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Atmospheric and Soil Carbon and Halophytes

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Abstract

World population is anticipated to grow 40% within 40–50 years (2008 baseline) with unprecedented demands for energy, food, freshwater, and clean environments. At 43% of the total landmass, exploiting the Earth's arid and semi-arid lands becomes a matter of necessity. Compared with glycophyte agriculture, we view seawater and brackish water halophyte saline agriculture in its nascent stage and see the need to explore and farm on a massive scale. Halophyte farming costs should be the same as glycophyte cellulosic biomass farming; processing for cellulosic matter should also be applicable. Halophyte life cycle analyses (LCA) within the fueling debate are incomplete, yet glycophyte LCA favors biomass fueling. The Biomass Revolution is in progress. The capacity, cost, and logistics required for biomass replacement of petroleum-based fuels, however, will require all feedstock sources and regional cooperative productivity, technical investments, and both the participation and cooperation of the American farmer and global farm community.

Introduction

We are dealing with opportunities of enormous proportions driven by conflicts between energy, food, and freshwater demands (and shortages); population growth; and climatic changes. The opportunity has arrived to use what we now do not use: salt water, wastelands, and a wholly different plant genus—halophytes. Halophytes have the capacity—a wholly new capacity not included in previous biomass studies or current agricultural programs—to deal directly with these conflicts at reasonable cost (similar to cellulosic biomass) and could offset or replace $70/bbl barrel crude oil. Technologically, halophyte agriculture is just more farming, utilizing resources that do not compete with the food chain or freshwater resources.

Soils, Water, and Soil Carbon

Worldwide, soil formation is estimated at 1 mt/ha-yr and losses are 5–30 mt/ha-yr, resulting in 75×10^9 mt/yr topsoil loss at a cost of nearly $\$0.5\times10^{12}$/yr. Further, it requires 100–2500 years to naturally form 25 mm of topsoil (Ref. 1). Thus soils are fast becoming a non-renewable resource. Further, the availability of freshwater, while considered a renewable resource, is rapidly reaching a peak, even while desalination is progressing (Ref. 2); in 40–50 years (2010 baseline) over half will be used in the cities and rejected as waste or brackish (Ref. 3). The continuous issues of freshwater rights and availability required for human survival and development of alternate energy sources spawn continuously conflict, growth limits, as well as public and private court fights; this will only escalate.

For organic soils characteristic of glycophyte crop productivity (wheat, corn, soybeans, rice), carbon is the basic ingredient, typically 57% by weight, and is lost through tillage and erosion. Maintaining and restoring soil biomass carbon through no-till production offsets carbon emissions, enhances soil quality and productivity, and reduces wind and water erosion: all qualify for clean development mechanism credits (CDMCs). But no-till farming also requires herbicides, fungicides, and insecticides to control weeds, pathogens, and insects (Refs. 4 and 5)—all of which can become pollutants. Is natural plant (and rudiment animal) methane, NOx,

methylbromide release acceptable and artificial no-till applications not? or to what extent (Ref. 5)? For that matter, active human CO_2 release is 450 L/day (0.9 kg/day), with 6.6 billion inhabitants (humans release over 2 billion tonnes CO_2 out of a world total of 29 billion mt), or close to 7% anthropogenic emissions.

Halophytes and Growth Demands

The anticipated population growth of 40% within 40–50 years (2008 baseline) will result in proportional increases in demands for energy, food, freshwater, and clean environments. Exploiting the Earth's arid and semi-arid lands—43% of the total landmass—thus becomes a matter of necessity. The majority of desert soils are saline, but with sufficient nonsaline water can be reclaimed. Halophytes grown with brackish waters require about the same volume of water as conventionally irrigated crops. Seawater irrigation requirements are higher to control salt build-up in the root areas requiring adequate as well as well planned and executed irrigation and drainage (Ref. 6).

With 50% of the population residing within 50 km of a shoreline, halophytes (which thrive in salt water) and salt-tolerant plants seem natural for crop selection (generically termed "salt tolerant"). One of several thousand is Salicornia bigelovii. Hodges (Ref. 7) has established a closed-cycle system (Seawater Foundation Farms) to conserve freshwater, arable land, provide food, and clean the environment. Salicornia (SOS-7, 7^{th} generation) provides a total biomass of (~20 mt/ha): straw, 10 mt/ha; salt (ash), 7.2 mt/ha; and oilseed, 2.2 mt/ha (comprising oil, 0.6 mt/ha (73% linoleic) and meal (1.6 mt/ha). Part of the straw is used to rebuild soils, part for construction materials (including bioplastics), and part for fuels. The algae, shrimp, and tilapia farms provide sources of food and nutrients with plant nutrients from wastes. Here it is best to remember that developing higher hydrocarbons in more complex organisms is energy intensive, and unless the byproducts warrant or are cost effective, it is best to harvest lower-developed organisms. Air is cleaned as it is cycled though the soil, which removes contaminants; freshwater lenses provide ponds; marshes provide for wildlife; and the salt is a byproduct of value. Further, mangroves offer costal restoration and long-term carbon storage; one species, Avicenia marina, is tolerant to 4.5% saline and 50 °C. Balancing the entire community requires a concerted effort.

Halophytes Production Costs.—Based on typical farming costs, salicornia production costs from initial land preparation (prorated over 10 years) to harvesting, bailing, and delivery to edge of field range from $44 to $53 per dry tonne ($175 to $211 per tonne carbon) for brackish and seawater irrigation, respectively. By comparison, glycophyte crops range from $30 to $40 per dry tonne. Halophytes can be grown on land that has not been forested or farmed, but glycophytes must be grown on arable land (Ref. 6).

Fossil fuel requirement (see note b, Table 1b) to deliver 1 tonne of halophyte carbon to edge of field 225 kg-fuel brackish and 300 kg-fuel saltwater irrigated fields, respectively. Other crops less dependent on irrigation require 130 to 180 kg/tonne-carbon, and corn grown as an energy crop requires 330 to 970 kg/tonne-carbon (Ref. 6). These cost and fuel requirements are summarized in Tables 1a and b.

TABLE 1A.—COMPARATIVE COSTS AND FOSSIL FUEL REQUIREMENTS FOR HALOPHYTES AND GLYCOPHYTES

Expense		Water		
		Fresh	Brackish	Sea
Production Costs [US $(1990)/mt]				
Halophyte	Dry	---------	44	53
	Carbon	---------	175	211
Glycophyte	Conventional	30–40	----	----
Fossil Fuel Required [kg/mt-carbon]				
Halophyte	Salicornia	---------	25	300
Glycophyte	Conventional	130–180	----	----
	Corn to fuel	300–970	----	----

TABLE 1B.—CARBON BALANCE ESTIMATES BASED ON DATA FROM DR. CARL HODGES (REF. 8) AND PROF. ED GLENN (REF. 9)

Salicornia crop water pumping[a]	1.8 m-H_2O/ha = 18000 m^3-H_2O/crop	
Fossil fuel required	3.8 m^3-H_2O/min requires 300 L-fuel/ha = 225kg/ha	
Fuel carbon content	85% C fuel → 191 kg-C/ha	191 kg-C/ha
Salicornia oil seed	2000 kg-oil seed/ha @30% seed-oil → 600 kg-oil/ha	5100 kg-C/ha
Salicornia straw returned to soil (cellulose)	20 mt/ha @70% cellulose @ 40% C → 5600 kg-C/ha	5600 kg-C/ha
–Optimistic	Straw C:N @32:1 and humus C:N @8:1 → 25% C-sequestration or 1400 kg-C/ha	1400 kg-C/ha
–Conservative	@20% → 1120 kg-C/ha	
Salicornia roots (Hodges)	700 kg-C /ha @30% → 210 kg-C/ha	210 kg-C/ha
Table Summary		
Fossil fuel consumed	0.191 mt-C/ha	
Seed oil produced (and consumed)	0.51 mt-C/ha	
Soil/root sequestration	1.3–1.6 mt-C/ha	
Net carbon balance[b,c]	0.6–0.9 mt-C/ha	

[a]Assume 5-m pumping head (conventional fueled pump).

[b]The wastelands we are advocating are mostly in very sunny regions. This means that we can use solar-thermal/PV systems for pumping energy, as well as the halophyte biomass to produce fuel for tractors and associated power equipment via combustion and Sterling cycles or conversion of electrical energy. Future systems WILL NOT NEED TO USE FOSSIL ANYTHING to raise halophytes.

[c]25% of the carbon in the atmosphere originates from deforestation, which is a glycophyte issue. We do not need to do this for halophytes, a major benefit. The other major atmospheric carbon sources: coal 26%, oil 31%, and natural gas 15% (Ref. 10).

With the perennial seashore mallow, different production approaches are being investigated (Ref. 11), such as nutrient applications, watering (natural, and irrigation); harvesting direct and swathing combining; no-till seeding with pre-emergent application and fertilizer regimens. While the 3-acre, 4-year stand has not been replanted in the past 4 years, some reseeding occurs from dropping and combine straw residuals. This past year, the pre-emergent was sprayed and a light amount of fertilizer spun on. Thus far, the stand has become thicker as stems per crown have increased each year, and production costs are being tracked.

Economic Analysis.—Whether halophytes such as salicornia (annual) or seashoremallow (perennial), biomass crop economics will be largely dependent upon the quantity and value of multiple products derived from the crop relative to the cost of their production.

Currently, seashore mallow products include

1. Oil, meal, and mucilage from the seed
2. Two types of fibers from the stems for paper or ethanol (and potentially bioplastics)
3. Carbon storage in the perennial living root systems and humus in the soils.

With a large number of products the profitability of the crop would not bring as much as a crop with only one or two uses when various commodity prices changed, resulting in an overall lower cost of production (Ref. 11).

Seawater Foundation has not yet provided their economic analysis delayed by changes in production management and product values (Ref. 8).

To date we do not have an economic analysis of the perennial seashore mallow, yet an analysis will follow this year's harvest of a 3-acre 4-year stand.

Halophytes Carbon Cycle and CDMCs

There are an abundance of life cycle analysis (LCA) studies for glycophyte crops such as those cited in Figures 1(a) and (b), where a negative CO_2 equivalent implies CO_2 emission/sequestration that is beneficial to climate in terms of greenhouse has (GHG) emissions. LCAs are involved with large changes in CO_2 equivalent attributed to changes in land use such as deforestation, which leads to a large CO_2 imbalance.

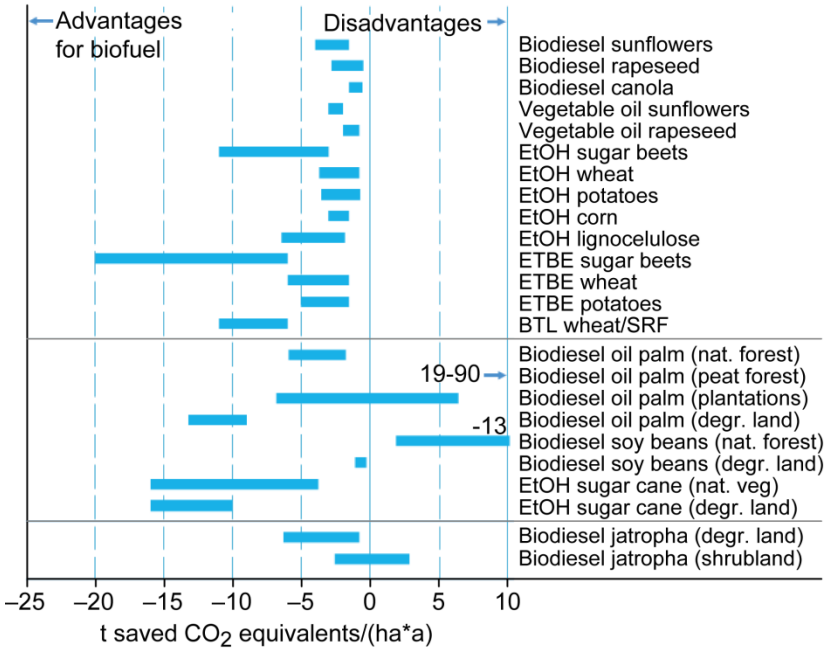

Figure 1a.—Tons (t) of CO_2 equivalent per hectare per year for biofuels for glycophite agriculture based on life cycle analysis method similar to their fossil fuel counterparts; degr. is degraded; nat., natural; ETBE, ethyl tertiary-butyl ether; BTL, biomass-to-liquid; and SRF, solid recovered fuel (from Ref. 12).

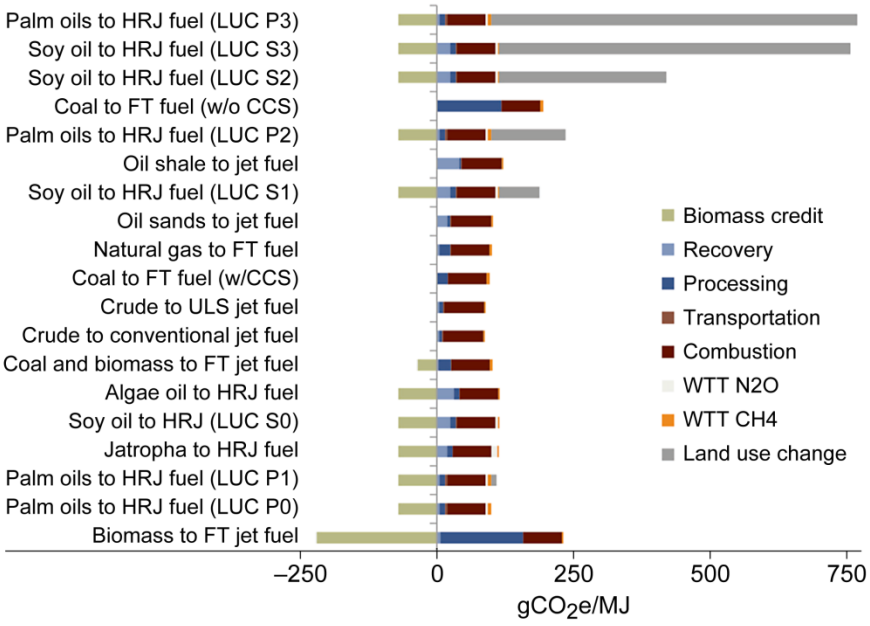

Figure 1b.—Alternate aviation fueling life cycle analysis greenhouse gas emissions for glycophyte agricultural crops; HRJ is hydrogenated renewable jet fuel; LUC, land use change; FT, Fischer-Tropsch; ULS, ultralow sulfur; WWT, waste water treatment; and CCS, carbon capture and storage (Figure B-17 in (Ref. 13)).

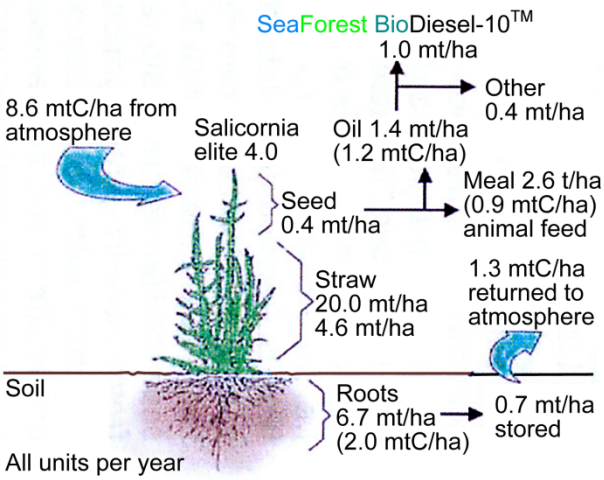

Figure 2.—Salicornia seed-oil fuel atmospheric and soil carbon balance (Ref. 7).

These analyses generally favor biomass fueling except for palm, although sustainable palm is competitive with sugar cane, yet not considered by LCA analysts. Still, most glycophyte biomass fuel sources compete directly with our food supply, and all compete for freshwater resources.

There are very few LCAs for halophytes. Dr. Carl Hodges (Ref. 14) created the atmospheric carbon balance sketch in Figure 2 (see also (Ref. 15)), which illustrates a system atmospheric carbon benefit ratio (C-fuel burn/C-removed and stored) and for SeaForest fuel, is 1/4; the biofuel removes and stores 4 times more carbon than is released when burned as a fuel (see notes 1 and 2, Table 1b).

Considering salicornia along with the pumping requirements and sequestering the straw-carbon in the soil, Prof. Ed Glenn at U. of Arizona provides the C-balance shown in Table 1b.

For the perennial seashore mallow, nearly half of the plant carbon is stored in the root system. The overall carbon balance is under consideration (Ref. 11).

It is very important to realize that the Seawater Foundation Farms life cycle analysis (Ref. 14) addresses social, economic, conservation, growth, and development issues in addition to climatic and environmental issues applicable to globally diverse localities. Such LCA brings new meaning to life cycle analysis not considered in fueling debates, yet more aligned with those advocated and to be addressed within the Millennium Institute (Ref. 16) and perhaps World Growth (Ref. 17) organizations.

Further studies are being conducted under the FAA-MIT PARTNER program with Dr. James I. Hileman on glycophyte LCA (Ref. 18) with potential forthcoming work on halophyte salicornia. The results of this study are not publically available in 2009.

Biomass Revolution

The issue of capacity for replacing petroleum per se, not just for aircraft fueling, appears to require ALL economically reasonable biomass sources, especially in the shorter term before algae costs come down and cyano-bacteria emerges from the laboratory stage. The productivity of algae and cyano-bacteria, IF their production and logistics costs can be brought down (or oil prices escalate drastically), practically ensures their place as the eventual biomass/biofuel sources. In the shorter term, ALL sources, cellulosic glycophytes as reasonable, halophytes, wastes, and weeds (all biomass) will be required to achieve capacity, and these will most likely be locally diverse, by necessity, as universal production is not a reality.

In the longer term halophytes will be used for food (as they are in parts of India today) simply because of the rapidly emerging shortages of sweet water, of which around 68% goes to agriculture. Shifting to halophytes for food would return much of this freshwater for direct human use. With the use of the 97% of the Earth's water (which is salty) and utilization of wastelands (about 44% of the Earth's land mass), the potential capacity of halophytes is massive, at costs potentials comparable to cellulosic glycophytes; it is just more farming.

Halophyte farming is in a nascent stage, and there are few-to-no real numbers for this approach, which can be relied upon for moving forward. Real work and development is required to obtain agricultural objectives. Life is just not that easy: a lot of effort is required. We need investments in technology and the American farmer (as well as farmers throughout the world), whose ingenuity and hard work are required to make it happen.

There are also the major opportunities proffered by genomics and synthetic biology to (1) greatly increase growth rates, (2) provide much more root CO_2 sequestration, (3) tailor biomass for specific processing approaches such as, utilize N_2 out of the atmosphere (soy beans, alfalfa), become "salt loving," not just salt tolerant, and (4) utilize less nutrients to achieve product are just a few examples. This is what the Biomass Revolution is all about. Also, after fuel extraction, properly managed residue pyrolysis could provide electrical base load to back up wind and solar power systems, which also need to be included in the economic models (assume they are, but if not, need to be).

Trying to "pick a winner" for biomass biofuels in the shorter term is not particularly productive, except that such studies should indicate shortfalls for various approaches in terms of costs and capacity so that these issues can be worked and improved. In short, we need a BIG Summation Sign Σ for adding together all potential sources with the prime metrics being cost and capacity—current and potential—including "economies of scale."

Summary

World population is anticipated to grow 40% within 40–50 years (2008 baseline) with unprecedented demands for energy, food, freshwater, and clean environments. Agricultural topsoil and soil carbon are key ingredients in plant productivity, yet worldwide, 75 billion metric tons of soil are lost annually and considered a nonrenewable natural resource. Exploiting the Earth's arid and semi-arid lands at 43% of the total landmass becomes a matter of necessity.

Basically, we view seawater and brackish water halophyte farming as follows:

1. According to the National Research Council (NRC) report (Ref. 19) India and others have been growing halophytes for a long time, yet massive production requires significant work as saline agriculture is in its a nascent stage.
2. Among the 10,000 halophytes are many, even before genomics, that are as productive as glycophytes and we need to explore and farm the most productive ones qualifying for clean development mechanism or system credits.
3. THEREFORE:

Halophyte costs etc. should be exactly the same as glycophyte/cellulosic biomass farming/processing (these are known), except for reduced real estate taxes (using wastelands) and the need for the wastelands to be near a source of brackish or salt water, either open or underground. Since ocean water has 80% of the nutrients, fertilizer costs should be reduced with respect to glycophytes. Then there is the genomic approach using the soybean or alfalfa system of atmospheric N_2 uptake to save use of nitrogen fertilizer. All the processing for cellulosic matter that is rapidly developing and multiferous should be applicable.

4. Life cycle analysis (LCA) within the fueling debate are incomplete. In addition to environmental issues, such analyses need to address social, economic, conservation, climatic, growth, and development issues applicable to globally diverse localities.
5. The Biomass Revolution is in progress, but the capacity, cost, and logistics required for biomass replacement of petroleum-based fuels will require all feedstock sources and regional cooperative productivity, technical investments along with the American farmer and global farm community.

References

1. Myers, N., and Kent, J., 2005, The New GAIA Atlas of Planet Management, Octopus Publishing Group, London, UK.
2. Fahey, J., 2009, "Making Sweet Water From (Almost) Perpetual Motion," Forbes Magazine, vol. 184, pp. 94–97.

3. Gleick, P.H., 2009, "The World's Water 2008–2009." *The Biennial Report on Freshwater Resources,* Ch. 1, Peak Water and Data Table 19, Water Content of Things, pp. 335–338.
4. Sundermeier, A., Reeder, R., and Lal, R., 2005, "Soil Carbon Sequestration—Fundamentals," Extension Fact Sheet AEX–510–05, The Ohio State University Extension, Columbus, OH.
5. Gressel, J., 2009, "Why Transgenics Are Imperative for Biofuel Crops," *NASA/OAI Seminar,* Based on Gressel, J., 2008, *Genetic Glass Ceilings: Transgenics for Crop Biodiversity*, Johns-Hopkins University Press, Baltimore, MD.
6. Glenn, E.P., Hodges, C.N., Lieth, H., Pielke, R., and Pitelka, L., 1992, "Growing Halophytes to Remove Carbon From the Atmosphere," *Environment*, Vol. 34, No. 3, pp. 40–43.
7. Hodges, C.N., 1990, "Environmental Technologies: Ordering Biological Development," Journal of Social and Biological Structures, Vol. 13, No. 2, pp. 83–92.
8. Hodges, C., 2009, Seawater Foundation, private communication.
9. Glenn, E.P., 2009, University of Arizona, Tucson, AZ, private communication.
10. Dembo, R., 2009, "Keynote Address BCNET Green Technologies for Research and Learning," Zerofootprint, Toronto, Canada. http://www.zerofootprint.net/
11. Gallagher, J., 2009, University of Delaware, Newark, DE, private communication. jackg@UDel.Edu.
12. Reinhardt, G.A., Rettenmairer, N., and Koppen, S., 2008, "How Sustainable Are Biofuels for Transportation?" Bioenergy. Challenges and Opportunities, Proceedings of International Conference and Exhibition on Bioenergy, Guimaraes, Portugal.
13. GIACC: Group on International Aviation and Climate Change, 2009, "Agenda Item 2: Review of Aviation Emissions Related Activities Within ICAO and Internationally: U.S. Fuel Trend Analysis and Comparison to GIACC/4–IP/1," *GIACC Fourth Meeting*, GIACC/4–IP/12, Montreal, Canada. http://web.mit.edu/aeroastro/partner/reports/proj28/fueltrend-analy.pdf
14. The Seawater Foundation, 2007, "The Seawater Foundation," http://www.seawaterfoundation.org/
15. Hendricks, R.C., 2008, "Potential Carbon Negative Commercial Aviation Through Land Management" ISROMAC12–2008–20242, *12th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery*, Honolulu, HI.
16. Millenium Institute, 2010, "Millenium Institute: a sustainable future for Earth is possible," http://www.millenniuminstitute.net/
17. World Growth, 2007–2010, "World Growth," http://www.worldgrowth.org/
18. Hileman, J.I., Ortiz, D., Bartis, J., Wong, H.M., Donohoo, P.E., Weiss, M.A., and Waitz, I.A., 2009, "Near Term Feasibility of Alternative Jet Fuels," Joint PARTNER-RAND Report No. TR–554, PARTNERCOE–2009–001. http://www.rand.org/pubs/technical_reports/TR554/.
19. Anon, 1990, "Saline Agriculture, *Salt-Tolerant Plants for Developing Countries,* National Research Council, National Academy Press, Washington, DC. http://books.nap.edu/openbook.php?record_id=1489&page=R1

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14. ABSTRACT
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