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A Plan to Extract Gigatons of Atmospheric CO_2 through Agroforestry

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Abstract

The UN International Panel Environment Programme ("UNEP"), 2023 Emissions Gap Report urgently presses the global community to adopt a two-pronged approach to reduce atmospheric concentration of CO_2—expedite efforts to reduce annual CO_2 emissions; and increase investment in large-scale carbon dioxide removal ("CDR") projects. The Gap Report sets a 2050 target of six-gigatons annual land-based CDR. Our proposed agroforestry project will convert thirty-five-million acres of rangeland in the American Great Plains to silvopasture, combining growing trees and raising livestock. Employing agroforestry interests 61% of Great Plaints farmers/ranchers recently surveyed. The Project plans to annually collect + six-gigatons CO_2 equiv. of fallen leaves and store the stable carbon-rich biomass underground for centuries. The purpose of this paper is to describe the framework for formation of a global partnership at the local, regional, and international levels to coordinate public and private financing mechanisms, implement, and operate a large-scale CDR Project that will meaningfully impact the global effort to mitigate climate change.

Keywords

Carbon Sequestration, Agroforestry, Silvopasture, Climate Solution, Carbon Dioxide Removal

1. Introduction

In order to limit global warming to 1.5˚C above pre-industrial temperatures, the international community set a target at the 2015 Paris Climate Agreement to steadily reduce annual global CO_2 emissions to a level 43% below 2005 levels by 2030 [1]. It is now apparent the goals of the Paris Agreement are unattainable. Annual global emissions are expected to remain above 2005 levels through the end of this decade, virtually guaranteeing temperature rise of more than 1.5˚C by 2030.

To offset the emissions reduction shortfall the UN 2023 Gap Report encourages a shift in international climate investment strategy to support both the transition to renewable energy sources, with the consequential reduction in emissions and the implementation of CDR operations. Our Project answers the UN call with an ambitious, impactful proposal to annually capture and store gigatons of atmospheric CO_2. The proposed Project converts individual livestock ranch operations in the Plains to silvopasture systems designed to work with cooperative enterprises which will operate equipment to annually harvest, transport, and indefinitely store underground billions of tons of carbon-rich biomass per year.

Silvopasture systems protect against the spread of potentially devastating disease and pest infestations in afforested areas in part by planting multiple varieties of trees [2]. The Project will identify and plant multiple fast growing tree species, which tend to produce more leaves by weight per year than average trees. For example, American sycamore, hybrid poplar, hybrid willow, and horse chestnut trees are fast-growing trees that after maturity annually produce more than 250 kilograms of leaves per tree [3]-[5]. The carbon sequestered from one ton of leaves represents extraction of 1.83 tons of atmospheric CO_2. The Project expects to cover thirty-five-million acres, out of the approximately one hundred million acres of rangeland in the Plains, with four hundred trees per acre for a total of fourteen billion trees. Within 12 years of launch, the Project expects to extract six and one-third-gigatons of atmospheric CO_2 per year.

The most effective and sustainable CDR efforts synchronize with the socioeconomic and geo-cultural characteristics of their surrounding region [6] [7]. The operation of the Project matches with the Plain's rich history of community involvement in agri-business and in particular raising livestock [8]. Agroforestry has succeeded in the Great Plains for decades. In 1934 President Roosevelt oversaw the planting of 220 million trees as wind shelter to protect topsoil during the Great Plains dustbowl era [9]. In the heart of the Great Plains, Nebraska, known for over fifty years by the official nickname "The Tree Planter State," recently celebrated the success of a statewide program to plant one-hundred-million trees [10].

The Project benefits area ranchers and native American tribe members economically by increasing livestock yield and land-use value; draws seasonal workers and life science experts to revitalize local rural communities; funds recharging efforts for depleting aquifers throughout the region; and creates a platform for wealthy nations to pool resources and equitably share in the costs to protect their own land and the entire world's resources from the damage brought by increasingly catastrophic climate change events.

Launch of the Project will require international agreements to provide sufficient sustained funding for the operation through the end of the century. The International Monetary Fund ("IMF") has recently committed to advise its member nations on funding large-scale climate mitigation operations including CDR [11]. Wealthier countries such as the G20 group of nations under the guidance of the IMF can devise sharing arrangements to determine each country's equitable contribution to funding CDR operations such as the Project. The G20 nations collectively produce 80% of global CO_2 emissions [12]. An equitable formula that factors each nation's past contribution to legacy atmospheric CO_2 with projections of their contribution to future CO_2 emissions can be used to calculate the amount each wealthy nation should contribute annually toward financing the Project and other climate mitigation efforts.

2. Proposal

2.1. Emission Reduction and CO_2 Removal

As the Project trees mature after planting the amount of CO_2 extracted and sequestered per year will increase exponentially. As a result, the US will become carbon neutral by the year 2035 from the combined effects of the CO_2 extracted by the Project (approximately five-gigatons CO_2 per year by 2035) and the emissions reductions projected from the Inflation Reduction Act (estimated 0.3 to 0.5 gigatons per year) [13] [14].

Within a few more years, Project year 12 (PY12), the projected extraction of six and one-third-gigatons CO_2 per year will surpass the 2050 UNEP goal for six-gigatons land-based CDR, with more than a decade to spare. Thereafter, accumulated CO_2 extracted by the Project combined with emissions reductions promised by National Designated Authorities in accordance with the Paris Agreement, should limit global temperature rise to less than 1.5˚C [6]. The combined effect will work to avoid the cataclysmic environmental tipping point many climate scientists believe would otherwise be inevitable [15].

2.2. Rangeland Conversion to Silvopasture

Converting rangeland to silvopasture allows ranchers to continue to live-off management of their existing livestock operations while generating additional income from the sequestration of CO_2. Silvopasture systems typically plant two to four hundred trees per acre [16] [17]. We propose planting four hundred fast growing trees per acre to maximize carbon sequestration. The silvopasture systems will be designed with wide-spaced rows to facilitate the use of currently available industrial size leaf vacuuming equipment for annual leaf harvesting [18].

The Great Plains have used large-scale agroforestry for decades, beginning with a crucial and very effective response to the 1930's dustbowl drought. From 1934 to 1942, President Franklin Roosevelt implemented the Prairie States Forestry Project, which planted 220 million trees in the Great Plains [9]. The Prairie Project planted lines of trees as windbreaks to protect Plains topsoil from wind erosion. The success of the Prairie Project sustained the agricultural economic viability of the region while irrigation networks were set up. The Prairie Project is considered to be the most effective large-scale environmental project in US history.

A. Planting Trees on Rangland/Grassland Improves Soil Quality and Livestock Health

In addition to acting as windbreaks, typical agroforestry benefits include shade from trees and improved soil aeration from tree root systems [19]. Shade trees increase livestock yield and improve animal health by reducing heat stress [20]. Soil aeration and irrigation systems improve soil moisture and accessibility for plants to underground nutrients. As the effects of desertification of the soil subside, ranchers will plant more lush varieties of grasses and foliage, which will also increase livestock yields.

Soil nutrients that would otherwise have leached into the ground from decomposing leaves can readily be replaced by the use of environmentally friendly fertilizers that do not release CO_2 or other greenhouse gasses [21]-[23]. On the related issue of methane exhalation from cattle, centralization of the silvopasture operations will distribute information to area ranchers regarding advancements in feed supplements and selective breeding techniques that reduce cattle methane production. Increased use and experimentation with methods that will limit atmospheric methane, a potent greenhouse gas, could also help mitigate global warming [24]. Agroforestry operations use fewer pesticides and other toxic chemicals, which will promote biodiversity. Most importantly in the Plains and Midwest region increased populations of pollinators, such as bees and butterflies in the afforested area will support the growth of colonies of these species throughout the Midwest.

B. 61% of Great Plains Ranchers Express Interest in Converting to Silvopasture

Great Plains ranchers are well-informed on the benefits of combining planting trees and raising livestock. Unfortunately, capital costs are too high to allow many individual ranchers to convert to silvopasture. Moreover, ranchers are not well-informed on the accessibility of markets for carbon credits.

Interest levels, however, remain high. In a recent survey of Great Plains farmers and ranchers, 61% expressed interest in the economic and environmental benefits derived from agroforestry [25]. This level of enthusiasm is important to implementation of the Project. The target of 35 million acres of the 100 million acres or 35% of rangeland in the Great Plains is well within the degree of interest surveyed and should allow the Project to grow to meet the 2023 UN Gap Report goal to sequester + six gigatons of CO_2 per year.

The Plains are facing a period of great economic and environmental stress [26]. A recent extended drought, likely a climate change consequence of global warming, has in general increased feed expenses for ranchers while depressing livestock yield [27]. The coordinated operations of raising livestock, caring for the afforested land and annually harvesting and sequestering fallen leaves will generate revenue for stakeholders throughout the entire Plains region thereby revitalizing the regional economy.

2.3. Leaf Harvesting

The photosynthesis process in leaves extracts atmospheric CO_2 and expires O_2 back into the atmosphere. Carbon is stored in tree and leaf biomass. The chemical effect of the decomposition of fallen leaves returns CO_2 to the atmosphere [21]

[22]. Harvesting fallen leaves and storing the carbon-rich biomass underground maintains the extraction of atmospheric CO_2 and can effectively reduce atmospheric CO_2 concentration for centuries.

The Project leaf harvesting operation will be similar to annual row crop harvests with wide pasture alleyways between rows of trees for the use of large, specialized equipment. Equipment operators will vacuum and shred fallen leaves and then load the biomass into companion wagons for transportation to central distribution centers [18].

We estimate annual leaf production at maturity of one quarter ton per tree. The estimation is arrived at by multiplying the average number of leaves of a typical fast-growing tree, by the average weight of each leaf. An average number of leaves for a single fast growing tree is approximately 227,729 [28]. For example, a recent study calculated the average dry weight of a sycamore leaf as approximately one to two grams [4] [5]. At maturity, 227,729 leaves per tree each weighing > one-gram annually produces approximately 250 kg of leaf biomass.

There are recently hybridized fast-growing poplar and willow trees that annually produce greater amounts of leaves per tree. There are also anecdotal estimates of much greater leaf numbers per tree and higher average leaf weights, although we were unable to verify those numbers in published studies [29]-[32].

Additionally, studies of afforested biomass have used higher than four hundred trees per acre planting densities and as many as two thousand trees per acre (five thousand per hectare) [3]. We use 400 trees per acre to preserve the existing usage of the regional rangeland for raising livestock and also to avoid the dilatory consequences of high-density planting of a single fast growing tree species, including increased risks of wildfire and disease spread [2].

We estimate the total amount of CO_2 extracted from the atmosphere by the harvest and sequestration of leaves based on the percentage of carbon in dry leaf biomass [approximately 50%] [33] multiplied by the rate of conversion from carbon to CO_2 (1 to 3.66). One ton of dry leaves contains approximately 500 kg of carbon, which represents extraction of 1.83 tons of atmospheric CO_2.

2.4. Water Resources

The afforested land will require reliable long-term sources of water. Fast growing tree species typically require ten gallons of water per week per tree for a 40-week growing year, which annually equals roughly four hundred gallons per tree [34]. The annual amount of irrigation water required for the Project's fourteen-billion trees at four hundred gallons per tree is approximately eighteen-million acre-feet.

Most agriculture operations in the Plains rely on underground water from regional aquifers [35]. The largest regional aquifer, the Ogallala, contains roughly 3-billion-acre feet of water. There appears to be sufficient water in the Ogallala and other regional aquifers to maintain the Project for the near future. However, current annual usage of water from the regional aquifers is greater than the rate of natural recharge, as a consequence the aquifer levels throughout the Plains are receding [36] [37].

To insure sustained underground water supplies, several communities in the Plains have invested in aquifer recharging systems ("ARS") [38]. In the Plains, 150 million-acre feet of water per year, sufficient to support additional ARS, is available from three major river systems, the Missouri, Arkansas, and Red/White rivers [39].

Redirecting, annually, tens of millions of acre feet of water, which would otherwise flow into the ocean, from the Plains river systems into aquifers will insure an adequate supply of water for the Project and the entire region and simultaneously will substantially reduce the rate of sea-level rise worldwide.

2.5. Project Cost

The costs of the Project include the initial implementation costs, land-use costs, irrigation water, and operating costs for harvesting and sequestering leaf biomass. We use a constant measure of 2024 dollars in our calculations of the costs for the duration of the Project. The components of the Project costs are as follows:

1) The primary costs to convert rangeland to silvopasture including planting trees average approximately $100 - 150.00 per acre [40]. Installation of irrigation systems, etc., can raise the price to $1000.00 per acre [41]. The initial investment for the entire Project is estimated to be $35 billion.

2) To incentivize participation by individual ranchers and members of Native American tribes we propose an annual payment of $150.00 per acre as compensation for land use value (an approximately 200% mark-up over the annual rental value of rangeland in the Plains, approximately $30 - 50.00 per acre) [42]. This represents additional annual revenue of $75000.00 for an average 500-acre ranch, and hundreds of millions of dollars each year collectively for Native American tribes if over two million acres of tribal land participates in the Project.

3) The average annual cost of leaf collection, anecdotally is $550.00 per acre [43].

4) The average annual cost of silvopasture operations to surveille and care for the afforested land is $300.00 per acre [44].

5) The cost of irrigation water from aquifer recharge systems is approximately $390.00 per acre foot, inclusive of typical water transportation costs [36] [45]. For the Project, the annual cost of eighteen-million-acre feet of water is approximately $200.00 per acre. Pumping costs for transportation of water add approximately $50.00 per acre to the cost of water for an annual cost of $250.00 per acre [46].

6) The cost for underground sequestration of carbon-rich biomass has been the subject of two recent detailed studies [47]. The cost of carbon sequestration using geological underground sites is the sum of transportation costs, of approximately $0.10 per ton per mile and the cost of indefinite storage at the site, approximately $10.00 per ton. Applying average 200-mile transportation cost of $20.00 per ton, the total cost for sequestration using this method is $30.00 per

ton [48] [49].

A second study suggests digging on site underground bio landfills. Chemically treated biomass is stabilized to prevent decomposition and release of CO_2 gas into the atmosphere. The cost for the alternate method is also estimated to be $30.00 per ton [50].

7) For the first twelve Project years before the trees reach maturity, the total projected biomass sequestration is sixteen and one-half gigatons. At $30.00 per ton, the total Project cost for sequestration is approximately $500 billion for the first twelve Project years.

8) After PY12 the projected biomass storage is three and one-half-gigatons per year. The anticipated cost for underground biomass storage will be approximately $105 billion per year.

The cost to implement the Project is a one-time cost of approximately $35 billion. The annual operating cost per acre for the silvopasture and leaf harvesting operations of the Project is approximately $300.00 (silvopasture operation) + $550.00 (leaf collection) + $150.00 (land use value) + $250.00 (irrigation water) = $1250.00 per acre or about $45 billion per year for thirty-five million acres. The reasonableness of our estimation is confirmed by the reported estimated costs for corn growing operations, including harvesting, of approximately $980.00 per acre [51].

The total cost of the Project for the first twelve Project years is approximately $500 billion for biomass storage, $540 billion for operating expenses and $35 billion for the cost to convert rangeland to silvopasture = $1075 billion. We add a markup of approximately 20% for insurance, administration, capital return etc. The total cost projection for the first twelve project years equals approximately $1300 billion. The leveled rate for the annual cost of the Project for years PY 1 to PY12 is approximately $110 billion per year, or approximately $43.00 per ton extracted atmospheric CO_2.

Thereafter, the operating costs per year will remain about $45 billion per year. The total annual cost of the Project after PY12, including cost of storage for three and one-half-gigatons of biomass per year will be approximately $150 billion. With a 20% markup the annual cost of the Project will be approximately $180 billion, or approximately $28.50 per ton extracted atmospheric CO_2.

2.6. Societal Value of CO_2 Extraction

The societal value of the extraction of one ton of atmospheric CO_2 is measured by the societal cost of the atmospheric emission of one ton of CO_2. The societal cost/value of one ton of CO_2 is regularly used by policymakers in cost-benefit analysis decision-making. In broad terms the societal cost of carbon emissions is calculated based on the economic impact on agriculture, health, energy use, and other aspects of society [52].

Two recent in-depth studies have arrived at totals for the societal cost of CO_2 extraction. The US Environmental Protection Agency in 2022 calculated the societal cost of carbon as $120.00 per ton CO_2 [52]. An academic study calculated the societal cost of carbon as $185.00 per ton CO_2 [53].

2.7. Funding Mechanism

The UN has called for nations to consolidate resources and develop collaborative funding methods to support large-scale climate change mitigation efforts. We propose funding the Project through a combination of certified participation in international carbon credit markets such as the European Emissions Trading System ("EU ETS"); and national transferable tax credits from wealthy nations similar to US IRS Regulation 45Q for operations that sequester carbon.

The price of carbon credits on the EU ETS has fluctuated over the recent past between $75.00 and $90.00 per ton of CO_2 equiv. Similarly, the US 45Q tax credit provides transferrable credits of $85.00 per ton of CO_2 equiv. for permanent carbon sequestration projects. Both figures are multiples of the Project cost per ton of CO_2 extracted.

3. Conclusions

The Project's cost benefit ratio of plus one to three justifies both public and private investment in a gigatons-scale agroforestry CDR Project in the Plains that will equitably spread among multiple rich nations the cost of removing CO_2 from the atmosphere. The Project will also revitalize a regional economy that is essential to feeding the world and is currently being wracked by the harmful effects of global warming. The Project exploits the economies of scale that allow efficient sequestration of carbon at a fraction of the cost of other methodologies [20].

There is time to mitigate the effects of global warming and avoid climate disasters if a global partnership forms to work on a massive CDR endeavor that will have a meaningful impact on atmospheric CO_2 levels.

Declaration and Statements

The author contributed to the entire study conception and design. Material preparation, data collection and analysis were performed by the author. The first draft of the manuscript was written by the author and no other authors commented on previous versions of the manuscript. The author read and approved the final manuscript.

The manuscript does not contain any original research that includes data sets which are not publicly available.

Conflicts of Interest

The author declares that he has no relevant or material financial interests that relate to the research described in this paper.

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