stored "within a cavity in the rock underground," regardless of whether these geological structures are "large man-made cavities" or "the pore space present within rock formations" [67]. However, different from BECCS, with geologic reservoir sequestration collected CO_2 is usually "pressurized until it becomes a liquid, and then…injected into porous rock formations in geologic basins", and this process of carbon storage, also known as tertiary recovery, plays an important part in enhanced oil recovery [68]. Other methods of storing fully oxidized carbon involve the transformation of CO_2, such as "dissolving CO_2 in underground water or reservoir oil", "adsorption trapping", and "decomposing CO_2 into its ionic components", and chemically combining and attaching these captured carbons with other underground substances by "locking CO_2 into a stable mineral precipitate" [67]. A large amount of these types can be found in the U.S.'s coastal plains regions (e.g., "The coastal basin from Texas to Georgia. . . accounts for 2,000 metric gigatons, or 65[%], of the storage potential" [68]. Therefore, it is crucial for organizations to pinpoint the most optimal location for such implementation, such as "mature oil and natural gas reservoirs[,] oil and gas-rich organic shale[,] uneconomic coalbeds[,] deep aquifers saturated with brackish water or brine (saline)[,] salt caverns[, and] basalt formations," [67] can help to ensure the process proceeds smoothly.

One of the most obvious benefits of geologic reservoir sequestration is the improvement in atmospheric concentrations of CO_2. By trapping the CO_2 before it reaches the atmosphere, CO_2 density will be reduced therefore slowing down the growth rate of greenhouse gasses. This process, however, may generate a larger consumption of fossil fuels if no cleaner energy sources are broadly adopted, which leads to one of the main concerns regarding geologic reservoir sequestration - the location and transportation of CO_2 as it affects the overall balance of energy and CO_2. Due to the locations of most "oil sands and coal-burning electrical plants" being situated away from the suitable geological areas for carbon injection, CO_2 must be transported through pipes or on trucks over long distances to be stored underground [67]. The transportation process entails extra costs and energy, and emits a considerable amount of CO_2 itself which undermines the strategy's intent. To put in perspective, approximately \$88.90/tCO_2 is required to transport 1 million tonnes per annum of CO_2 (MtpaCO_2) over 500 miles while it "assumes extra monitoring requirements for CO_2 storage" [69]. In addition, an increase in energy and resource consumption can be observed through the construction and operation of such facilities, bringing further concerns both economically and environmentally to the surface. The number of carbon injections is ultimately limited to prevent increasing the probability of natural disasters such as earthquakes. Current EPA underground injection control programs, such as the Maximum Allowable Surface Injection Pressure (MASIP), establish regulations for carbon injections based on "calculated, testable, and well documented" pressure requirements that will prevent unintended formation fracturing which may arise during the process of injections. Other substantive risks include fracking which would potentially lead to brine water leakage and result in freshwater contamination. This, in turn, may also affect how the strategy is perceived by the government and the general public [70].

As a contemporary of BECCS, geologic reservoir sequestration has been implemented in only a few instances and is still largely in its developmental stage. Some examples where geological sequestration is used include "offshore natural gas production" and to "boost production from oil fields by displacing trapped oil and gas". Similar uses of this strategy can be further adopted as the technology more fully develops (e.g., carbon transportation, pipe leakage prevention, injection methods/architectures, etc.), increasing its carbon capture potential and reducing the costs and landmass requirements [71]. Geological sequestration is largely interconnected with many other mitigation

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technologies, so the increased implementation of others is likely to lead to an expansion of geologic reservoir sequestration practices as well.

Table 6: Geologic Reservoir Sequestration Data Analysis

Work Cited: [50]	Approximate CO_2 sequestered in depleted oil reservoirs	Global annual CO_2 removal Potential ($GtCO_2$)	Global total CO_2 removal capacity ($GtCO_2$)[a]	Global land mass required (Mt) to store CO_2 (km^2)	Total cost for implementation of practice ($/tCO_2$)
Geologic Reservoir Sequestration	30 $GtCO_2$	≈ 35	5,000 – 25,000	50 - 100 Mt ≈ 100 km^2	7 - 13

a: Gigaton of CO_2

Soil Carbon Sequestration:

Throughout human history most anthropogenic soil alterations usually resulted in a degradation of up to 50% to 70% of soil carbon storage and decreased more than 840 $GtCO_2$ of soil carbon. For example, forests were converted into farms or croplands, and farms were replaced by industrial factories or cities, etc. Therefore, soil carbon sequestration serves as a reversal process of these and other carbon-depleting practices and restores the soil with plants that best suit the land, transforming infertile soil back to its initial generative states and re-introduces "the chemicals that inhibit the mycorrhizal and microbial interactions that store carbon" [72]. "Launched by France on December 1st 2015 at the COP 21," [73], the 4 per 1,000 initiative is one of the many soil carbon sequestration organizations and initiatives. Intending to increase plant and soil (top 30 – 40 cm) carbon absorption and storage by 4% every year through afforestation and other agroecological practices, the initiative not only hopes to improve soil carbon storage but also food security and agricultural adaptation under climate change. Other practices such as changes in agricultural methods and restoration of forests, grasslands, and wetlands can all yield increases in soil carbon storage.

The main benefits brought through soil carbon sequestration are that a healthier soil obtains a stronger defense against challenges brought by climate change such as drought, flood, and heavy rainfall, and by requiring fewer fertilizers to be used, is economically, ecologically, and environmentally less of a burden. In addition, by improving and restoring the health of the soil, afforestation and reforestation can encourage an increase in agricultural productivity.

However, soil carbon storage is not infinite, meaning the amount of carbon that can be stored in the soil will reach its natural capacity at a given point, so residents and farmers are encouraged to better understand the details of new techniques and their role in increasing soil carbon storage. Transitions from one agricultural technique to another requires time and money, so providing a considerable amount of financial support to the people involved can efficiently improve the smoothness of this transition. In addition, the composition of soils varies worldwide, so to truly understand which species of plant or crop and farming techniques are best for a specific region and its type of soil requires a large amount of research. By encouraging research, different areas will have a better understanding of the particulars of their soil and accordingly, will be better equipped to maximize improvements by implementing the most optimal techniques for their soil rather than merely planting more trees.

Similarly, "blue carbon" (discussed further in the following section) serves the same purpose as soil carbon sequestration, only here sequestration is implemented in coastal and other regions involving bodies of water (e.g., mangroves, tidal marshlands, seagrass beds, and other tidal or saltwater wetlands).

Table 7: Soil Carbon Sequestration Data Analysis

Work Cited: [74] [72]	Measurable amount of soil for CO_2 (cm)	Global annual CO_2 removal Potential ($GtCO_2$)[a]	Global total CO_2 removal capacity ($GtCO_2$)[a]	Global soil carbon storage capability (tCO_2/acre)	Total cost for implementation of practice (\$/tCO_2)
Soil carbon sequestration	(15 – 40)[b]	(1 – 5)[b]: 2050[c]	(104 – 130)[b]: 2100[c]	≈ 8	(0 – 100)[b]

a: Gigaton of CO_2
b: "x - y" represents the domain and limitation of the variable from x to y
c: "(z)" represents the year said goal should be achieved

Coastal/Oceanic

For coastal and oceanic areas, the ocean CO_2 removal techniques are separated into four general sub-sections: ecosystem restoration (e.g., mangrove/seaweed/wetland restoration, marine permaculture, and restocking of whale populations), ocean fertilization (e.g., iron/nitrogen/phosphorus fertilization, and artificial upwelling/downwelling), modification of ocean chemistry (e.g., ocean alkalinity enhancement, and seawater CO_2 stripping), and CO_2 storage (e.g., seabed/sub-seabed storage of CO_2 capture on land, and deep-sea storage of crop waste/macroalgae deposition). Although not all of the listed solutions will be explored, some of the most optimal and beneficial sub-sections and solutions are included in this section of the paper (e.g., ocean alkalinity enhancement, ocean fertilization, and enhanced ocean productivity) [75].

Ocean Alkalinity Enhancement:

Associated with climate change and global warming consequences, the ocean presents our society and governments with many concerns and issues such as sea level and temperature rise, melting of the polar ice caps, and ecosystem and bio-habitat imbalances. One of the many sources that triggered these related issues is the increasing atmospheric CO_2 level. This has caused the escalation of ocean acidity, and with ocean acidification, many florals, corals, and other oceanic organisms are significantly affected, disrupting the complex food web of the oceans. In addition, a higher concentration of CO_2 in our atmosphere had led to a higher temperature overall, defrosting the ice caps and elevating the sea level. Utilizing the vast material for carbon capture and storage provided by the ocean, however, a mitigation strategy can be implemented that would withdraw and chemically lock away CO_2 from the atmosphere in the ocean basin for hundreds and possibly thousands of years. Currently, ocean basins worldwide naturally hold roughly 39,000 $GtCO_2$, while the increasing CO_2 concentration level of Earth's atmosphere currently is at 412 parts per million (ppm). Alkalinity can be produced to neutralize ocean acidity through the process of alkaline minerals (e.g., limestone and basalt) weathering and eroding, from which the alkaline minerals extract hydrogen ions (H^+) from the ocean basin to drive up the basicity of the seawater. This restoration of equilibrium can be achieved, albeit over geologically long periods of time, via the reaction where "[the] chemical change shifts the carbonate chemistry equilibrium from dissolved CO_2 and carbonic acid (H_2O + CO_2) to bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions," so "[t]he conversion of dissolv[ing] CO_2 into bicarbonate [would be able to] create a CO_2-deficiency in surface waters, thereby pulling more atmospheric CO_2 into the ocean" [76]. In another CO_2 mitigation path, carbonic acid, produced when CO_2 reacts with the seawater, is broken into hydrogen ions and bicarbonate ions and calcifying organisms which then transforms these bicarbonate ions into calcium carbonate as the chief components of their shells and skeletons. As those organisms expire, they bury the calcium carbonate they carry within themselves in the ocean floor and the CO_2 is locked away in the form of minerals. Throughout recent human history, this natural process alone managed to "absorb approximately thirty percent of [the] anthropogenic carbon CO_2 emissions since the beginning of the Industrial Revolution," [75]. Regardless of the natural process of ocean acidity neutralization and carbon storage exceeding the human survival timeline, this constitutes only a minimal force in combating climate change. Therefore, artificial ocean alkalinity enhancement such as the "accelerated weathering of alkaline rock", "addition of manufactured alkalinity products", and molecular pumps are recommended for consideration when adapting this negative emission technology to increase this process's efficiency and effectiveness in carbon extraction and sequestration [76].

Ocean alkalinity enhancement can be put into practice by accelerating the natural process of locking CO_2 and ocean acidity in the ocean basin in a variety of ways, requiring 30% of the ocean body. Two ocean alkalinity enhancement methods will be explored in this section. The first strategy is to use a controlled accelerated weathering reactor that combines crushed limestone, extracted seawater, and CO_2-rich flue gas to separate the acidic seawater and create an alkalized seawater solution that is then injected back into the ocean and locked away in the deep ocean's carbon vault. The second strategy is to insert finely ground alkaline rocks (e.g., limestone ⇒ lime, and silicate-rich rocks) into the ocean floor, thereby promoting and advancing the natural geological cycle of securing CO_2 in the ocean basin. Both strategies mimic oceanic carbon extraction processes which have been occurring over the past few billions of years, but are implemented in this practice to greatly compress its naturally long timescale [76].

When ocean alkalinity enhancement is implemented to scale, in proportion to the threats posed by climate change, a significant amount of CO_2 can be mitigated successfully through this Negative Emissions' Technologies (NET), although the result will come with a corresponding price [77]. Several benefits ocean alkalinity enhancement brings to Earth's overall environment, atmosphere, and ecosystem, are associated with the specific alkaline methods. For example, methods such as electrochemical weathering, a technology that allows scientists and operators to produce enough alkalinity to securely sequester CO_2 by pumping seawater through an electrochemical system, rearranges the water and salt molecules in that pumped seawater to produce two separate solutions: acid and basic. The acidic solution is removed and can be sampled for scientific research enabling better ocean alkalinity enhancement methods, while the basic solution is injected back into the ocean to neutralize ocean acidity and increase the ocean's carbon extraction ability [76]. For this method specifically, valuable by-products such as hydrogen and oxygen gas, silica, and nickel/iron hydroxides, presenting as a source of energy, are created. Other methods, such as the utilization of silicate-rich minerals (e.g., olivine), produce carbonate sediments which are disposed into the sea water where they release iron and silica, fertilizing the ocean's biodiversity to various scales. Moreover, this method alone can mitigate 12% of the global energy-related CO_2 emissions annually, hence ocean alkalinity enhancement methods can capture and sequester vast amounts of CO_2 from the atmosphere for an extremely long duration lasting up to hundreds of thousands of years. In general, regardless of the acid neutralization methods, ocean alkalinity enhancement is aimed at directly reversing ocean acidification; therefore, increasing marine ecosystems' biodiversity, health, and population protection while removing CO_2 from the atmosphere [78].

The biggest concern regarding ocean alkalinity enhancement technologies is the uncertainties of different aspects related to the processes. Biogeochemical side effects such as alteration of ocean chemistry and damage to the marine ecosystem are likely to be introduced by this mitigation strategy, where such changes can intensify the vulnerability of biodiversity, food security, resident health, water quality, etc., and possibly disrupting and degrading the local and

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even regional economics [78]. The root cause of biogeochemical side effects are the heavy metals embedded in the alkaline materials that are dumped into the ocean, which can become widespread among the oceanic food chains, and the extensive mining of alkaline raw materials, raising environmental, societal, and local health concerns along with these processes having a comparably high level of energy consumption [79].

Table 8: Ocean Alkalinity Enhancement Data Analysis

Work Cited: [78] [75] [80] [81]	Proportion of Carbon (t) ⇐⇒ Material (t[a])	Global annual CO_2 removal Potential ($GtCO_2$)[b]	Global total anthropogenic activity CO_2 extraction ($GtCO_2$)	Global land mass required (% of Earth's surface)	Total cost for implementation of practice ($/tCO_2$)[c]
Ocean alkalinity enhancement	$1tCO_2$ = 1 - 3.5	≥ 2.5 - 2.9	≈ 67	≥ 70.9%	5 - 160

a: Ton
b: Gigaton of CO_2
c: Cost in United States Dollars (USD) per tons of CO_2

Despite developments in research on ocean alkalinization and ocean chemistry associated techniques, ocean alkalinity enhancement technology still resides at an early theoretical level. Only if one were to ignore the negative environmental, biological, and economic side effects of ocean alkalinity enhancement, the technology could be put into practice. However, to responsibly minimize these negative effects and maximize the efficiency and effectiveness of the technology, ocean alkalinity enhancement technology will require much more research to be conducted before large-scale implementation can be reasonably considered. Additionally, the government should consider that research, development, operation regulations, environmental restrictions, and social sustainability should be applied and carried out in concert with the implementation of the ocean alkalinity enhancement to promote the beneficial factors of this technology while not neglecting the negative effects it brings [78].

Ocean Fertilization (OF):

Ocean fertilization (OF), a mitigation strategy that pulls out CO_2 from the atmosphere, utilizes the alteration of geoengineering on the ocean surface and ecosystem by adding nutrients (e.g., iron) to the upper layer of the ocean (i.e., euphotic zone) in an attempt to increase the phytoplankton population and activity, therefore increasing the ocean's carbon extraction efficiency and capacity. Nevertheless, because the marine carbon and nutrient cycle are considerably complex, to safely implement this mitigation strategy a detailed understanding of marine biology and the carbon/nutrient cycle must be obtained.

The ocean layer can be roughly categorized into four layers: surface ocean (i.e., euphotic zone: 0 - 100 m), twilight zone (i.e., mesopelagic zone: 100 - 1000 m), deep ocean (≥3700 m) and the seafloor (i.e., benthic zone). Activities and exchanges of carbon and nutrients thrive between the first three layers, while the seafloor contains mostly reactive sediments and the burial of CO_2. Starting from the first layer, the large phytoplankton resides at the ocean surface. The phytoplankton consume CO_2 and atmospheric depositions (e.g., iron [Fe] and nitrogen [N]) through photosynthesis, which are then consumed by the bacteria, viruses, and zooplankton in the microbial loop [82]. Zooplankton, who also prey on the small phytoplankton and microzooplankton populations, are then captured by a higher trophic level of marine organisms, who are then devoured by the predators such as birds and fish. Through aquatic respiration, marine organisms extract the dissolved oxygen from the ocean water and excrete metabolic waste products (e.g., carbon dioxide, dimethyl sulfide, nitrous oxide, and methane) into the water, where those compounds move down the oceanic layers from the surface ocean to the twilight zone through the process of physical mixing. In addition, marine phytoplankton aggregate formations and detritus from the ocean surface drops down into the mesopelagic zone and combines to form the sinking particles of carbon and nutrients, where they settle into the deep ocean and are then decomposed by bacteria. There they are consumed by archaea who produce CO_2 through aquatic respiration and will be captured by the migrating zooplankton population in the twilight zone, or they condense their carbon and nutrient storage to create organic carbon. Regardless of the different pathways presented for these sinking particles, all pathways will eventually find their way into sediments and descend to the benthic zone where the carbon and nutrients they carry within them are locked away below the seafloor [82]. Moreover, when the temperature of the ocean's surface water decreases and its salinity increases, the surface becomes much denser than the water beneath, causing it to sink to the deep sea, in turn causing downwelling and deep-water formations, which can lock away the CO_2 from the surface in the ocean floor. Moreover, ocean upwelling occurs when the surface currents become dislocated from each other, bringing up the deep water to the surface while pushing down the surface water to the deeper layers (i.e., ventilation). This leads to a redistribution of water and with that heat, nutrients, and oxygen within the ocean, fertilizing the surface water and increasing the biological productivity of the surface ocean [83]. With the pathogen/pollutant/nutrient runoff from the coastal land area and the emission of CO_2 from the ocean floor sediments during its organic matter decomposition process (i.e., benthic CO_2 flux), which produces nitrogen, phosphorus [P], iron, and silicon [Si], ocean upwelling, downwelling, and ventilation can regulate and better distribute these materials, maximizing the ocean fertilization goals [82]. Therefore, because leveraging the ocean's carbon storage capacity is well into the distant future, by artificially accelerating these two processes (i.e., phytoplankton population activities & ocean upwelling/downwelling), the ocean carbon extraction effectiveness and efficiency can be greatly improved.

Because ocean fertilization is implemented to accelerate a natural process that extracts CO_2 from the atmosphere, it is a relatively safe practice and technology. However, due to the lack of research on certain aspects of marine carbon and nutrient cycling that has not been fully explored, some unexpected problems may be created from the fertilization of ocean phytoplankton populations and the cumulative effects of ocean up/downwelling. Not only will ocean fertilization aid in the ocean alkalinity enhancement strategy to reduce seawater acidity, it can also serve to pull more CO_2 from the atmosphere in less time. Nevertheless, ocean eutrophication (i.e., "excessive richness of nutrients in a body of water, frequently due to runoff from the land, which causes a dense growth of plant life and death of animal life from lack of oxygen" [84] presents as a disadvantage of ocean fertilization, whereby the nutrient needs of the ocean may be exceeded, causing potential negative side effects. Needless to say, ocean fertilization on the phytoplankton population has a short-term effect and requires further research to be conducted for longer-lasting results.

Calculations and data collection based on the "current technological readiness [and] the time needed to reach full implementation" [85] reflect the technological feasibility of ocean fertilization and is comparably low to other mitigation and adaptation technologies (e.g., reef restoration, renewable energy, vegetation, etc.) Furthermore, the cost-effectiveness of ocean fertilization is relatively lower than most other technologies in the same broad category, resulting in a desired "good" result with lesser economic input. Ultimately, to achieve high levels of carbon extraction without provoking ocean eutrophication and/or other negative effects, governments are recommended to establish restrictions, regulations, and distribution of resources, promoting ocean carbon uptake only within tight controls.

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Table 9: Ocean Fertilization Data Analysis

Work Cited: [86] [87] [88]	Lasting effect period (week/cycle)	Global annual CO_2 removal Potential (GtCO2)	Global ocean CO_2 storage (100-year net carbon sequestered)	Surface area needed ($km^2/GtCO_2$) [a]	Total cost for implementation of practice ($\$/tCO_2$)
Ocean Fertilization	≈ 1	(1 – 2)[b]	0.4% - 8.3%: carbon biomass 2% - 44%: carbon exported through iron fertilization	≈ 1,000	(30 – 60)[b]

a: Gigaton of CO_2
b: "x - y" represents the domain and limitation of the variable from x to y

Artificial Sand Dunes and Dune Rehabilitation:

Worldwide, including the 95 nations and states that appear as islands, the total shoreline length stands at 356,000 km, and the total coastal area globally, including the land (148.94 million km^2) and water (361.132 million km^2) portions, amounts up to 510.072 million km^2 [89]. Using these natural resources, artificial dunes and dune nourishment can be widely distributed and implemented as an adaptation technology in response to oceanic and coastal threats introduced by climate change. The goal of artificial dunes and dune regeneration is similar to the construction of seawalls where both aim to establish a barrier between the sea and the land, protecting the local residents and natural habitats from coastal erosion and flooding. The dynamic ability of dunes, whether artificially or naturally assembled, enabled this technology to adjust and shift in shape and size as the sea level, ocean currents, wind, and wave climate fluctuates; therefore allowing the dunes to supply and store sediments to the beach according to their prevailing environment. Whether accomplished by artificial assembly or by natural formation, dredged sources as well as naturally occurring deposits such as mud and sediment on the coastal regions of the beach can create or restore the dunes. Furthermore, by attaching supplementary defense structures (e.g., fences, planted vegetation) on these dunes, wherein such fences built next to the sea are constructed with natural materials that can easily decompose while vegetation can collect sediments near their location, both are done to promote dune growth, trap sand, and stabilize dune/sand surfaces. In total, there are five general types of sand dunes: "transverse, linear/longitudinal, star, barchan/crescentic, and parabolic/blowout," [90]. Needless to say, artificial dunes and dune stabilization are not limited to the developed beaches alone. Rather, they can be implemented on a variety of land, including "existing beaches, beaches built through nourishment, existing dunes, undeveloped land, undeveloped portions of developed areas[,] areas that are currently fully developed but may be purchased so that dunes can be restored," [91], minimizing the limitations and prior restrictions of sand dune creation and restoration.

Different from sea walls, dune nourishment/creation occurs and can be maintained more naturally, leaving less waste and pollutants on the coasts. Additionally, the dunes contribute largely to the maintaining of wide coastal zones on the beaches they reside in. Further, dunes can dissipate wind, wave, and storm energy and present an ablative barrier to coastal erosion, where sand from the dunes will be eroded away during different seasons, coming to rest as sediments at the bottom of the coastal regions' waters instead of a decreasing landmass of beaches that are being eroded without the protection of dunes. Likewise, due to the protection provided by the dunes that shield local inland residents from coastal erosion and flooding, sustainable commercial and other development are more likely to be promoted as a result.

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This in turn benefits local regions economically, just as naturally created dunes can benefit the residents, habitats, and organisms environmentally and ecologically [91].

Although dune regeneration and creation can be implemented with fewer costs and are flexible with many other mitigation and adaptations technologies, some negative side effects of this practice, more specifically with the introduction of new dunes, can still be encountered. Not only will the dunes present as a barrier that protects the residents from oceanic hazards, but it also creates an obstruction that prohibits the residents of their beach access that was once much easier. As well, when implemented in unsuitable regions dunes may create destruction of natural habitats, killing and/or dislocating native species. This result can occur most likely when dune creation and regeneration necessitate that construction areas be zoned off from the public and wildlife residents to maximize the growth process of the dunes. Correspondingly, dunes take up a considerable amount of landmass, yet some may not have sufficient protective effects on the landmass designated for protection as the residents and government may desire. This may commercially and recreationally affect the residents, where land loss may arise as a potential problem, and the general public, where fewer tourist activities may be enabled [91]. Furthermore, even though dunes can dissipate wave energies, some may not be strong enough to stand against strong storms and wave action, thus easily destroyed by such coastal activities. Given that dunes cannot regenerate themselves in a relatively short period, the costly process of reconstruction must then be repeated to maintain the dissipating and erosion process.

Technologically, artificial dune and dune rehabilitation are at a matured and developed level for implementation, where the practice has been adopted for roughly 70-100 years (e.g., the U.S. [1920s], Europe[1950s]) [92]. However, residents and governments are yet to reach a compromise or agreement on the size, type, frequency, and other factors concerning this adaptation technology to avoid conflicts of interest, public opposition, and additional negative effects from both which would otherwise be avoidable. Nevertheless, dunes can serve as an opportunity to educate the public about climate change concerns and the threats posed to Earth's ecosystems, environments, and essentially, their everyday life, physically and mentally preparing local residents as well as the public at large for possible future events. As more and more people accept the challenges and dangers climate change brings, dune rehabilitation and creation can be implemented for wider areas, better protecting inland regions as it serves its multi-purpose function.

Social

Raising Public Awareness

The disastrous effects of climate change on life around the globe are undeniable; however, public action has remained relatively low compared to other catastrophes of a similar scale and impact. According to a study conducted in 2019, only 63% of Americans support climate change policies and believe their necessity is worth the economic cost [93]. This public view is nearly identical to the response given 25 years ago, indicating that there has not been major improvement, if any, in public support about global warming's consequences. Although many communication campaigns have been established during this time period, many are criticized for being inadequate to provoke real action. In addition, although knowledge about climate change may be more advanced with the spread of information via media, changing attitudes and behaviors are crucial for enacting actual improvements on the issue.

One strategy to achieve real actions and positive perspectives regarding climate change is to introduce local issues into the discussion which stem from global warming in order to increase a sense of realism, immediacy, and community involvement. Climate change must be stressed as a present, local, and personal threat instead of a far off political, economic, and environmental factor, and only then will the public begin to take action in their individual lives. Regional impacts should be publicly discussed and all members of the community should participate in the debate and decision-making process. There are many courses of action to consider, but any technique that is considered should result in

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local households noticing that immediate action leads to observable positive changes, bringing the issue of global warming closer to their personal lives rather than being a problem in the hazy distance.

Another method to instigate public support of climate action is binding communication, which consists of a preparatory act by the target population followed by a communication message that clearly states the relationship between various factors, such as recycling and the effects it has on local environments. In other words, fulfilling a simple, low-cost task increases the chance that participants would comply with subsequent larger requests. Research results indicate that this model "increases the effectiveness of a communication message in terms of (a) attitude change, (b) self-reported behavior, (c) behavioral intention, and (d) compliance with costly requests related to the previous one" [94]. In a particular study conducted on high school students to research the effect of binding communication on raising awareness regarding climate change, participants who were in the binding communication group were four times more likely to subject themselves to behavioral follow-through than the control group. Such paradigms are shown to engage targeted audiences on an emotional level as well as informational. Preparatory acts increase the efficiency of a persuasive message, relying on commitment theory and the classic communication process, respectively.

Finally, separating politics and climate change is absolutely critical to ensure cooperation and agreement between both major political parties in the United States. This will allow for major cuts in expenditure of time and budget on political arguments and decisions, instead, emphasizing the importance of saving the environment over political affairs and setting an example for the public. Moreover, excessive international political arguments should be minimized by way of diplomacy and negotiations conducted in good will by all sides to avoid wasting time and money. Bipartisanship, along with international cooperation, is invaluable to communicating unbiased data that will eliminate many climate change deniers and encourage those who are aware of it to begin taking action in their own households.

Youth Education

The societal, economic, and welfare impacts from global warming will endure into the indeterminate future, affecting many generations to come unless the threat is successfully and absolutely confronted. Therefore, each generation that inherits the Earth plays a critical role in protecting it and empowering future generations to be knowledgeable about climate change. As such, this should be an important goal in education. Although the scientific community has largely reached a consensus view regarding the importance of youth education to help bring about climate change action, details of such plans are unclear. Most controversy surrounds the topic of the value of the individual's contributions. "The old argument that 'if everyone does their small part, it will make a difference' is, according to some, simply not valid", because individual contributions on a global scale are simply too microscopic [95]. In addition, cooperation of all citizens of the world - or even only a majority of people across the world - is likely impossible unless impactful economic policies are initiated.

Climate education is unfavored by traditional subject-based curriculums. This is apparent in the "compartmentalization" of subjects, such as a split of different areas of science. While climate change touches on a diverse range of topics, traditional education separates these into distinct topics and oftentimes is taught at different grade levels and at various depths, leading to a disadvantageous division of time and energy. In addition, traditional education places heavy emphasis on academic grading and standardized test results, leading to primarily extrinsic motivations for students to learn and participate in mitigating global warming. Once students are independent of these stimuli, they may well no longer feel the need to actively engage as before. Thus, climate education requires the reform of public education, for example, reorganizing academic topics to point out that school subjects are interrelated with each other and are embedded into a complex network of real-world cause and effect. A robust, non-graded standardized

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curriculum related specifically to climate education across all states, should be considered to ensure future generations are equipped to understand the challenges their generation will face in combating this issue.

Importantly, educators who directly interact with students must be willing to provide climate education and support the cause. Daily interactions between students and teachers can be highly influential on young students' minds and beliefs. One study showed that teachers do not consider "the role of science education to try to solve today's major social, political, economic, technical or scientific problems'' [95], which is detrimental to a students' knowledge and views on climate change, especially if such teachers are involved in the child's education from early on. In addition to actively endorsing climate intervention, teachers must be accurately trained in climate education using a source of unbiased data. Misinterpretation, bias, and lack of support must all be eliminated before an educator can satisfy the requirements of climate education training. If teachers are in disagreement regarding aspects of climate change, the student may end up confused and simply conclude that the teacher they personally prefer is more reliable, which would likely result in gaps in the education of and/or misinformation to the student. This consistency must also apply to teachers across different schools, districts, counties, states, as well as teachers of other subjects such as the arts or English, to avoid confusion and doubt. The student will then realize that climate change affects life in general, and is not just a remote issue that is discussed only in science class.

Lastly, youth education must be strictly bipartisan and unbiased in every aspect. Teachers, although entitled to their own opinions, should not advocate for their personal beliefs but rather bring different perspectives based on broadly verified facts and sound, logical reasoning, as well as encourage sensible discussion from everyone in the class. Educators should not fear but rather embrace diverse opinions in the classroom, welcoming these opinions by approaching them with patience and understanding, demonstrating to their students this important component of the climate education discussion. Further, discussions should incorporate both formal and informal elements, for example, technical terminology can be explained in relatively more vernacular language and thus still carry authoritative weight and a sense of reliability while also being more accessible to students' level of understanding.

Domestic Funding

Domestic funding is closely linked with public awareness and youth education, which if successful, will lead to greater public support and more investments and funding towards mitigation and adaptation strategies. Domestic funding is vital as well for the encouragement of technological innovation and providing secured and stable motivation for the continuation of climate change research. One example of a new climate mitigation technology with major potential is the Traveling Wave Technology, which "offers 30 times more efficient use of mined uranium and a factor of five reduction in waste, all based on a once-through fuel cycle without the safety and proliferation concerns of reprocessing used fuel" [96]. Its key characteristic is that it employs depleted uranium — or the "excess" uranium that is not fissile — to generate nuclear energy, thus enabling a significantly more efficient method of obtaining nuclear energy. Similar technologies that are still in earlier research stages must have sufficient funding to continue development.

Before 2017, the United States had been one of the largest contributors towards financing climate change action; however, this trend was halted with former President Donald Trump. Current President Joseph Biden budgets more than $36 billion to combat global warming, including $10 billion for clean energy innovation, $7 billion for NOAA research, $6.5 billion for rural clean energy storage and transmission projects, $4 billion for advancing climate research, $3.6 billion for water infrastructure, $1.7 billion for retrofitting homes and federal buildings, $1.4 billion for environmental justice initiatives, plus another $21 billion on research.

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In addition, domestic funding will very likely originate from and be sustained by economic needs for conversion rather than environmental concerns, unless areas of the United States are dramatically damaged or otherwise experience direct and irrefutable consequences specifically traceable to climate change. While environmental complaints are beneficial to reformation, true change will require a certain critical amount of economic and financial momentum in order for politicians and policymakers to become sufficiently incentivized to initiate them.

3. Combination

Optimal Combination:

After analyzing the effectiveness of solutions in all sections above in terms of potential effectiveness, financial feasibility, current readiness, and most importantly, compatibility, we selected the most outstanding few and drafted an optimal combination as a suggestion and reference for governments when making political decisions regarding climate change and corresponding actions. As the combination draws from solutions in various topics, from economics to energy to agriculture, it has a better likelihood of resolving more aspects of the fundamental problem, as compared to taking individual action in isolation. Synthesizing solutions together also allows them to make-up for others' flaws in order to achieve maximum potential. Since prevention of global warming no longer exists as an option given that the effects of this crisis have already commenced, all climate change solutions have been limited to mitigation and adaptation strategies that best match the present and expected future situation. Incorporating both mitigation and adaptation strategies, this combination merges and emphasizes the benefits acquired both from the selected Negative Emissions Technologies (NETs) (i.e., afforestation, ocean alkalinity enhancement, and bioengineering) and governmental policy solutions (i.e., cap-and-trade, clean energy industry establishment and expansion, and international contract proposals) while constraining the concerns and side-effects generated by each strategy to a minimum through a beneficial cycle of systems.

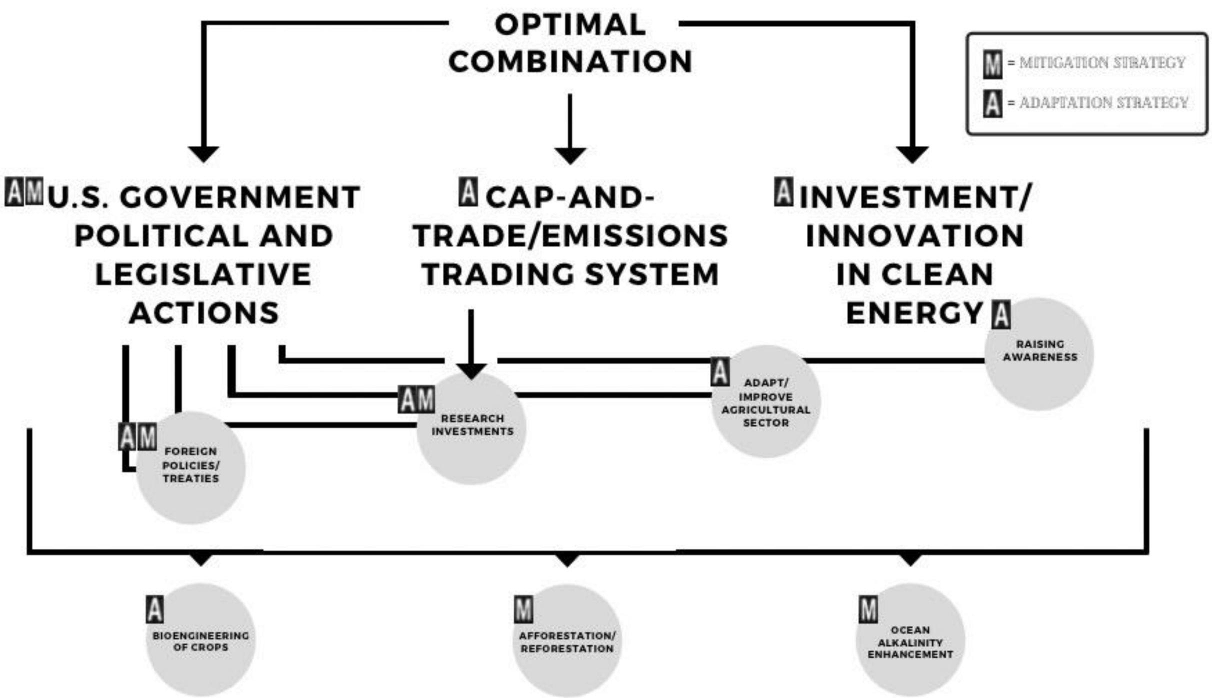

Figure 2: Optimal Combination Model: The model labels each proposed solutions as "M" (mitigation strategy), "A" (adaptation strategy), or "AM" (both mitigation and adaptation strategy), and explains the relationships and interconnectedness between each solutions, where the political (U.S. Government Political

and Legislative Actions), economic (Cap-and-Trade/Emissions Trading System & Investment/Innovation in Clean Energy), and social strategies (Raising Awareness and Public Education) enables the implementation of technological mitigation (Ocean Alkalinity Enhancement and Afforestation/Reforestation) and adaptation (Bioengineering of Crops) strategy.

Climate intervention is very likely to only come about through economic forces driving countries and corporations to change their former methods and adopt new carbon free/low/neutral practices that they decide are most efficient and cost-effective. Thus, the need for an economic framework with the ability to reduce GHG emissions while compelling policymakers and others with the potential to bring about change (e.g., corporation leaders) to reduce and/or eliminate the need for energy derived from pollution heavy sources is inevitable. A cap-and-trade/emissions trading system is one of the most efficient ways to inspire such a reduction in GHG emissions without raising the threat of substantial negative effects on the economy. As mentioned above, the main advantage of the cap-and-trade system, as compared to another economic system such as a carbon tax, is its flexibility in the marketplace. For instance, this system allows for free trade between organizations and lets the market determine the price for carbon credits, while relieving the government of the difficult task of setting a fixed carbon tax policy that would allow companies to simply pay emission fees which would be seen as just another cost of doing business and increased cost passed on to consumers. Allowing the market to function freely with minimum government intervention will produce the best price for carbon credits and establishment of this price would be assimilated into the market automatically. An emissions trading system would also allow for businesses to undergo an easier acceptance and transition into this framework, since it initially allocates free carbon credits before placing a cap on excess carbon emissions, therefore giving firms extra flexibility as well as profit incentives for innovation and renovation instead of simply enforcing penalties for exceeding the cap. On the other hand, a carbon tax would have the opposite effect on businesses as its strict regulatory regime would lead to overall dissatisfaction from the entire industrial sector, making it harder to be cooperated with and risks politically charged lobbying or price spikes in consumer goods and services. Moreover, cap-and-trade systems bring with them more freedom to consumers by allowing them to shift their purchasing from a given company to its competitors offering relatively lower cost products because they utilize the trading aspect of cap-and-trade.

An example that demonstrates the effectiveness of a successful cap-and-trade program is one of California's climate policies, Assembly Bill 32 Scoping Plan. California's Cap-and-Trade Program, which involves entities that emit 25,000 or more metric tons of GHG responsible for approximately 85% of the state's emissions. After its implementation, other climate change projects and research have benefited from the revenue generated from this cap-and-trade program, which was estimated to be over $5 billion and was deemed to be environmentally effective and economically efficient. Similarly, implementing a large-scale cap-and-trade system on a national level would promote the implementation of the other NET solutions in combination. Program compliance has been at a "near 100% rate at each compliance event", and California achieved its 2020 GHG Reduction Target four years earlier than mandated [97]. Therefore, a more extensive cap-and-trade framework proposed in this combination likewise needs to be imposed to stimulate greater reform regarding energy consumption and drive the economy away from dangerous GHG emission levels. Similar compliance instruments and goals can be established with modifications suitable to the large-scale electricity generation, industrial, and fuel supply sources that would be covered in a more comprehensive plan.

Investment and innovation in clean energy is also important to provide zero/low/neutral emission energy source alternatives for corporations and individuals. Heated debates have occurred between supporters of nuclear energy and renewable energy, and this disunity of the scientific and political communities have greatly hindered progress in legitimate action regarding the topic. Therefore, to ensure that all solutions are fairly considered and all aspects of the issue have been addressed, a blend of both clean energy sources is recommended for uniting two important factions of the scientific community, as well as the general public, providing a better way to combat climate change. For instance, a greater positive effect can be achieved with emphasis set around a clearly defined goal that involves both energy sources rather than unproductive disputes, which only serves to squander time and averts attention from the environment to politics. On the other hand, a coexistence of renewable energy and nuclear energy allows these clean energy forms to be utilized to their maximum potential.

Certain renewable energy types (i.e., solar and wind energy) have had massive drops in production expenses. Moreover, hydroelectric and geothermal power are one of the cheapest sources of energy, averaging around $0.04 per kWh. Despite being the least expensive energy source for global generation, renewable energy types lack the deserved support in the energy sector. The primary opposition to renewable energy is the fossil fuel industry; investments, political policies, as well as the energy infrastructure, all favor the use of fossil fuels. Obstacles preventing the rapid growth of renewable energy include: long-term contracts for fracking, energy monopolies powered by private investors, consumer dependency on single suppliers (the lock-in effect), and inconsistency of energy production amounts (as mentioned in the *Renewable Energy* section). Thus, instituting a cap-and-trade system and encouraging the use of renewable energy would be most optimal in deterring energy monopolies and large corporations from continuing to use fossil fuels and shift the market more favorably towards renewables.

The main reasons for the opposition to most sources of renewable energy is its instability and usually low energy capacity factor, as well as how they do not produce as much energy as say nuclear or fossil fuels. However, its main advantage lies in the fact that it is widely accessible and can be easily implemented on large scales because instruments like solar panels and windmills can be quickly constructed, even in residential areas. On the other hand, nuclear energy has a high energy capacity factor completely distinct from other energy sources, including both fossil fuels and renewables, and it also produces a large sum of energy once a plant begins operation. This critical advantage should not be ignored or nullified due to its heavy expenses and lack of public support, especially because cost per unit of nuclear energy will significantly decrease with the rise in demand. However, in contrast to renewables, nuclear energy requires much more advancement in cost efficiency for building a power plant and has a critical lack of public support, which may take years or decades to rebuild a favorable reputation. It also requires a large, isolated area for the plant to be constructed. Therefore, the most optimal usage would be for nuclear plants to be constructed in any isolated lands available to take advantage of its larger energy output and to construct renewable energy producing facilities in residential areas to take advantage of flexibility and easier access.

The conjunction of utilizing both renewable energy and nuclear energy provides many benefits. Members of the scientific community are critically divided among promoting nuclear energy or renewable energy, and a complete discrimination of one energy source over the other will lead to the exclusion of a substantial mass of this community, while converting to clean energy to reach these ambitious energy goals will require assistance from all members of the energy sector. Those who support renewable energy or nuclear energy are still able to conduct research funded by the government, however, clear goals must be enforced with specific deadlines to avoid regression into this current inactive state where both factions are unable to make significant progress. Secondly, a more diverse energy plan creates many opportunities for utilization. Different areas of the United States are more suitable for installment of solar panels, while other areas are better used for construction of nuclear plants. Ecological advantages may factor into the specifics of this plan, but avoidance of general disorganization and scattered weak attempts is crucial. Rooftop solar panels, for example, should be promoted by the government for inclusive citizen participation and mass energy generation. Large-scale wind energy products can be stationed in deserts and other arid land regions - even, possibly, positively impacting regional climates by changing solar reflectivity amounts and air currents, causing a beneficial feedback loop leading to the promotion of rainfall and vegetation growth. Nuclear power plants should be located in remote areas with a steady

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water supply. Drafting a plan based on geological benefits and technological requirements – dividing the funding and support to both renewable and nuclear energy – will result in a more accelerated abandonment of carbon-emitting energy sources and expeditiously lower GHG emissions in the coming years.

In addition to all aforementioned actions relative to the combination, the U.S. government itself must ensure that it is maintaining necessary progress in terms of political and legislative actions. With the goal to increase support towards such efforts, raising awareness is vital, and thus so is the need for reform in the education system. All schools and other educational facilities in the U.S. need to incorporate a consistent and robust study of climate change into the academic curriculum. Detailed precautions of implementing this curriculum can be found in the Social section above. Second, the U.S. government needs to adapt and improve its agricultural sector by supporting it through economic and/or humanitarian means. As climate change impacts the country, the agricultural sector faces especially destructive consequences from severe weather and the longer-term implications of a changing climate. Adaptation measures such as improving infrastructure, constructing dams or other forms of crop protection, and subsidies to farms most directly exposed to the impacts should be considered. Furthermore, scientific research targeted towards the sustainability of crops must be conducted in order to preserve maximum yields. The protection of the agricultural industry is crucial as it is responsible for maintaining the nation's food supply and occupies a major role in international trade. Extreme events caused by climate change, such as droughts and floods, have historically crumbled certain areas of the industry. For example, in 2010 and 2012 high night-time temperatures [negatively] affected corn yields across the U.S. Corn Belt, and premature budding due to a warm winter caused $220 million in losses of Michigan cherries in 2012 [98]. Third, research investment should be increased. This refers to all types of spending for combating climate change efforts including research for more efficient emission technologies, better mitigation strategies for CO_2, deeper scientific research on the impacts of climate change, and more. As stated, the US government needs to match and aid in efforts by non-governmental organizations already involved in research and investment. The budget would come from either revenue generated by the cap-and-trade system recommended above or cuts in funding for less urgent issues. Finally, the government ultimately needs to interact with other countries through foreign policies. For instance, cooperation, discourse, economic pressure, and potentially political pressure are most of the time necessary for America to initiate a chain of desired actions. Drafting treaties with poor oversight or supervision, although commendable, ultimately will result in a lack of legitimate action. Stepping beyond the stage of only discourse and into concrete actions is now needed to move forward on improved efforts for cooperation and results, on a global scale.

Between 2007 and 2010, the total military budgets the United States spent increased by more than $200 billion in the span of three years ($453.32 billion to $665.27 billion), taking a larger proportion in the total expenditures [99]. Yet, the U.S. military budget continued to increase during the following years at a rate of 4.6% above the U.S.'s total spending annually, becoming an ever-increasing priority [100]. Driven by tensions with its neighboring countries and the U.S., China, as of 2018, has annually and consecutively increased their military budget for the 24th time by 5%, taking up 14% of all global military spending [101]. The governments of other countries such as India, Pakistan, and South Korea have all increased spending in their respective departments of defense - indicative of many countries worldwide who are re-focusing or shifting their economic priorities onto military systems as a result of the international tensions driven by various reasons. With the implementation of a carbon tax and other revenue-gaining mechanisms, countries are more likely to obtain increased budgets for investment. Consequently, governments are encouraged to plan out a considerably fair portion of the total budget for climate change mitigation and adaptation technology research and development purposes (e.g., ~5% of total spending) from such gains and the otherwise continuously increasing military budgets. With better utilization of capital resources, countries are more likely to fund more critical technologies to combat climate change, resulting in a more realistic goal and achievements that can reduce climate change damage and threats far more effectively.

With encouragement and investment available for action, the aforementioned mitigation and adaptation technologies most suitable to be in the optimal combination for maximizing positive impact in combating climate change are the bioengineering of crops, afforestation/reforestation, and ocean alkalinity enhancement. In the case where no action is conducted in response to climate change, the global environment will be largely degrading worldwide, punctuated by declining condition of soils (e.g., salinification and desertification) and habitats (e.g., increase of temperature, water shortage, and loss of habitats in general) causing and exacerbating many problems within countries, nations, and society in general (e.g., food insecurity, economic inequalities, etc.)

In response to this concern, bioengineering of crops serves to upgrade the soil condition adaptation of the crops themselves and creates more crops with desired traits and characteristics suitable for their growing conditions. Subsequently, this allows for more crops to be produced within a more compact land area which reduces food insecurities and excessive water usages in agriculture by keeping pace with the demands for food production and storage to feed the rapidly growing population despite. In areas that previously proved inefficient to support large quantities of agricultural plants to be grown and harvested, crop bioengineering allows local and regional farmers to select appropriate crops that are genetically modified to withstand the prevailing harsh environment, therefore making use of many wastelands or empty spaces that would not be implemented for alternative means otherwise. By maintaining a steady production of food, the impact of climate change on people's lives will be substantially diminished, enabling society a longer period of time to counter climate change while minimizing serious consequences such as famine and conflicts over resources.

4.0 Summary

By implementing technologies through acceleration of natural mitigation processes in the forest (i.e., afforestation/reforestation) and the ocean (i.e., alkalinity enhancement), the negative environmental effects are reduced to a manageable, controlled rate with benefits that are much more predictable. Given that Earth's soil and ocean carbon storage capacity well exceeds many other methods and the processes required demand much less economic investment than many other more technologically challenged approaches, the processes can be conducted to scale over a long period of time to mitigate the desired amount of CO_2 from the atmosphere with little concern of reaching carbon storage capacity or economic limitations. With minimized interference versus other technologies, afforestation and ocean alkalinity enhancement can be conducted over large portions of the globe without incurring serious social, economic, or environmental disputes. Moreover, not only will these technologies benefit the environment, it can also benefit local habitats by restoring many that have been lost due to the degrading natural structures in that region and improve the local residents' living conditions socially (e.g., lessen unemployment rate, reduce food insecurity, etc.) and economically (e.g., boost of food production and trade). With all three steps combined, countries can work together within their states and provinces to maximize the beneficial effects of their applied technologies, mitigating atmospheric CO_2 efficiently and effectively with realistic and adequate economic support and investments from governments.

Table 10: Mitigation Technologies Data Analysis

Measurable Mitigation Strategies	Cost per Gt of CO_2 Mitigated ($)	Total CO_2 Mitigation Capacity by 2030 (Gt)	Technological Readiness for Large-Scale Implementation

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 6 April 2022 doi:10.20944/preprints202204.0032.v1

CCUS	$100 billion - $1 trillion	N/A	Yes
BECCS	$20 - $100 billion	0.5 - 5 (2050)	Yes
Afforestation/Reforestation	$0 - $50 / $104 billion	3.6 (2050)	Yes
Geologic Reservoir Sequestration	$7 - $30 billion	62.5 (2050)	No
Soil Carbon Sequestration	$0 - $100 billion	1 - 5 (2050)	Yes
Ocean Fertilization	$18 - $60 billion	3.2 - 9.4	No
Ocean Alkalinity Enhancement	$55 - $160 billion	2.5 - 10	No
Carbon Tax ($40)	+$26 billion net revenue	20	Yes
Cap and Trade ($40)	+$7.9 billion net revenue	38	Yes

Note: Summarizes the aforementioned mitigation solutions to provide a comparison of their effectiveness through their cost per Gt of CO_2 mitigated, total CO_2 mitigation capacity by 2030, and technological readiness for nation-wide implementation.

5. Conclusion

The content of this paper could essentially be separated into two parts. The first consists of a detailed analysis and breakdown of almost twenty-five different climate change combating solutions, ranging from a cap-and-trade system to stratospheric aerosol injection. These proposals include both mitigation solutions, referring to those that directly decrease greenhouse gas emissions per year or total quantity in the atmosphere, and adaptation solutions, which are those that prepare vulnerable communities to better face the consequences of climate change. Arranged into seven categories, the approaches listed are classified as energy (i.e., nuclear & renewable), economic and political (i.e., carbon tax, cap-and-trade, research & investment, government subsidies, and direct/indirect aid to other countries), agricultural and agroforestry (i.e., afforestation, reforestation, bioenergy carbon capture and storage [BECCS], bioengineering [BE] of crops/genetically modified organisms [GMOs], and irrigation systems), atmospheric and astronomical (i.e., carbon capture, utilization & storage, stratospheric aerosol injection, marine sky brightening, and space-based mirrors), geological (i.e., geologic reservoir sequestration and soil carbon sequestration), coastal and oceanic (i.e., ocean alkalinity enhancement, ocean fertilization [OF], and artificial sand dunes and dune rehabilitation), or social (i.e., raising public awareness, youth education, and domestic funding) applications. The analysis of each solution includes a detailed description of its functions, advantages and disadvantages, numeric data, and/or any historic implementations.

Since it is impractical for governments to attempt to utilize all twenty-three solutions at once, only a selected few should be chosen for implementation. The second part of the paper provides the most optimal combination, taking into account the perspective of the U.S. government at the present time, in order to achieve maximum potential positive outcomes. It is important to note that combining certain solutions together can provide unique benefits that would not exist if any one of them were to be implemented individually. In this section, the paper explains the reasoning for the selection of every solution in the optimized combination and why those would outperform other solutions in their respective categories, along with how these chosen solution components can enhance the effectiveness of other component solutions contained in the optimized group. The final combination includes the implementation of a cap-and-trade system, an energy industry reformation plan, recommended actions to be taken by the U.S. government (i.e., education, research, foreign aid), negative emissions mitigation solutions (i.e., afforestation, ocean alkalinity enhancement), and an adaption solution by way of cautious bioengineering.

As the effects of climate change are nearing irreversibility, we sincerely and strongly suggest governments of the Earth to take into careful consideration the aforementioned proposal and unite together to combat this serious challenge that all of humanity faces.

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References

[1] UNCCS (2019) Climate action and support trends, United Nations Climate Change Secretariat. https://unfccc.int/sites/default/files/resource/Climate_Action_Support_Trends_2019.pdf.

[2] Leahy, Stephen. "Most Countries Aren't Hitting Paris Climate Goals, and Everyone Will Pay the Price." Science, National Geographic, 3 May 2021, www.nationalgeographic.com/science/article/nations-miss-paris-targets-climate-driven-weather-events-cost-billions.

[3] Unfccc.int, unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement.

[4] Metcalf, Gilbert E., and David A. Weisbach. "Design of a Carbon Tax." SSRN Electronic Journal, 2009, doi:10.2139/ssrn.1324854.

[5] Richards, John R. "Control of Nitrogen Oxides Emissions - 4cleanair.Org." National Association of Clean Air Agencies, Sept. 2020, https://www.4cleanair.org/wp-content/uploads/APTI/418Combinedchapters.pdf.

[6] Unfccc.int, unfccc.int/resource/ccsites/zimbab/conven/text/art02.htm.

[7] "Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities." The Ocean and Cryosphere in a Changing Climate, 2022, pp. 321–446., doi:10.1017/9781009157964.006.

[8] Ray, Suparna. "Nuclear and Coal Will Account for Majority of U.S. Generating Capacity Retirements in 2021 - Today in Energy - U.S. Energy Information Administration (EIA)." U.S. Energy Information Administration, 12 Jan. 2021, www.eia.gov/todayinenergy/detail.php?id=46436.

[9] Comstock, Owen. "Less Electricity Was Generated by Coal than Nuclear in the United States in 2020 - Today in Energy - U.S. Energy Information Administration (EIA)." U.S. Energy Information Administration, 18 Mar. 2021, www.eia.gov/todayinenergy/detail.php?id=47196.

[10] "Levelized Cost of Energy 2017." Lazard.Com, 2 Nov. 2017, www.lazard.com/perspective/levelized-cost-of-energy-2017.

[11] "Taxing Carbon: What, Why, and How." Tax Policy Center, 25 June 2015, www.taxpolicycenter.org/publications/taxing-carbon-what-why-and-how.

[12] "A Guide to Environmentally Related Taxation for Policy Makers." Taxation, Innovation and the Environment, 2010, pp. 135–149., doi:10.1787/9789264087637-8-en.

[13] Peters, Siobhan et al. "Stern Review: The Economics of Climate Change." (2006).

[14] Pomerleau, K. & Asen, E. (2019). Carbon tax and revenue recycling: revenue, economic, and distributional implications. Tax Foundation. https://taxfoundation.org.

[15] "Impose a Tax on Emissions of Greenhouse Gases." Congressional Budget Office, 13 Dec. 2018, www.cbo.gov/budget-options/54821.

[16] Marron, Donald B., and Adele C. Morris. "How to Use Carbon Tax Revenues." SSRN Electronic Journal, 2016, doi:10.2139/ssrn.2737990.

[17] "What Is a Carbon Tax?" Tax Policy Center, www.taxpolicycenter.org/briefing-book/what-carbon-tax.

[18] Carlson, Ann E. "Designing Effective Climate Policy: Cap-and-Trade and Complementary Policies." Harv. J. on Legis. 49 (2012): 207.

[19] Schmalensee, Richard, and Robert Stavins. "Lessons Learned from Three Decades of Experience with Cap-and-Trade." 2015, doi:10.3386/w21742.

[20] Morris, Adele, and Aparna Mathur. "6. The Distributional Burden of a Carbon Tax: Evidence and Implications for Policy." Imfsg, International Monetary Fund, www.elibrary.imf.org/view/books/071/21375-9781138825369-en/ch006.xml#:~:text=Analyzing a 15 percent cut,provide lump-sum rebates to.

[21] Chandler, Sarah. "Preparing a Portfolio for Climate Change." Investopedia, Investopedia, 13 Sept. 2021, www.investopedia.com/articles/investing/051514/preparing-your-portfolio-climate-change.asp.

[22] "About CIF." Climate Investment Funds, 31 Mar. 2022, www.climateinvestmentfunds.org/about-cif.

[23] Denny, Eleanor, and Mark O'Malley. "The Impact of Carbon Prices on Generation-Cycling Costs." Energy Policy, vol. 37, no. 4, 2009, pp. 1204–1212., doi:10.1016/j.enpol.2008.10.050.

[24] Kumar, Surender, and Shunsuke Managi. "Energy Price-Induced and Exogenous Technological Change: Assessing the Economic and Environmental Outcomes." Resource and Energy Economics, vol. 31, no. 4, 2009, pp. 334–353., doi:10.1016/j.reseneeco.2009.05.001.

[25] Vadakkepatt, G., Shankar, V. & Varadarajan, R. Should firms invest more in marketing or R&D to maintain sales leadership? An empirical analysis of sales leader firms. J. of the Acad. Mark. Sci. 49, 1088–1108 (2021). https://doi.org/10.1007/s11747-021-00774-2

[26] Hafner, Sarah, et al. "A Scoping Review of Barriers to Investment in Climate Change Solutions." MDPI, Multidisciplinary Digital Publishing Institute, 8 June 2019, www.mdpi.com/476418.

[27] Unfccc.int, unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance.

[28] "The Policy Framework for Investment (PFI)." OECD, www.oecd.org/investment/pfi.htm.

[29] Jones, Aled W. "Perceived Barriers and Policy Solutions in Clean Energy Infrastructure Investment." Journal of Cleaner Production, Elsevier, 27 May 2015, www.sciencedirect.com/science/article/pii/S0959652615006277.

[30] Blyth, William, et al. "Investment Risks under Uncertain Climate Change Policy." Energy Policy, vol. 35, no. 11, 2007, pp. 5766–5773., doi:10.1016/j.enpol.2007.05.030.

[31] Linkov, Igor, and Todd S. Bridges. Climate Global Change and Local Adaptation. Springer, 2011.

[32] Pernick, Ron and Wilder, Clint (2007). The Clean Tech Revolution: The Next Big Growth and Investment Opportunity, p. 280

[33] President, Julia Cusick, Interim Vice, et al. "Good Government Investments in Renewable Energy." Center for American Progress, 6 Sept. 2018, www.americanprogress.org/article/good-government-investments-in-renewable-energy/.

[34] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Renewable Energy Explained - Incentives - U.S. Energy Information Administration (EIA), www.eia.gov/energyexplained/renewable-sources/incentives.php.

[35] Kolstad, Charles, et al. "Social, economic and ethical concepts and methods." Climate change 2014: Mitigation of climate change. Cambridge University Press, 2014. 173-248.

[36] Mendonça, Miguel. "Feed-in Tariffs." 2012, doi:10.4324/9781849771313.

[37] Brown, Phillip. "European Union wind and solar electricity policies: overview and considerations." (2013).

[38] Timmons, David, Jonathan M. Harris, and Brian Roach. "The economics of renewable energy." Global Development And Environment Institute, Tufts University 52 (2014): 1-52.

[39] Change, Intergovernmental Panel On Climate. "Policies, Instruments and Co-Operative Agreements." Climate Change 2007, pp. 745–808., doi:10.1017/cbo9780511546013.017.

[40] "Guidelines for Public Expenditure Management--Section 3--Budget Preparation." International Monetary Fund, www.imf.org/external/pubs/ft/expend/guide3.htm.

[41] Hultman, Nathan, and Samantha Gross. "How the United States Can Return to Credible Climate Leadership." Brookings, 16 June 2021, www.brookings.edu/research/us-action-is-the-lynchpin-for-successful-international-climate-policy-in-2021/.

[42] Hultman, Nathan. "Accelerating America's Pledge: Going All in to Build a Prosperous, Low Carbon Economy for the United States." Center for Global Sustainability, https://cgs.umd.edu/research-impact/publications/accelerating-americas-pledge-going-all-build-prosperous-low-carbon.

[43] Markolf, Sam, et al. "Pledges and Progress: Steps toward Greenhouse Gas Emissions Reductions in the 100 Largest Cities across the United States." Brookings, Brookings, 9 Mar. 2022, www.brookings.edu/research/pledges-and-progress-steps-toward-greenhouse-gas-emissions-reductions-in-the-100-largest-cities-across-the-united-states/.

[44] Hultman, Nathan E., et al. "Fusing Subnational with National Climate Action Is Central to Decarbonization: the Case of the United States." Nature Communications, vol. 11, no. 1, 2020, doi:10.1038/s41467-020-18903-w.

[45] Environmental and Energy Study Institute (EESI). "How Foreign Climate Aid Benefits the United States." EESI, www.eesi.org/briefings/view/041117aid.

[46] Kinhal, Vijayalaxmi. "Afforestation And Reforestation." WorldAtlas, WorldAtlas, 25 Apr. 2017, www.worldatlas.com/articles/afforestation-and-reforestation.html.

[47] Gitau, Jane. "The Green Belt Movement Annual Report 2019," The Green Belt Movement (GBM). 2019, http://www.greenbeltmovement.org/sites/greenbeltmovement.org/files/GBM%20AR%202019.pdf#overlay-context=user/494.

[48] Keystone 10 Million Trees Partnership, "All About Trees," Chesapeake Bay Foundation, 2022, http://www.tenmilliontrees.org/trees/.

[49] Soomro, Ahsen, et al. "Afforestation; Importance, Advantages & Disadvantages. Current Efforts!" Environment Buddy, 22 Apr. 2020, www.environmentbuddy.com/plants-and-trees/what-is-afforestation-importance-advantages-disadvantages/.

[50] "Read 'Negative Emissions Technologies and Reliable Sequestration: A Research Agenda' at NAP.edu." National Academies Press: OpenBook, www.nap.edu/read/25259/chapter/1.

[51] "Institute for Carbon Removal Law & Policy." American University, www.american.edu/sis/centers/carbon-removal/.

[52] Kemper, Jasmin. "Biomass with Carbon Capture and Storage (BECCS/Bio-CCS)," IEA Greenhouse Gas R&D Programme; Imperial College London, 10 March 2017, https://ieaghg.org/docs/General_Docs/IEAGHG_Presentations/2017-03-10_Bioenergy_lecture_2_Read-Only.pdf.

[53] "Bioenergy, Carbon Capture and Storage (BECCS)." Chatham House – International Affairs Think Tank, 18 Aug. 2021, www.chathamhouse.org/about-us/our-departments/energy-environment-and-resources-programme/bioenergy-carbon-capture-and.

[54] Consoli, Christopher; "Bioenergy and Carbon Capture and Storage," Global CCS Institute, 2019, https://www.globalccsinstitute.com/wp-content/uploads/2019/03/BECCS-Perspective_FINAL_18-March.pdf.

[55] Pacumbaba, Posted by: Rudy. "GMO Food Facts: Bioengineered Crops - A Look at Modern Agriculture." Alabama Cooperative Extension System, 20 July 2020, www.aces.edu/blog/topics/fruits-vegetables-urban/gmo-food-facts-bioengineered-crops/.

[56] Clements, R., J. Haggar, A. Quezada, and J. Torres (2011). Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Risø Centre, Roskilde, 2011

[57] "Water and Agriculture." OECD, www.oecd.org/agriculture/topics/water-and-agriculture/.

[58] 28, Paul Balsom - September. "Water Usage In The Agricultural Industry: High Tide Technologies." High Tide, 29 Sept. 2020, htt.io/water-usage-in-the-agricultural-industry/.

[59] Taghvaeian, Saleh; "Surface Irrigation System," Oklahoma State University; Feb. 2017, https://extension.okstate.edu/fact-sheets/surface-irrigation-systems.html#:~:text=The%20term%20%E2%80%9Csurface%20irrigation%E2%80%9D%20refers,more%20than%206%2C000%20years%20ago.

[60] Bustler. "AirDrop Irrigation Wins First Prize at 2011 James Dyson Awards." Bustler, 11 Nov. 2011, bustler.net/news/2383/airdrop-irrigation-wins-first-prize-at-2011-james-dyson-awards.

[61] Lebling, Katie. "Direct Air Capture: Resource Considerations and Costs for Carbon Removal." World Resources Institute, 6 Jan. 2021, www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal.

[62] Global Warming of 1.5 ºC, www.ipcc.ch/sr15/.

[63] Realmonte, Giulia, et al. "An Inter-Model Assessment of the Role of Direct Air Capture in Deep Mitigation Pathways." Nature Communications, vol. 10, no. 1, 2019. Nature.com, doi:10.1038/s41467-019-10842-5.

[64] Robock, Alan, 2014: Stratospheric aerosol geoengineering, Issues Env. Sci. Tech. (special issue "Geoengineering of the Climate System"), 38, 162-185.

[65] Salter, Stephen, et al. "Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming." Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 366, no. 1882, 2008, pp. 3989–4006. Crossref, doi:10.1098/rsta.2008.0136.

[66] Sánchez, Joan-Pau, and Colin R. Mcinnes. "Optimal Sunshade Configurations for Space-Based Geoengineering near the Sun-Earth L1 Point." Plos One, vol. 10, no. 8, 2015, doi:10.1371/journal.pone.0136648.

[67] "Geological Sequestration: Climate Change Connection." Climate Change Connection | Connecting Manitobans to Climate Change Facts and Solutions, 14 Dec. 2018, climatechangeconnection.org/solutions/carbon-sequestration/geological-sequestration/.

[68] What's the Difference between Geologic and Biologic Carbon Sequestration?, www.usgs.gov/faqs/what-s-difference-between-geologic-and-biologic-carbon-sequestration?qt-news_science_products=0#qt-news_science_products.

[69] Smith, Erin, et al. "The Cost of CO2 Transport and Storage in Global Integrated Assessment Modeling." SSRN, 31 Mar. 2021, papers.ssrn.com/sol3/papers.cfm?abstract_id=3816593.

[70] Hovorka, Susan; "Risks and Benefits of Geologic Sequestration of Carbon Dioxide - How Do the Pieces Fit?*," AAPG Annual Convention, June 7-10 2009, https://www.searchanddiscovery.com/pdfz/documents/2009/80058hovorka/ndx_hovorka.pdf.html.

[71] Which Area Is the Best for Geologic Carbon Sequestration?, www.usgs.gov/faqs/which-area-best-geologic-carbon-sequestration?qt-news_science_products=0#qt-news_science_products.

[72] Judith D. Schwartz, March 4, et al. "Soil as Carbon Storehouse: New Weapon in Climate Fight?" Yale E360, e360.yale.edu/features/soil_as_carbon_storehouse_new_weapon_in_climate_fight.

[73] "Welcome to the'4 per 1000' Initiative." 4p1000, www.4p1000.org/.

[74] "Fact Sheet: Forestation." American University, www.american.edu/sis/centers/carbon-removal/fact-sheet-forestation.cfm.

[75] Webb, Romany M., Korey Silverman-Roati, Michael B. Gerrard; "Removing Carbon Dioxide Through Ocean Alkalinity Enhancement and Seaweed Cultivation: Legal Challenges and Opportunities," Columbia Law School: Sabin Center for Climate Change Law; February 2021, https://climate.law.columbia.edu/sites/default/files/content/Webb%20et%20al%20-%20Removing%20CO2%20Through%20Ocean%20Alkalinity%20Enhancement%20and%20Seaweed%20Cultivation%20-%20Feb.%202021.pdf.

[76] Ocean CDR, oceancdr.net/approaches/alkalinity.

[77] Bach, Lennart T., et al. "CO2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-Benefits for Marine Pelagic Ecosystems." Frontiers, Frontiers, 1 Jan. 1AD, www.frontiersin.org/articles/10.3389/fclim.2019.00007/full.

[78] "Fact Sheet: Ocean Alkalinization." American University, www.american.edu/sis/centers/carbon-removal/fact-sheet-ocean-alkalinization.cfm.

[79] Masindi, Vhahangwele, and Khathutshelo L. Muedi. "Environmental Contamination by Heavy Metals." Heavy Metals, 2018, doi:10.5772/intechopen.76082.

[80] Monroe, Rob. "How Much CO2 Can The Oceans Take Up?" The Keeling Curve, 19 Nov. 2020, keelingcurve.ucsd.edu/2013/07/03/how-much-co2-can-the-oceans-take-up/.

[81] Dr Jamie Shutler, Associate professor in earth observation. "The Oceans Are Absorbing More Carbon than Previously Thought." World Economic Forum, www.weforum.org/agenda/2020/10/oceans-absorb-carbon-seas-climate-change-environment-water-co2/#:~:text=While previous estimates put the,of CO2 rather than 43bn.

[82] Oak Ridge National Laboratory. "The Ocean Carbon Cycle," Earthlabs, July 20, 2021, https://serc.carleton.edu/eslabs/carbon/6a.html.

[83] "NOAA Ocean Explorer: Education - Multimedia Discovery Missions: Lesson 8 - Ocean Currents: Activities: Currents and Marine Life." NOAA Ocean Explorer Podcast RSS 20, oceanexplorer.noaa.gov/edu/learning/8_ocean_currents/activities/currents.html.

[84] "Oxford Languages and Google - English." Oxford Languages, languages.oup.com/google-dictionary-en/.

[85] Gattuso, Jean-Pierre, et al. "Ocean Solutions to Address Climate Change and Its Effects on Marine Ecosystems." Frontiers, Frontiers, 1 Jan. 1AD, www.frontiersin.org/articles/10.3389/fmars.2018.00337/full.

[86] Powell, Hugh. "Dumping Iron and Trading Carbon." Woods Hole Oceanographic Institution, 10 Jan. 2008, www.whoi.edu/oceanus/feature/dumping-iron-and-trading-carbon/.

[87] Harrison, Daniel. (2013). A method for estimating the cost to sequester carbon dioxide by delivering iron to the ocean. Int. J. of Global Warming. 5. 231 - 254. 10.1504/IJGW.2013.055360.

[88] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

[89] "Central Intelligence Agency." Field Listing :: Area - The World Factbook - Central Intelligence Agency, web.archive.org/web/20201022070334/www.cia.gov/library/publications/resources/the-world-factbook/fields/279.html.

[90] M., Kate; "What are the Different Types of Sand Dunes?" Socratic Q&A, Mar. 21, 2017; https://socratic.org/questions/what-are-the-different-types-of-sand-dunes#394492.

[91] Zhu, X., Linham, M. M., & Nicholls, R. J. (2010). Technologies for Climate Change Adaptation - Coastal Erosion and Flooding. Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. TNA Guidebook Series

[92] OURCOAST II Project; "Beach and Shoreface Nourishment," Climate-ADAPT, Mar. 04 2020, https://climate-adapt.eea.europa.eu/metadata/adaptation-options/beach-and-shoreface-nourishment.

[93] Funk, Cary, and Brian Kennedy. "How Americans See Climate Change and the Environment in 7 Charts." Pew Research Center, 21 Apr. 2020, www.pewresearch.org/fact-tank/2020/04/21/how-americans-see-climate-change-and-the-environment-in-7-charts.

[94] Parant, Aymeric, et al. "Raising Students Awareness to Climate Change." SAGE Journals, vol. 49, no. 3, 2016, pp. 339–53, doi:10.1177/0013916516629191.

[95] Schreiner, Camilla, et al. "Climate Education: Empowering Today's Youth to Meet Tomorrow's Challenges." Studies in Science Education, vol. 41, no. 1, 2005, pp. 3–49, doi:10.1080/03057260508560213.

[96] TerraPower. "Traveling Wave Reactor Technology." TerraPower, 19 Aug. 2021, www.terrapower.com/our-work/traveling-wave-reactor-technology.

[97] "California Air Resources Board." FAQ Cap-and-Trade Program | California Air Resources Board, ww2.arb.ca.gov/resources/documents/faq-cap-and-trade-program#:~:text=California achieved its 2020 GHG,and high demand for allowances.

[98] "Climate Impacts on Agriculture and Food Supply." EPA, Environmental Protection Agency, 6 Oct. 2016, 19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html.

[99] "A New Era of Responsibility Renewing America's Promise." Office of Management and Budget, https://web.archive.org/web/20110209062139/http://www.gpoaccess.gov/usbudget/fy10/pdf/fy10-newera.pdf.

[100] Bridgeworth, Sam, et al. "Global Defense Spending Is at a Record High – 4 Charts That Show Where the Money Goes." World Economic Forum, www.weforum.org/agenda/2019/04/4-charts-that-show-the-state-of-global-military-spending-now-at-its-highest-since-the-cold-war/.

[101] Stockholm; "World Military Expenditure Grows to $1.8 Trillion in 2018," SIPRI Military Expenditure Database; 29 April 2019, https://www.sipri.org/media/press-release/2019/world-military-expenditure-grows-18-trillion-2018.