Review

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Halophytes/Saline Water/Deserts/Wastelands Nexus As A Scalable Climate Mitigation Including Fresh Water Impacts

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Halophytes/Saline Water/Deserts/Wastelands Nexus as a Scalable Climate Mitigation Including Fresh Water Impacts

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Abstract: Climate change is rapidly exacerbating and adding to major-to-existential issues associated with fresh water availability and utilization. The massive thus far untapped saline/salt water - oceans/wastelands/deserts – Halophytes resources nexus can, at scale and profitably provide major climate change mitigation and greatly alleviate most extant fresh water 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 the some 70% of the fresh water now utilized by current agriculture for direct human use. Also enables production of huge amounts of Bio/SAF fuels and bio mass based chemical feed stock employing the massive capacity of cheap saline/ seawater and cheap deserts, wastelands. Overall saline/ seawater can, uniquely, at the scale of the climate and fresh water issues, without desalinization, profitably, utilizing extant technologies and the some 44% of the land that is deserts/ wastelands, and the 97% of the water that is saline/ seawater rapidly, seriously, address land, fresh water, food, energy and climate.

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

1. Introduction

" The planet is on track for Catastrophic warming unless countries take extreme action" [U.N., IPCC, 2023]

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 becoming rapidly 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, in the great plains and southwest especially. The major characteristics of the climate problem are its IMMENSE scale, scope of impacts and their 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]. However, Climate mitigation is also a huge developing market, an increasingly essential market, and with the right scalable approaches can be a very profitable market. Now that climate impacts are readily apparent and worsening rapidly, there is increasing motivation to take actions. Also, there have been, still are concerns about the adverse econometric impacts of taking action, e.g. losses not profits, especially historically wrt fossil fuels. The renewables and storage replacements, once their costs went below fossil carbon fuels and nuclear and they produced increasing profits, are now replacing fossil fuels, and also nuclear. The scale of the climate problems and their massive existential impacts requires major changes. Climate mitigation approaches include reducing the generation of CO_2, reducing the CO_2 presence in the atmosphere, increasing the planets albedo, reducing energy use and Geo-Engineering [4,5] and all need to be pursued concomitantly to produce serious mitigation effects at this critical stage of the climate crisis. Several Climate mitigation approaches which have been suggested have serious issues including the possibilities of major adverse,

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unintended effects. These include cost, scale and adverse effects for geo-engineering, major cost, latency, scale and waste issues for fission and fusion nuclear, and cost, scale and leakage for non-bio-CO_2 sequestration.

Fresh Water issues were already increasingly severe before climate impacts upon water became critical. Fresh water related climate effects include flooding, sea-level rise, droughts, glacial melting, evaporation and salination. Current approaches to address these and other fresh water issues such as fracking/ pollution, increased requirements/ population levels, energy generation requirements, etc. are focused upon improving the quality and efficiency of the extant available fresh water including a focus upon fresh water agriculture, which utilizes some 70% of such water. Some 97% of the available water is saline, 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 wrt solution spaces for fresh water issues writ large.

The enabling key to serious solutions for fresh water across the board and climate is the many thousands of saline/ salt water plants, both dry land and aquatic plants termed Halophytes, which have a rich literature [7–42] ranging from scientific studies to econometrics. Many are food plants, they mimic much of the fresh water plant characteristics. The massive extent of these saline/ salt water/ arable land/ halophyte nexus resources are uniquely at scale to address climate. This profitable, unique nexus could, utilizing cheap land and water, provide food, replacing fresh water ag, freeing up fresh water for direct human use, sequester massive amounts of CO_2, produce massive amounts of biofuels and chemical feed stock, largely “solving” land, water, food, energy and climate.

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

2. Methodology

This research involves “sense-making” , akin to an intelligence analysis concerning the putative future utilization, optimization and econometrics of water writ large including climate mitigation. Requires extensive literature search and examination/ understanding of status, issues and current research with respect to water availability, fresh water issues, the characteristics of wastelands and deserts, climate change and its’ progress and impacts, climate change mitigation needs and approaches, halophyte, salt plant characteristics and 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 fresh water, arable land and the serious to 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 kick in.

2.1. Water/Land Issues

As stated, some 97% of the planets water is saline/ salt water. This includes oceans, seas, some lakes, and saline aquifers, many of them large. Seawater has some 80% of the elements to fertilize plants and has trace minerals needed for human health which are often depleted from arable land [7]. As humans have been pumping what started out as mostly fresh water 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 fresh water with some 68% of it tied up in glaciers, 30% in ground water, most of the rest in permafrost and the great lakes, Lake Baikal, little of the planets’ water is “available” fresh water. Of that available fresh water some 70% is utilized for agriculture/ food, 15% for industry and some 15% for households. Due to the current prevalence of fresh water agriculture and the human health needs for fresh water, except for ocean fisheries, oceanography and sea water flooding, the major focus of water concerns and research has long been concentrated upon fresh water. The availability of fresh water is a major determiner of the value of land for various purposes. A huge percentage of the land, some 44% is deemed to be deserts and wastelands and valued much lower than "arable land". However, such 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 such low-cost land has sunlight for solar energy generation. There are proposals to generate solar energy on the Sahara for use in Europe. Such solar energy could be used to pump saline, seawater at low-cost for sizable distances for irrigation of saline/ seawater agriculture. Overall, even before climate considerations, fresh water scarcity was of increasing to major importance, involving serious resource levels to provide fresh water availability pure enough to drink and for agriculture and industry. As population has increased and the amount of fresh water 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 fresh water, especially droughts are resulting in a situation where drinking water as well as fresh water agriculture are increasingly imperiled, a serious-to-existential societal concern, including from an econometric perspective.

"Water scarcity is now the single greatest threat to human health, the environment and the global food supply" [David Seckler, director-general of the Washington-based International Water Management Institute, 1999]

2.2. Halophytes

There is another option for agriculture, food and much else that is at 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 10,000 halophytes covering nearly all fresh water plant functionalities – food, fodder, biomass/ energy, wood, landscaping, CO_2 sequestration, wildlife habitat and in addition land desalinization. There has long been a saline agriculture in India for food and fodder. Some 22 nations are developing, experimenting, conducting research on halophytes. There are dry land halophytes and ocean halophytes, algae, seaweed are halophytes. In general ocean, water plant halophytes are more productive than land halophytes. The lowest cost water halophyte approach is open water, sans land and 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 over decades using sandy soils have evidenced 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. Given the massive scale of putative halophyte agriculture, land and sea halophytes could, profitably, and soon using existing technology, sequester over some 4 gigatons of CO_2 which is an appreciable fraction of the additional amount emitted. Halophytes are profitable bio land and sea CO_2 sequestration uniquely at the scale of climate. Switching to halophyte saline/seawater AG for food would free up increasing amounts of the 70% of the fresh water now used for conventional agriculture, solving many to most of the fresh water issues including climate induced droughts. Halophyte biomass provides inexpensively massive amounts of biofuels and chemical feedstock , the latter is now provided by some 50% of the petroleum. Since seawater contains some 80% of plant nutrients, fertilizer requirements are lower. Then there are the trace minerals in seawater that are needed for human health that are being depleted from arable land. There are now approaches in development to 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 fresh water rain downwind, possibly increasing fresh water resources in the middle east , which could possibly aid in region stabilization, and also reduce the desertification of the sub-Sahara. These huge resources, saline, salt water and deserts, wastelands , enabled by halophytes, could conceivably

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largely solve land, fresh water, food, energy and climate, at scale, profitably. Perhaps the last large-scale planet resources not yet utilized by society. Would also enable productive use of arable land already salinated, some 25% of irrigated lands. Halophytes cover the product spectrum - seeds, fruits, roots, tubers, grains, foliage, "wood," oils, berries, gums, resins, 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, Southwest U.S. including West Texas and the Atacama in South America.

2.3. Ocean Fertilization

- Ocean Fertilization involves adding micro and macro nutrients to the upper ocean to enhance algae growth to increase the biological pump for ocean CO_2 and Methane sequestration to mitigate climate. The most effective approach utilizes iron micronutrients. Trace amounts of iron, 1 kg fixes some 100,000 kgs of carbon, particle size is less than 1 micron. Issues include efficiency, lowering ocean O2 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 in some cases subsequent fish population increases. For CO_2, the iron enables algae photosynthesis, algae takes up CO_2, uses carbon for skeletons, which drop to the ocean bottom. Ice cores from before the last ice age 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, etc. 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, that reduced the transport of iron rich dust over the Atlantic. The Asians in parts planted winter wheat also, reducing 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 have reduced the algae populations and consequently reduced algae sequestration of such as 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 fresh water to salt water 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/ salt water AG would be greatly accelerated by two situations: Major profits [apparently available] and continued degradation/ shortages of food, water, climate/ ecosystem writ large. When/as things become bad enough halophytes will happen, is 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

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developed and training readily available for the differences, such as some 35% additional irrigation levels, wrt saline Agriculture. Also Adult Ed to explain the opportunities. The seawater Ag 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], 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 bio-conversion/refining processes, "safe/contained" saline/seawater irrigation practices to avoid-to-obviate fresh water aquifer contamination. Algae research areas include more transparent algae to allow multi-level production, increased oil content, increased growth using less nutrients, disease resistance, optimization for bio-refining processes and enhanced growth in cold water. Estimates indicate there is some 60 years of halophyte agriculture in the eastern Sahara from the Nubian aquifer before the need to pump the Red Sea and the Mediterranean. The recent droughts in East Africa instigated planning for halophyte AG in that region. The way forward to green aviation is to use drop in SAF biofuels, Boeing has grown aviation fuels using halophytes and only halophytes on deserts and wastelands can at 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 ag. Quinola is a halophyte. Estimates indicate some 50% of the planet will be in fresh water deficit as climate effects continue to develop. Over 800 million HA of fresh water arable lands have been salinated, with more expected to be salinated going forward. Markets for replacements for fresh water Ag products are increasing, due to increasingly negative climate effects on fresh water AG and population increases. "Products" available from halophyte Ag, land and sea, include vast amounts of food, fodder, biomass, biofuels, chemical feed stock, fish, lipids, protein, along with attendant sequestration of greater than 4 gigatons of CO2. The enablers are vast quantities of cheap deserts and wastelands, cheap saline and seawater, available technologies, cheap solar energy, profits, 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 AG industry is fresh water, they well know that salt kills things they deal with, so few in the industry thus far appear to be motivated to seriously consider halophytes. They are still largely pursuing the traditional get-well fresh water AG approaches, with some decreasing success as water stresses become more severe. Also. just as the fossil fuel folks abhorred renewables, until they were more profitable, the equally large fresh water AG industry may perceive little profitability motivation to change. Halophytes, sea water AG is a really big idea, major change, one of the few approaches to seriously mitigate climate at the scale of climate. There are two at scale ways to produce major change, in dire straits, government will produce such, but usually slowly as 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 industry will do it, and halophytes with cheap land and water and all the benefits, markets arising from climate impacts will be profitable at scale. With the renewables. we went decades until we reduced their costs below, now much below fossil fuels, then they became highly utilized. Climate is becoming so dire now, including calls for pulling CO_2 from the atmosphere, fresh water and food shortages, need for large quantities of biofuels, etc. that profits and raw needs will make halophytes happen. There is no other viable profitable alternative at scale. What is required now includes serious wide spread adult ed, many have never heard of halophytes. Also need halophyte seed availability. Refs 7,15,26, 29, 34,and 40 have previously addressed some of the climate related benefits, options of saline agriculture.

3. Conclusions

Humans and human society require large quantities of fresh water, as population continues to grow, fresh water requirements increase. Historically humans have been profligate wrt the available fresh water, including the pollution of major fractions thereof. Water availability has determined human habitation and econometrics. The current climate change impacts upon water are increasingly major including evaporation, soil salination, droughts/ floods, and glacier melting. The overall effects of population plus climate are creating increasing concerns wrt water availability, scarcity and cost[s]. There is a ready alternative to fresh water agriculture, an alternative water universe, the nexus of saline/ seawater [97% of the water] – some 10,000 varied halophytes, salt tolerant plants – the some 44% 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 fresh water there is increasing interest in this lower cost/ profitable saline/ salt water 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 greater than 4 gigatons of CO_2, at scale amounts of chemical feed stock and biofuels, the opportunity to utilize plants at scale with a higher albedo, and release of quantities of the 70% of the fresh water currently utilized for fresh water ag for direct human use. Overall, this alternative water universe is profitable, at scale, near term, uses available technology, and greatly mitigates land, water, food, energy and climate.

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