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Review

Halophytes/Saline Water/Deserts/Wastelands Nexus as a Scalable Climate Mitigation including Freshwater Impacts

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Abstract: Climate change is rapidly exacerbating and adding to major-to-existential issues associated with freshwater availability and utilization. The massive, thus far untapped saline/salt water/ocean—wastelands/deserts—Halophytes resources nexus can, at scale and profitably, provide major climate change mitigation and greatly alleviate most extant freshwater issues. Approaches include ocean fertilization and saline/seawater agriculture on deserts and wastelands to sequester massive amounts of CO_2 and methane and for food, freeing up some 70% of the freshwater now utilized by current agriculture for direct human use. This also enables the production of huge amounts of biofuels and biomass-based chemical feedstock employing the massive capacity of cheap saline/seawater and cheap deserts and wastelands. Overall, saline/seawater can, uniquely, at the scale of the climate and freshwater issues, without desalinization, profitably, utilizing extant technologies, some 40% of the land that is deserts/wastelands, and the 97% of the water that is saline/seawater rapidly, seriously, address land, freshwater, food, energy, and climate.

Keywords: halophytes; seawater agriculture; CO_2 sequestration; climate mitigation; droughts

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1. Introduction

Climate is the existential societal issue of the age [1,2]. For decades, we have not been willing to make the major changes at the scale and scope of the problem to solve it largely due to the perception that solving it required major near-term econometric losses vice profits. As a result, it is rapidly becoming much worse, not better. Climate impacts include increasingly serious temperature rise, floods, droughts, storms, disease, sea level rise, species extinction, ocean acidification, and ocean thermohaline circulation reduction, all occurring now with increasing severity. One-sixth of the population lives off the water from Himalayan glaciers, which are going away. The aquifers in the U.S. are drying up, especially in the Great Plains and Southwest. The major characteristics of the climate problem are its IMMENSE scale, scope of impacts, and severity. Most approaches do not scale to the size of the problem. Projected world costs of climate are 51% of global GDP in this century [3]. Climate change is rapidly approaching what are termed tipping points, where smallish additional changes cause major climate change impacts. One of these positive feedbacks is the slowing of the ocean thermohaline circulators with attendant reductions in oxygen content. Another is the warming near the poles, which is some factor of 3 greater than the rest of the planet, melting the methane hydrate and releasing CO_2 and methane that is in the tundra and the oceans into the atmosphere. Methane is 30 times greater than CO_2 for climate forcing. The increased ocean CO_2 uptake is turning the oceans into weak carbonic acid. As the ice melts, the albedo of the planet reduces. These and other positive feedbacks are accelerating and increasing the impact of climate change. Our current climate mitigation approaches are, except for renewables and storage, not at the scale of climate, as is apparent from the worsening climate impacts. Major mitigation efforts at the climate scale are needed.

However, climate mitigation is potentially also a huge developing market, an increasingly essential market, and with the right scalable approaches, possibly a very profitable one. Now that climate impacts are readily apparent and worsening rapidly, there is increasing motivation to act. Furthermore, there have been, and still are, concerns about the adverse econometric impacts of acting, e.g., losses as opposed to profits, especially historically concerning fossil fuels. Renewables and storage replacements, once their costs were driven below fossil carbon fuels and nuclear and produced increasing profits, are now replacing fossil fuels and nuclear energy. The scale of the climate problems and their massive existential impacts require major changes. Climate mitigation approaches include reducing the generation of CO_2, reducing the CO_2 presence in the atmosphere, increasing the albedo of the planet, reducing energy use, and geo-engineering [4,5], and all now need to be pursued concomitantly to produce serious mitigation effects at this critical stage of the climate crisis. Several climate mitigation approaches that have been suggested have serious issues, including the possibility of major adverse, unintended effects. These include cost, scale, and adverse effects for geoengineering, major cost, latency, scale, and waste issues for fission and fusion nuclear, and cost, scale, and leakage for non-bio-CO_2 sequestration.

Freshwater issues were already increasingly severe before climate impacts on water became critical. Freshwater-related climate effects include flooding, rising sea levels, droughts, glacial melting, evaporation, and salination. Current approaches to address these and other freshwater issues, such as fracking/pollution, increased requirements/population levels, energy generation requirements, falling water tables, etc., are focused on improving the quality and efficiency of the extant available freshwater. These efforts include a focus on freshwater agriculture, which utilizes some 70% of such water. Some 97% of the available water is saline and salt water [6]. Thus far, except for costly desalination, the massive resources of saline/salt water and the 44% of the land, which is deserts, wastelands have not been seriously addressed/utilized as solution spaces for freshwater issues writ large.

The enabling key to serious solutions for freshwater across the board and climate is the many thousands of saline/saltwater plants, both dry land and aquatic plants termed Halophytes, which have a rich literature, e.g., [7–14] ranging from scientific studies to econometrics. Many are food plants; they mimic many of the characteristics of freshwater plants. The massive extent of these saline/salt water/arable land/halophyte nexus resources is uniquely at scale to address climate. This potentially profitable, unique nexus could, utilizing cheap land and water, provide food, replace freshwater agriculture, freeing up fresh water for direct human use, sequester massive amounts of CO_2 [15], and produce massive amounts of biomass for biofuels and chemical feedstock, overall, largely "solving" land, water, food, energy and climate [7,8].

Saline/seawater agriculture via halophytes is a big idea, a major change, uniquely at the scale needed to address climate and emerging freshwater scarcity adequately. Such changes are usually undertaken for reasons of either profits or dire threats. This nexus uniquely addresses both extant change drivers/enablers.

2. Methodology

This research involves "sense-making", akin to intelligence analysis, concerning the putative future utilization, optimization, and econometrics of water writ large, including climate mitigation. This requires an extensive literature search and examination/understanding of status, issues, and current research with respect to water availability, freshwater issues, the characteristics of wastelands and deserts, climate change and its progress and impacts, climate change mitigation needs and approaches, halophyte, salt plant characteristics, applications for both dry land and ocean environments, energetics sources, requirements and utilization, water and energetics econometrics, and societal adoption of major changes. With this background, the task is then to ideate concomitant potential impacts of a shift from the current situation of increasing scarcity of freshwater, arable land, and the serious existential societal need for climate mitigation to a situation of resource abundance and wide band effectiveness utilizing the massive capacity of the concomitant nexus of saline/seawater, deserts/wastelands, and halophytes to mitigate land, water, food, energy and climate issues. Requires horizon thinking and conception, which is necessitated now by the increasingly massive, dire, and ever nearer-term effects of climate change as the positive climate feedbacks kicks in. As opposed to experimental research, where clear paths and details can be presented to enable replication, this study is more akin to a theoretical study, where new theories are ideated and developed based on extensive study. This effort studied the issues cited and utilized the study results in a concomitant fashion to ideate combinatorial solution spaces for serious societal issues associated with water. This process/methodology is sometimes referred to as "sense-making" and solution formulation.

2.1. Water/Land Issues

As stated, about 97% of the planet's water is saline/salt water. This includes oceans, seas, some lakes, and saline aquifers, many of them large. Seawater has some 40 elements to fertilize plants and trace minerals needed for human health, which are often depleted from arable land [16]. As humans have been pumping what started out as mostly freshwater aquifers, many of these are becoming more saline, and using them for irrigation has increasingly salinated "arable land". Some 2.5% of the water is freshwater, with some 68% of it tied up in glaciers, 30% in groundwater, with most of the rest in permafrost and the great lakes, Lake Baikal [6]. Little of the planet's water is "available" freshwater. Of that available freshwater, 70% is utilized for agriculture/food, 15% for industry, and 15% for households. Due to the current prevalence of freshwater agriculture and the human health needs for freshwater, except for ocean fisheries, oceanography, and seawater flooding, the major focus of water concerns and research has long been concentrated on freshwater. The availability of freshwater is a major determiner of the value of land for various purposes. A huge percentage of the land, over 40%, is deemed to be deserts and wastelands [17] and valued much lower than "arable land". However, deserts/wastelands often have sizable saline aquifers, such as the Nubian aquifer in North Africa, and many are near seacoasts with access to seawater. Also, much of this low-cost land has sunlight for solar energy generation. There are proposals to generate solar energy in the Sahara for use in Europe. Increasingly low-cost solar energy could be used to pump saline and seawater for sizable distances for irrigation of saline/seawater agriculture. Overall, even before climate considerations, freshwater scarcity was of increasing major importance, involving serious resource levels to provide freshwater availability that was pure enough to drink and for agriculture and industry. As the population has increased and the amount of freshwater has not, the considerable efforts and technology needed to provide for an ever more populous society have increased in scope and cost. More recently, the increasing impacts of climate upon freshwater, especially droughts, are resulting in a situation where drinking water and freshwater agriculture are increasingly imperiled, a serious-to-existential societal concern, including from an econometric perspective.

2.2. Halophytes

There is another option for agriculture, food, and much else that is at a vast scale. The scale of climate, low cost, posits serious profits and has massive upsides—Halophytes. These are "salt plants", plants that can grow/thrive using saline/salt water and salinated land. There are up to some 6000 halophyte varieties covering nearly all freshwater plant functionalities—food, fodder, biomass/energy, wood, landscaping, CO_2 sequestration, wildlife habitat, and, in addition, land desalinization [18–21]. There has long been a saline agriculture in India for food and fodder [13]. Many nations are developing, experimenting, and conducting research on halophytes. There are dry land halophytes and ocean halophytes. Algae, seaweed are halophytes. In general, ocean and water plant halophytes are more productive than land halophytes. The lowest cost water halophyte approach is open water, sans land, ponding, etc. expenses. A particularly interesting open water region for wet halophytes would be the Gulf of Mexico, utilizing the continent-sized nutrient stream from the Mississippi River efflux. "Ocean Fertilization", where iron-rich dust is used to fertilize microalgae for atmosphere CO_2 sequestration in the ocean, is a form of seawater agriculture. The resultant algae blooms create profitable amounts of protein and lipids for food and energy and much-increased fish populations. For dry land halophyte farming test plots using sandy soils over decades, there has been evidence of little salt buildup if some 35% or so additional [salt] water is used in irrigation to flush the salt into the soil. Halophytes can sequester up to some 18% of their CO_2 uptake in their deep desert roots. Studies indicate that Halophytes can remove some 4 metric tons of CO_2/hectare [15] and, in their roots, sequester approximately 0.7 metric tons or more. The immense capacity/scale of halophyte agriculture [97% of the water, some 40% of the land], along with low cost, available technology, cheap land and water, and profitability, proffers the possibility of literally "greening the planet" to rapidly remove atmospheric CO_2. The Earth's land mass is some 13 billion Ha. If Halophytes are planted on 40% of the land mass, which is wastelands and deserts, and irrigated with saline seawater, they could sequester nearly 4 gigatons of carbon, which is an appreciable fraction of the additional amount emitted. However, not all dry lands are suitable for halophytes. Halophytes can provide profitable bio land and sea CO_2 sequestration uniquely at the scale of climate. Switching to halophyte saline/seawater agriculture for food would free up increasing amounts of the 70% of the freshwater now used for conventional agriculture, solving many to most of the freshwater issues, including climate-induced droughts. Halophyte biomass provides massive amounts of biofuels and chemical feedstock inexpensively. Since seawater contains many plant nutrients, fertilizer requirements are lower. Then there are the trace minerals in seawater that are needed for human health and are being depleted from arable land. There are now approaches in development that enable plants to extract nitrogen from the air. If, as an example, halophyte seawater Ag were to be practiced on the Sahara, the seawater irrigation would create an unstable atmosphere and produce freshwater rain downwind, possibly increasing freshwater resources in the Middle East, which might aid in region stabilization and also reduce the desertification of the sub-Sahara. These huge resources, saline, salt water, deserts, and wastelands, enabled by halophytes, could conceivably largely solve land, freshwater, food, energy, and climate problems profitably at scale. Perhaps the last large-scale planet resources that have not yet been utilized by society. It would also enable productive use of arable land already salinated, including some 25% of irrigated lands [22]. Halophytes cover the product spectrum—seeds, fruits, roots, tubers, grains, foliage, "wood," oils, berries, gums, resins, and pulp and are rich in energy, protein, and fats. Wastelands/deserts particularly suited for Halophyte Ag include Western Australia, around the Arabian Sea/Persian Gulf, the Middle East, the Sahara, and the Southwest U.S., including West Texas and the Atacama in South America.

2.3. Ocean Fertilization

Ocean fertilization involves adding micro and macronutrients to the upper ocean to enhance algae growth and increase the biological pump for ocean CO_2 and methane sequestration to mitigate climate change [23,24]. The most effective approach utilizes iron micronutrients. Trace amounts of iron, 1 kg, fixes some 100,000 kgs of carbon [24], particle size is less than 1 micron. Issues include efficiency, lowering ocean O_2 levels, altering usual phytoplankton species, and reducing biodiversity. The concerns are apparently, "we just do not know enough", vice, "we know there is a problem". At sea experiments where iron-rich dust was put overboard, and the area monitored indicated algae blooms, as expected, with subsequent fish population increases in some cases. For CO_2, iron enables algae photosynthesis. Algae take up CO_2 and use carbon for skeletons, which drop to the ocean bottom. Ice cores from before the last ice age [25] indicate both extremely low atmospheric CO_2 and Methane and some factor of 4 to 7 greater atmospheric density of iron-rich dust than today. The supposition is that there were droughts that caused extensive iron-rich dust to be blown off the land out over the oceans [as happens today from the Sahara, etc.], which resulted in significant CO_2 and methane sequestration, serving as a contributor to an ice age, along with earth tilt. Apparently, at scale, ocean fertilization could significantly mitigate current climate change. Fans operated by solar energy on near-ocean wastelands could be set up to increase the current [reduced] passive aeolian transport rate of iron-rich dust over the oceans. To counter the Dust Bowl, we planted winter wheat, which reduced the transport of iron-rich dust over the Atlantic. The Asians, in part, planted winter wheat also, which reduced iron-rich dust transport over the Pacific. That, plus the relatively recent increased ocean CO_2 uptake, which is turning the oceans into weak carbonic acid, has reduced the algae populations and consequently reduced algae sequestration of CO_2 and methane. That is, we are currently in an "unnatural" state wrt iron-rich dust and algae populations; ocean fertilization would correct this. Salable products include algae, sources of protein and lipids [food and fuels], and fish that eat the algae.

Given the ongoing necessity of resorting to fish farming/reductions in open ocean fish populations/the health benefits of omega-3 fats/the dearth of protein sources, and the adverse climate impacts of many of the current protein sources, these markets should be motivational/profitable.

2.4. Societal Adoption of Halophytes, Econometrics

Given that a significant switch from freshwater to saltwater Ag is a major change of the same scale as the switch from fossil fuel energy to renewables and storage, such a switch from fresh to saline/saltwater agriculture would be greatly accelerated by two situations: Major profits [apparently available] and continued degradation/shortages of food, water, climate/ecosystem writ large, increasing market pull. When/as things become bad enough, halophytes will happen as they are the only nearer term, very affordable to profitable no new technology solution space with the requisite scale and ready availability for land, water, food, energy, and climate. A seed catalog for halophytes needs to be developed, and training on the differences between saline and freshwater agriculture made readily available. Adult education is also needed to explain the opportunities and drivers. The seawater agriculture solution spaces include seawater irrigation near "dry" coastal areas, saline irrigation where saline aquifers are available, seawater irrigation inland where econometrics appear feasible [piping and energy for pumping becoming ever less expensive] and enhanced freshwater rainfall induced by saline/seawater irrigation [the "terraforming" aspect[s]]. Ongoing halophyte research areas include enhanced plant growth rates and enhanced "salt-loving", reduced water/nutrient requirements, irrigation efficiency Improvements, plant/lifeform tailoring for specific bioconversion/refining processes, and "safe/contained" saline/seawater irrigation practices to avoid-to-obviate freshwater aquifer contamination. Algae research areas include more transparent algae to allow multi-level production, increased oil content, increased growth using fewer nutrients, disease resistance, optimization for biorefining processes, and enhanced growth in cold water. Estimates indicate there are some 60 years of halophyte agriculture in the eastern Sahara from the saline Nubian aquifer before there would be a need to pump the Red Sea and the Mediterranean. The recent droughts in East Africa instigated planning for halophyte agriculture in that region. The way forward to green aviation is to use drop-in biofuels. Boeing has grown aviation fuels using halophytes, and only halophytes in deserts and wastelands can, at a lower cost, produce the large quantities of fuel needed for aviation use. The Chinese have developed halophyte tomatoes, eggplant, peppers, wheat, rice, and rapeseed. Halophyte biomass can be used to produce the requisite piping for halophyte agriculture. Quinola is a halophyte. Estimates indicate increasing freshwater deficits as climate effects continue to develop. Markets for replacements for freshwater agriculture products are increasing due to increasingly negative climate effects on freshwater agriculture and population increases. Potential "products" available from halophyte agriculture, land, and sea include vast amounts of food, fodder, biomass, biofuels, chemical feedstock, fish, lipids, and protein, along with attendant sequestration of nearly 4 gigatons of CO_2. The enablers are vast quantities of cheap deserts and wastelands, cheap saline and seawater, available technologies, cheap solar energy, profits, and products, which are increasingly existential for society due to the increasingly dire wide spectrum impacts of climate change.

Why not yet? Nearly the entire current applied agricultural industry is freshwater, which well knows that salt kills things they deal with, so few in the industry thus far appear to be motivated to seriously consider halophytes. There are also issues concerning the salination of freshwater aquifers and a common query regarding salt buildup on the surface. They are still largely pursuing the traditional get-well freshwater agricultural approaches, which enables further exploitation of current investments and markets. However, this is becoming more expensive as water stresses become more severe. Furthermore, just as the fossil fuel folks abhorred renewables until they were more profitable, the equally large freshwater agricultural industry may perceive little profitability motivation to change. Halophytes and seawater AG are really big ideas, major changes, and one of the few approaches to mitigate climate seriously at the scale of climate. There are two at-scale ways to produce major change. In dire straits, the government will produce such, but usually slowly, as the government has many to answer to. Climate is becoming dire enough that there is increasing government motivation. The alternative way, much faster, is if there are serious profits, the industry will do it, and halophytes with cheap land and water and all the benefits, markets arising from climate impacts should be profitable at scale. With the renewables. we went decades until we reduced their costs below, now much below, fossil fuels, and then they became highly utilized. Climate is becoming so dire now, including calls for pulling CO_2 from the atmosphere, along with issues such as increasing freshwater and food shortages, the need for large quantities of biofuels, etc., and profitability should incite the switch to halophytes. There is no other viable, profitable alternative at scale. What is required now includes serious widespread adult education. Many have never heard of halophytes.

3. Conclusions

Humans and human society require large quantities of freshwater. As the population continues to grow, freshwater requirements increase. Historically, humans have been profligate wrt the available freshwater, including the pollution of major fractions thereof. Water availability has determined human habitation and econometrics. The current climate change impacts on water are increasingly major, including evaporation, soil salination, droughts/floods, and glacier melting. The overall effects of population plus climate are creating increasing concerns regarding water availability, scarcity, and cost[s]. There is a ready alternative to freshwater agriculture, an alternative water universe, the nexus of saline/seawater [97% of the water]/some 6000 varied halophytes, salt tolerant plants/some 40% of the land that is deserts and wastelands. Humans have historically utilized this nexus for food and fodder, among other uses. With the increasing scarcity and cost of freshwater, there is interest in this lower cost/profitable saline/saltwater nexus whose scale is uniquely at the scale of climate change. This nexus proffers, along with producing huge quantities of food and biomass, major climate mitigations, including sequestration of nearly 4 gigatons of CO_2, at scale amounts of chemical feedstock and biofuels, the opportunity to utilize plants at scale with a higher albedo, and release of quantities of the 70% of the freshwater currently utilized for freshwater ag for direct human use. Overall, this alternative water universe should be profitable, at scale, in the near term, employ available technology, and greatly mitigate land, water, food, energy, and climate. Needed for development are detailed financial studies to determine profitability, which largely dictates the speed and scale of investment and development of markets. Governments would perhaps be early investors due to the potential commercial outcomes and the major favorable climate impacts. Industrial/commercial investment would be needed to develop markets that, along with profit levels, tend to drive the speed, scale, and goals of such major societal shifts due to the private sector. In addition to the private sector, there are government actions that can institute major changes, such as a measured switch to a possibly more profitable biosaline agriculture from the current dominant freshwater agriculture. Such government actions will be driven by the wide spectrum of major favorable societal impacts, which are unique at scale but probably require climate and freshwater adverse effects to become more dire, which is happening. Commercial industry interests, given sizable profit projections, will probably act to foster biosaline agriculture sooner than the government.

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