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POTENTIAL CARBON NEGATIVE COMMERCIAL AVIATION THROUGH LAND MANAGEMENT

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ABSTRACT

Brazilian terra preta soil and char-enhanced soil agricultural systems have demonstrated both enhanced plant biomass and crop yield and functions as a carbon sink. Similar carbon sinking has been demonstrated for both glycophyte and halophyte plants and plant roots.

Within the assumption of 3.7 t-C/ha/yr soils and plant root carbon sinking, it is possible to provide carbon neutral U.S. commercial aviation using about 8.5% of U.S. arable lands. The total airline CO_2 release would be offset by carbon credits for properly managed soils and plant rooting, becoming carbon neutral for carbon sequestered synjet processing. If these lands were also used to produce biomass fuel crops such as soybeans at an increased yield of 60 bu/acre (225gal/ha), they would provide over 3.15×10^9 gallons biodiesel fuel. If all this fuel were refined into biojet it would provide a 16% biojet-84% synjet blend. This allows the U.S. aviation industry to become carbon negative (carbon negative commercial aviation through carbon credits). Arid land recovery could yield even greater benefits.

INTRODUCTION

Commercial aviation's primary engine emissions are CO_2 and H_2O, which are not considered recoverable and can lead to climate change issues. Addressing secure, sustainable fuel supplies and emissions requires reductions in the use of petroleum-based fuels.

For many years our ancestors used ashes to condition garden soils in order to enhance plant productivity to feed their families. This art has been set aside in favor of artificial fertilizers, cleaner fuels as natural gas, and other fossil fuel as petroleum. More recently archeological work in Brazil's Amazon Basin has theorized that the indigenous people used a technique now termed "slash-and-char," a process similar to pyrolysis, to condition their soils.*

Theory holds that these nutrient-poor soils were conditioned into rich black fertile soils, called terra preta do Indio or simply terra preta, providing a rich source of natural foods. The process is theorized to be based on a mixture of low-temperature burning of plant and wood matter, pottery chards, bones, manure, and micro-organisms (arbuscular mycorrhizal fungi).[1]

Plants and soils represent a sustainable long-term solution for removing CO_2 from our living environment. Pumping it underground or into the ocean only delays the problem as oxygen is also sequestered with it. The carbon needs to be put away and the oxygen recovered. No civilization can maintain itself over long periods without living within its means, including its food and energy supply. While equilibrium is not necessary during periods of "progress," it is the norm for most of human history. The last 200 years of industrialization is but a drop in the bucket in the history of human civilizations. To sustain our civilization, our global climate, food, and energy life cycle balance needs to be addressed.

Herein we investigate soil conditioning and plant rooting, and postulate a potential method to produce carbon-negative life-cycle aviation fuels through soil and root crop management. That is, the CO_2 produced by commercial aviation would be offset with carbon enhanced plant soils and rooting.

OXISOLS BIOMASS FEEDSTOCKS

Oxisols characterize those soils and planting management currently practiced in modern agriculture. Common current plantings of corn, rice, wheat, soybeans, and grasses in a variety of soils produce biomass and food crops, which for the most part are glycophytes (freshwater crops). Modern agriculture is heavily dependent on artificial fertilizers derived from a petroleum intensive industry.

*Wim Sombroek was a pioneer of Brazilian soils management with prior efforts reported in 1874 by Cornell Professor Charles Hartt and 1879 by Herbert Smith (Marris, 2006)

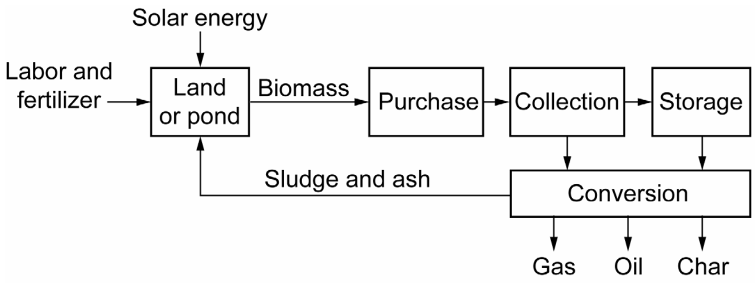

Figure 1.—Diagram showing overall system for conversion of biomass.

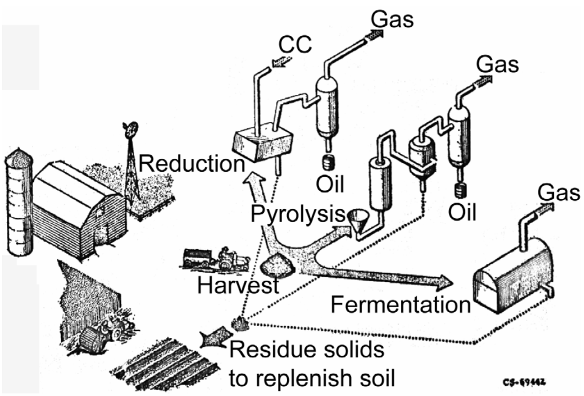

Figure 2.—Methods of converting crops to fuel.

In the early 1970s, clean fuels from biomass were the subject of NASA Lewis studies in response to the fuel crisis (Hsu, 1974 and Graham et al., 1976). Basically all biomass is based on nutrients, water, soil, and solar energy input (fig. 1). Hsu cited reduction, pyrolysis,† and fermentation as methods of converting conventional oxisols glycophyte biomass to liquid (BTL) fuels and gases (fig. 2).

In all three feedstock conversion processes, Hsu carefully returned the process residuals to the soil. This included the pyrolysis char and organic wastes from other processes to be mixed with the soils and fertilizers as manure and nitrogen-potassium-phosphorous (NPK). For the most part, oxisols agriculture depletes the soil and increases salinity to the point where only halophyte (salt-tolerant) plants become productive (Hendricks, 2008).

To determine crop yields (ton/acre-yr) and energy equivalent (W/m^2), Hsu investigated the effects of solar flux, photoefficiency, location, and crop along with production costs. Napier grass was among the highest yields (table 1).

Table 1.—Representative Biofeedstock Yields of Dry Mass[a,b]

Crop	Location	Yield, ton/acre-yr
Napier grass	Puerto Rico	21.6
Napier grass	India	15.5
Congo grass	Puerto Rico	22.4
Buffelgrass	---------	28.0
Dallis grass	Taiwan	10.7
Kikuyu grass	Taiwan	23.3
Canary grass	United States and Canada	3.6 to 8.3
Ryegrass	Great Britain	10.0
Sugarcane	United States	9.5 to 10.7
Corn	United States	10.0
Sugar beets	United States	9.5

[a]From Hsu (1996).
[b]Values from Ohio Agricultural Research and Development Center survey.

Hsu cites that in 1970 each person in the United States required 3.5×10^8 Btu/yr of fuel. Fuel crops at 10 ton/acre supplied 10^8 Btu/acre, requiring 6.5 acre/person, and thus could support a population of 250M.

The 2006 U.S. demand for energy at 0.271 Quad/day‡ (equivalent to 50 million bbl/day or 580 bbl/s) of oil outstrips our ability to sustain it with current oxisol glycophyte biofuel crops. We need alternate biomass fuel-food feedstocks in order to meet demand.

TERRA-PRETA-ENHANCED SOIL MANAGEMENT

Agricultural productivity can be improved by introducing char into the soil. While Hsu (1974) indirectly cited the benefits of char soil additives, Mann

†Pyrolysis, the heating of biomass in the absence of oxygen and theorized as a key factor in terra preta soil system, is endothermic up to about 280 °C, exothermic from 280 to 500 °C and above 500 °C is mixed. Free water comes out about 140 °C. Noncombustibles as steam, CO_2, and some acids evolve at 200 °C. Combustibles as methane, CO, and tars evolve at 280 °C with dewpoints at 400 °C. At 500 °C and above, the char glows, and most gases have evolved leaving a porous structure. The best C-storage product range is between 280 and 390 °C while the more porous structure is better suited for microbial life (Day et al. (2006)). Day also notes that woodstocks are better for char with little char residue from grasses.

Reduction is the process of reducing complex organics, as biomass and wastes into, oil, gas, tars, and char. It may be thought of as a subset of a broader class processes for converting biomass and wastes into oils, called thermal depolymerization[2] (Thermal depolymerization 2007).

Operating range: Temperature 250 to 450 °C and pressures 7 to 48.4 MPa CO partial pressure 10 to 30% total pressure. CO decreases dehydration, increases decarboxylation (splitting off a carboxyl group (-COOH)) and some enters the water–gas shift reaction (Appell, 1973). It should be noted that most substances break down in supercritical water [critical point: 647 K (374 °C or 705 °F) and 22.064 MPa (3200 PSIA or 218 atm.)]

‡1Quad (Q) is 10^{15} Btu.

(2002) reviewed agriculture practiced centuries ago in Amazonia (Brazil) citing soil improvements methods and large-scale developments in terms of population and land.[§] The anthropogenic nutrient-enriched soil is called terra preta do Indio, typically 0.4 to 0.6 m deep; however, terra preta soils have been found up to 2 m in depth.

Steiner et al. (2004) experimented with rice and sorghum in NPK-treated soils with and without charcoal. NPK plus charcoal-treated plots showed a 49% increase in average crop yield and a 31% increase in biomass for an overall increase of 40% over plots with NPK alone. A significant finding, most likely also used by the indigenous people, was in adding condensed smoke (piopirol) to the charcoal that provided enhanced microbial respiration (nearly 3 times). The 40- by 40-m test area was sectioned into 2- by 2-m test plots and covered 15 treatments with 5 repetitions each for a total of 75 plots. Some plots achieved 880% plant biomass over NPK alone (Mann, 2002). The study covered a 3-yr period.

Marris (2006) provides a very nice review of terra preta soils, soil-conditioning research, and similar soil conditioning methods. Marris cites the work of Sombroek (1992) who proposed terra preta soil management in the 1960s, later extending the methodology as a means to sequester carbon. The work of Glaser (2007) shows that charcoal enriched soils (terra preta) store up to 250 t-C/ha-m, compared to ordinary soils (oxisols) storing 100 t-C/ha-m. The sequestered carbon being home to sustained bacterial activity enhances plant-soil symbiosis. Thus the symbiotic system is highly carbon-negative relative to other systems such as petroleum, coal, or gas as energy sources.

Day et al. (2006) originally directed efforts toward biofuels, yet found that combining char with ammonium bicarbonate produces a soil additive that enhances plant production. The process does not seek to maximize production of char, hydrogen or biodiesel, but produces all three at a reduced efficiency for each. Yields are not cited, yet several presentations have been forthcoming which indicate up to 3 to 4 times crop yields and significant reductions in carbon through carbon sinking. Quantitative comparison of corn yield is illustrated in figure 3.

Figure 4, from Day et al. (2006), illustrates their estimations of carbon-intensive alternate energy sources and show that even solar energy (panel production process) requires significant carbon release, yet terra-preta-type soils (char-enhanced) are carbon negative.

[§]Low temperature carbonization (LTC) used in America until the early 1870s, heats any carbonaceous matter (coal, shale, lignite) biomass in the absence of oxygen (pyrolosis) to provide oil. In the Kerrick-LTC, the substance is heated up to the destructive distillation temperature about 370 to 430 °C (same temperature as cracking petroleum) producing (per ton coal) oil (1-bbl), smokeless-char (3/4 ton) and gas (3000 cf) rather than tar. The char can be used in smelters or boilers. Or the char can be converted to (water gas) town gas FT process feedstock and converted to oil. (Karrick; Christian Science Monitor). A similar char may have been formed by the Brazilians.

Figure 3.—Best and worst of corn yields with various soil conditioning Day et al. (2006) http://www.eprida.com/presentations/lerdwgcom.pdf

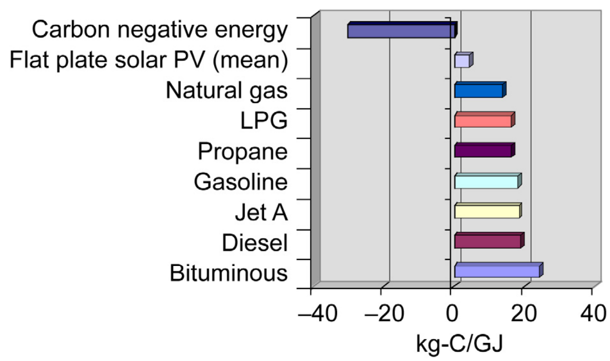

Figure 4.—Relative carbon rankings for various energy sources, [after Day et al. (2006) http://www.epa.gov/climatechange/emissions/downloads/2007GHGFastFacts.pdf]

Activated charcoal has long been used as an absorbent, and Day (2006) also points out alternative uses of charcoal such as absorbing ammonia in scrubbers and removal of NOx and SOx from flue gases.

In addition to plant growth enhancement, the terra-preta- and char-enhanced soils stimulate root growth which also functions to condition soils. Alfalfa rooting is extensive as are other rooting plants that also function as sinks for carbon. The combined effect of both terra preta and plant root soil conditioning serves as multiple carbon sinks in our quest for carbon-negative aviation fueling. If the sink is sufficiently negative, the release of CO_2 as a combustion gas may be neutralized or in the worst case, significantly reduced.

Carbon fixation can be accomplished through plantings with deep roots. While the focus of Samac et al. (2007) is to stem the spread of common alfalfa root rot (Aphanomyces and Phytophthora), they also compare the root systems of corn, switchgrass, and alfalfa (fig. 5).

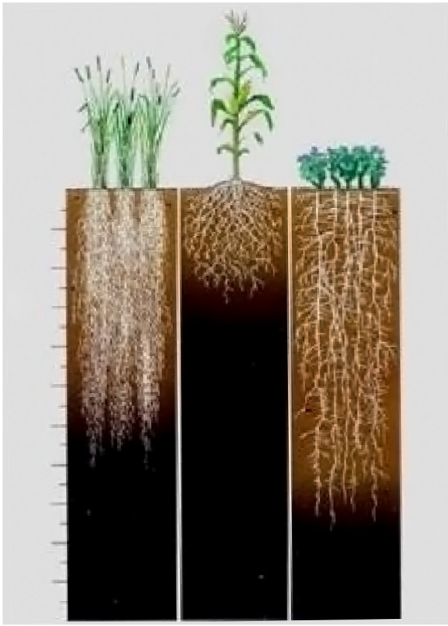

Figure 5.—Schematic of relative root lengths of switchgrass (left), corn (center), and alfalfa (right). Courtesy of Michael Russelle ARS USDA Minnesota Extension Service and Samac et al. (2007). http://www.extension.umn.edu/cropenews/2007/07MNCN14.htm

Alfalfa roots can grow nearly 2 m/yr in loose soils, and have been found 18 m or more below grade. Alfalfa roots symbiotically work with soil bacteria (Sinorhizobium meliloti) to fix atmospheric nitrogen and store carbohydrates produced in the leaves enabling rapid regrowth and spring greenup.

For Brazilian forest root depths to 6 m, Sommer et al. (2000) cite carbon sequestration for primary forest at 196 t-C/ha, slash-and-burn 185 t-C/ha and semipermanent cultures at 146–167 t-C/ha.

CARBON SINKING POTENTIAL

Aviation's unrecovered primary engine emissions, CO_2 and H_2O, can lead to climate change issues. Addressing issues of secure, sustainable fuel supplies and emissions requires reducing use of petroleum-based fuels. Synthetic fuels derived from coal (CTL) and natural gas (GTL) are considered drop in fuels, yet produce 1.8 and 1.5 times more CO_2, respectively, than that produced from consuming Jet A alone. Blends of biojet and synjet are being considered as methods to reduce the commercial aviation CO_2 footprint (Daggett et al., 2007).

TERRA PRETA CARBON SINKING

Currently arable soils produce most of our planet's food and biofuels. However, halophytes or salt-tolerant plantings have significant potential to not only supply food and fuels, but also would conserve fresh waters as a natural resource (Hendricks, 2008).

Notil- and till-arable land agriculture arguments abound. Currently, notil agriculture is favored based on crop production costs. Also current production is highly dependent on NPK with little soil conditioning and in many cases irrigation, resulting in soil depletion and an increase of soil salinity. This state of our lands calls for new forms of soil conditioning such as terra preta methodologies.

Nevertheless, assuming arable soil average tillage depths of 0.2 m and following Glasser (2007), assuming a terra preta to oxisol soil carbon sinking differential of 150 t-C/ha-m, 30 t-C/ha can be sequestered. Now, U.S. total land is [9,161,923 km^2 or ~0.9×10^9 ha][3] and if all U.S. arable land at 18% of total land [0.165×10^9 ha] were terra preta managed, it would store 4.95×10^9 t-C.

PLANT ROOT CARBON SINKING

Although roots also condition soils and in the case of alfalfa, fix nitrogen and grow to extreme depths, plant roots also can store large amounts of carbon.

For U.S. arable land area of 0.165×10^9 ha, assuming glycophyte deep root sequestration of 14.5t-C/ha (10% of that cited by Sommer et al. (2000)), root-sequestered carbon would be 2.4×10^9 t-C or 8.8×10^9 t-CO_2 equivalent.

If 10% of the Sahara Desert (0.86×10^8 ha), or equivalent arid lands, were converted into irrigated halophyte production with root storing at 14.5 t-C/ha, the sequestered carbon would be 1.25×10^9 t-carbon (4.57×10^9 t-CO_2). This represents 16.9% of the 2004 World CO_2 emissions.[**]

Hodges et al. (1993) investigated rivers of pumped seawater flowing from the ocean to arid lands, converting them into seawater-irrigated agricultural areas supporting halophyte crops and aquaculture. With nearly 50% of the world's population living within 50 km of the sea, Hodges proposes seawater-based communities, aquatic animal production, and halophyte farms as a solution to the energy-water-food triangle of conflicts. Hodges argues that we must enhance the flow of carbon from the atmosphere into the soil (app. A).

In addition, properly irrigated and drained halophytes remediate and build soil which would be able to store more carbon, produce more food-fuel biomass, and conserve fresh water natural resources (Hendricks, 2008).

While not considered a rooting system, algae are biomass intensive producing 150 to 300 times more biofuel than soybeans (Daggett et al., 2007), and the residue could potentially be used as a soil conditioner thereby storing carbon.

[**]Typical halophytes include Salicornia (glasswort), Suaeda (sea blite), Atriplex (saltbush) and to a lesser extent the hardy Jatropha.
World 2004-CO_2 emissions were 27.06×10^9 t-$CO_2\times12/44 = 7.38\times10^9$ t-C.
U.S. share of World CO2 is 5.912×10^9 t-$CO_2\times12/44 = 1.6\times10^9$ t-C.
[http://www.eia.doe.gov/pub/international/iealf/tableh1co2.xls]
http://www.seed.slb.com/en/scictr/watch/climate_change/co2.htm

AVIATION FUELING AND CARBON SINKING

Modern aircraft achieve 67 passenger-miles/gal of fuel with projections for Airbus A380 and Boeing 787 near 78 passenger-miles/gal, which is respectable relative to automotive standards, yet still discharge large amounts of CO_2 and water emissions at altitude. World aviation Jet A-1 fuel consumption for 2005 was 55×10^9 gallons which corresponds to 0.54×10^9 t-CO_2 (1 t-JetA1 = 31.6 t-CO_2) or 2% of the World CO_2

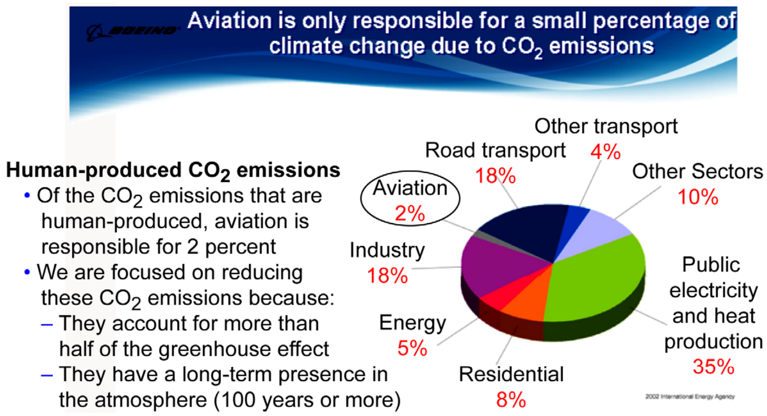

Figure 6.—The relative distribution of CO_2 by various industrial sectors; courtesy Dave Daggett, Boeing Commercial Airplane. (Data source, International Energy Agency).

Release.[4] The relative distribution of World CO_2 is shown in figure 6 for various industrial sectors, illustrating that over one-third comes from the power heat and light sector.

With proper tradeoffs, soil, and root conditioning and suitable land fuel feedstock symbiosis, aviation fueling has the potential of becoming carbon negative. In the previous sections, coupled U.S. arable lands root and soil carbon sinking could provide 30 t-C/ha to 44.5 t-C/ha. Assuming only 10% of this potential capacity is readily achievable annually, 3.7 t-C/ha/yr, for U.S. arable lands [0.165×10^9 ha], 0.61×10^9 t-C/yr could be sequestered. This represents 38% of the total U.S. CO_2 production. Thus an investment in these biosystems could provide biomass fuel feedstocks, which for biojet-synjet blends would offset commercial aviation CO_2 release.

U.S. domestic commercial aviation uses 13.5×10^9 gal of Jet A fuel (0.13×10^9 t-CO_2) and total use is 19.6×10^9 gal (0.19×10^9 t-CO_2). If the U.S. aviation industry invested in terra-preta-managed soils, with 3.7 t-C/ha/yr (13.6 t-CO_2/ha/yr) a land area of 0.014×10^9 ha or 8.5% of U.S. arable soils (size of New York), the industry would become CO_2 neutral via carbon credits.[††] Over time these soils will enhance biomass and crop yield, providing benefits to both the biofuels and foods industries.

A similar investment could be made in halophyte planting in areas considered too salty for glycophyte planting. Combining the two agriculture methods would increase energy biofuel feedstocks, increase food supply and free up fresh water for human consumption.

With symbiotic investment in both soil-root management and biofuels, the industry becomes carbon negative. The amount or degree negative depends on the percentage of biojet-synjet blends recalling that synjet is carbon positive, and both are feedstock dependent.

As has been shown, root carbon sequestration becomes a major benefit of both glycophyte and halophyte plants. If necessary, it would not be difficult to envision an energy system of low-pressure subsoil pipeline networks coupling CO_2 capture with plant root sequestration. System safety becomes paramount as tasteless, odorless CO_2 pockets can form in low areas; once into these areas, asphyxiation is eminent. The best technique would be natural recycling via roots and terra preta or char soil conditioning.

[††]8.5% assumes carbon sequestration in synfuel CTL or GTL processing; otherwise 12.8% for nonsequestered GTL and 15.3% nonsequestered CTL.

Managed arable crop e.g., soybeans yield at 60 bu/acre (225gal/ha) would provide 3.15×10^9 gallons biodiesel fuel. If all refined to biojet would provide a 16% biojet-84% synjet blend or nearly 25:75 and 30:70 blends potential for 12.8% and 15.3% , respectively.

The 3.7 t-C/ha/yr (13.6 t-CO_2/ha/yr) estimates are conservative relative to those anticipated by Robert Brown's terra preta soil management work at Iowa State University (Ames, Iowa) using chars. For a system of char and ammonium nitrate, there is a potential to store 7.6 t-C/ha. While this is small compared to 150 t-C/ha-m (Glasser, 2007) for Brazilian terra preta, the depth of soil penetration in Brown's estimate was not cited nor was the baseline native soil ,which could account for the significant differences. Brown also suggests that the U.S. corn crop could store 0.25×10^9 t-C/yr (Marris, 2006).

In prior estimates, Lehmann et al. (2003) believe that soil systems as terra preta and biochar, combined with biofuels management could offset up to 9.5×10^9 t-C/yr (34.8×10^9 t-CO2/yr). If properly implemented, such a system would be 28.6% World carbon negative.

CONCLUSIONS

Brazillian agriculture experiments have shown that terra preta soil management enhances plant biomass and yield and functions as a carbon sink. Similar carbon sinking has been demonstrated for plant roots.

1. Properly managed soils and plant rooting systems are capable of carbon sinking of 3.7 t-C/ha/yr. Investing 8.5% of U.S. arable lands into managed soils and plant rooting the total U.S. airline CO_2 release would be offset as carbon neutral, for carbon-sequestered synjet processing.
2. If these lands were also used to produce biomass for fuels (palm oils, jatropha, algae, soybeans, switchgrass, etc.), crops such as soybeans at increased yield of 60 bu/acre (225 gal/ha) would provide over 3.15×10^9 gal of biodiesel fuel.
3. In addition, if all were refined to biojet they would provide a 16% biojet-84% synjet blend.
4. Investing in halophyte agriculture would capture carbon, recover arid land, and free up freshwater resources.
5. Through properly managed soils and plant rooting carbon credits, U.S. commercial aviation industry becomes carbon negative.

REFERENCES

Appell, H.R. U.S. Patent 3733255, 15 May 1973. Conversion of Municipal Refuse, Sewage Sludge and other Wastes to Heavy Oil or Bitumen.

Christian Science Monitor (13 August 1951) Fuel Plant Plan: How Story Was Bared." (see also http://rexresearch.com/karrick/karric~1.htm)

Daggett, D.L., Hendricks, R.C., Walther, R., Corporan, E. (2007) Alternate Fuels for use in Commercial Aircraft, ISABE–2007–1196, Beijing China, Sept. 2–8.

Day, D., Evans, B., Lee, J., Reicosky, D., Das, K.C., Realf, M., Zang, L., (2006) Renewable Energy and Soil Carbon Management—A Symbiotic Role for the Human Species, LERDWG 8 Nov 2006.
[http://www.eprida.com/presentations/lerdwgcom.pdf]

Douglas, J. (1993) A Rich Harvest from Halophytes, EPRI Journal, October/November, pp. 16–23.

Glaser, B. (2007) Prehistorically Modified Soils of Central Amazonia: A Model for Sustainable Agriculture in the Twenty-First Century. Philosophical Transactions of the Royal Society B-Biological Sciences 362 (1478): 187–196, Feb. 28 2007.

Graham, R.W., Reynolds, T.W., Hsu, Y.Y. Preliminary Assessment of Systems for Deriving Liquid and Gaseous Fuels from Waste or Grown Organics, NASA TN D–8165, 1976.

Hendricks, R.C. (2008) Halophytes Energy Feedstocks: Back to Our Roots, Paper: ISROMAC–12–20241, (ISROMAC–12) Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, Hawaii February 17–22, 2008. http://www.isromac.org/

Hsu, Y.Y. Clean Fuels from Biomass. Southeastern Seminar on Therma Science; 10th; Apr. 11–12, 1974; New Orleans, LA, NASA–TMX–71538. (see also Energy Quarterly Vol. VI, No. 1, 1976).

Hodges C.N., Thompson, T.L., Riley, J.J, Glenn, E.P. (1993) Reversing the Flow: Water and Nutrients from the Sea to the Land, Ambio, Journal of the Human Environment, (Tropical and Subtropical Coastal Zones) Vol. XXII, No. 7, Nov. http://www.seawaterfoundation.org/

Karrick, Lewis C.: U.S. Patent 1945530, 16 Feb 1934 Destructive Distillation of Solid Carbonizable Material One of 17 U.S. Patents between 1931 and 1942.

Lehmann, J., Kern, D.C., Glaser, B., Woods, W.J. (Editors) (2003) Amazonian Dark Earths: Origin, Properties, Management Kluwer Academic Publishers, Dordrecht, The Netherlands. ISBN 1-4020-1839-8 http://www.wkap.com/

Mann, C.C. (2002) The Real Dirt on Rainforest Fertility, Science Magazine, vol. 297, 9 Aug 2002, pp. 920–923.

Marris, E. (2006) Black is the New Green, Nature Vol. 442, 10 Aug 2006, pp. 624–626.
[http://bestenergies.com/downloads/naturemag_200604.pdf]

Samac, D.A., Malvick, D., Hudelson, B., Gibbs, A. (2007) Alfalfa Root Health and Disease Management: A Foundation for Maximizing Production Potential and Stand Life, Minnesota Crop e-News, University of Minnesota, 16 April.
http://www.extension.umn.edu/cropenews/2007/07MNCN14.htm

Sombroek, W. G. (1992) Biomass and Carbon Storage in the Amazon Ecosystems
Interciência 17 (5) 269–272 Sept.–Oct.1992.

Sommer, R., Denich, M. and Vlek, P.L.G. (2000) Carbon storage and root penetration in deep soils under small-farmer land-use systems in the Eastern Amazon region, Brazil. Plant Soil, 219: 231–241 (Springer).

Steiner C., Teixeira, W.G., Lehmann, J. and Zech, W. (2004) Microbial Response to Charcoal Amendments of Highly Weathered Soils and Amazonian Dark Earths in Central Amazonia—Preliminary Results. In Amazonian Dark Earths: Explorations in Space and Time. eds., B. Glaser and W.I. Woods, pp. 195–212. Springer Verlag, Heidelberg.

SOURCE MATERIAL

[1]http://en.wikipedia.org/wiki/Terra_preta (general description of terra preta soils)

[2]http://en.wikipedia.org/wiki/Thermal_depolymerization

[3]https://www.cia.gov/library/publications/the-world-factbook/geos/us.html (U.S. land areas)

[4]http://www.atag.org/content/showissue.asp?level1=3&level2=472&folderid=472&pageid=1084 (World CO_2 release)

APPENDIX A: HALOPHYTE CARBON CAPTURE

Hodges et al. (1993) proposed seawater farms (halophyte plants) and communities with soil remediation to enhance carbon flow from the atmosphere into the soil. They also suggest that 30% salicornia oil seed (SOS) blended with diesel fuel (70%) (biodiesel) when used in power production would be CO_2 neutral. The fuel production cycle is nicely portrayed in figure 7.

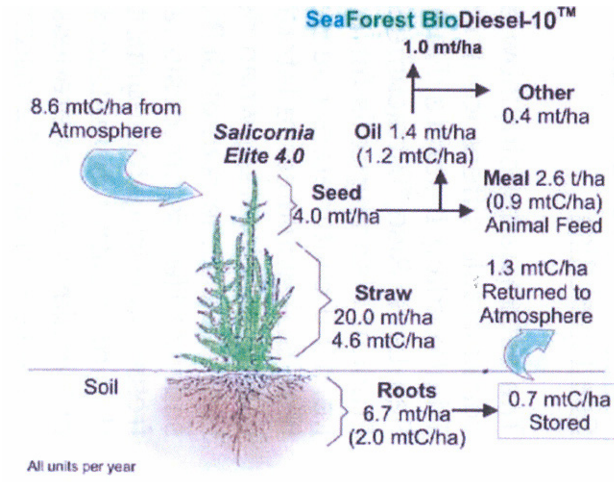

Figure 7.—Atmospheric Carbon Biomass Cycling for Salicornia Bigelovii Torr., [Courtesy Dr. Carl Hodges, http://www.seawaterfoundation.org/index.html]

In the model forest of Dr. Hodges, salicornia is planted within mangrove trees. The mangrove biomass yields are 35mt/yr, roots, 18 mt/yr leaves, and 10.6 mt/yr stems. For the 1 mt-salicornia-biodiesel/ha model, 8.6 mt-C/ha (includes diesel to produce crop) is input to salicornia with 1.3 mt-C/ha returned to the atmosphere. The model assumes that the 4.6 mt-C/ha celluostic biomass is fully captured. If plowed under, as suggested by Hsu (1974), the combined root and straw storage would become $[0.25\times20+0.3\times6.7]/3$ and 4.2 mt-C/ha would be returned to the atmosphere. Here the system atmospheric carbon benefits (SACB), essentially the ratio of carbon captured to carbon released by fuel use, depends on the plant use.

If a strip of land, 1990 km long and 130 km wide (about 10% of the U.S. coastline), was dedicated to halophyte agriculture, the carbon captured would equal the carbon released by airline fuel combustion. The seed oil, if all 6.6×10^9 gal were converted to biojet, also would provide nearly a 50:50: blended with Jet A.