"GREEN PLANET ARCHITECTURE"—A METHODOLOGY FOR SELF-SUSTAINABLE DISTRIBUTED RENEWABLE ENERGY ECOSYSTEMS

Nikita T. Saxena[1], Anna E. Thomas[2], Shawana Johnson[3], John P. Venners[4], Robert C. Hendricks[5]

[1]Tufts University
Medford, Massachusetts, 02155, USA
nikita.saxena@tufts.edu

[2]Georgia Institute of Technology
Atlanta, Georgia, 30332, USA
aet4@gatech.edu

[3]Global Marketing Insights Inc.
Cleveland, Ohio, 44131, USA
www.globalinsights.com

[4]BioEcoTek-Hawaii
Honolulu, Hawaii, 96815, USA
http://www.bioecotek.com/

[5]NASA Glenn Research Center
Cleveland, Ohio, 44135, USA
Corresponding Author: Phone: 216–433–7507, Fax: 216–433–3000,
Robert.C.Hendricks@nasa.gov

Abstract

Our planet has been endowed with a host of natural mechanisms to keep the environment and climate in balance. Humans are now facing the need to restore this balance that has been upset in the past years because of a growing population and resource demands. To steer dependency away from freshwater crops and decrease environmental damage from humanity's fuel and energy demands, it is necessary to take advantage of the natural adaptive biomass resources that are already in place. Using methods of "Green Planet Architecture," based on compilations of current research and procedures, could lead to new forms of energy and fueling as well as new sources for food and feed. Green Planet Architecture involves climatic adaptive biomass; geospatial intelligence; agri- and aqua-culture life cycles; and soil, wetland, and shoreline restoration. Plants such as *Salicornia*, seashore mallow, castor, mangroves, and perhaps *Moringa* can be modified (natural, model-assisted, or genetically modified) to thrive in salt-water and brackish water or otherwise not arable conditions, making them potentially new crops that will not displace traditional farming. These fueling sources also have potential to be used in other rapid-growth industries, such as the aviation industry, that have incentive to move towards more sustainable fuel supplies. This paper highlights an example of how synergistic development of biomass resources and geospatial intelligence high-performance computing capabilities can be focused to resolve potential drought-famine problems. These techniques, provide a basis for future e-science-based discovery (and access) through technology that can be expanded to support global societal applications.

Introduction

Since inception, climatic adaptive biomass has provided humanity with our basic energy sources, feed, food, fuel, and waste recovery (recycling); this is natural green planet architecture. With the advent of modern agriculture, our food and feed sources have become essentially dependent on four major crops: wheat, maize (corn), rice and soybeans [1]. Producing enough to satisfy humanity's demand for food and feed requires large amounts of energy, including fuels, fertilizers, herbicides, and fungicides. Current energy needs, in terms of fuels required, will mirror the anticipated world population growth of 40% over the next 4–5 decades. This sets an anticipated peak at 2050–60 of over 9 billion people demanding upwards of 650Q (650×10^{15}

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Btu; 680×10^{18} joules) of energy, [2] with some attenuation based on virtual crop selections [3]. In addition, humanity is facing climatic change, loss of top-soils, increasing desertification with increasing soil salinity, warming oceans, and methane released from clathrate deposits around the world, among other concerns. By the same timeline of 2050–60, half of all freshwaters will be concentrated in the cities [4]. We are a planet in transition, and as freshwater resources melt away or "dry up," severe conflicts between agricultural and domestic water rights will place high demands for remediation of brackish waters and restricted water usage.

Such climatic changes and demands call for Green Planet Architecture, creating symbiotic relations between ecological systems and geospatial intelligence (based on satellite surveillance and ground sources data). The architecture can provide predictive and preventive modeling networks that reflect global needs and induce the possibility of corrective action. Global distribution networks connecting sources of food, feed, freshwater, waste-recovery, and energy in closed ecological cycle climate adaptive systems are required to provide environmentally neutral-to-positive benefits (returning more to the environment than taking from it, such as two projects envisioned by Dr. Carl Hodges [5]: (1) the Middle East Cradle Two Project followed by (2) The Med-Dead Project with principle and first product, Hope, through abundance instead of scarcity of resources.)

Green Planet Architecture provides for the introduction and development of new climatic adaptive biomass sources for feed and food that displace the intense demand for energy, as well as those already known but little developed. Currently, some energy forms can be diverted for aviation or other fuels; safe, high-energy-density, sustainable, secure, and economically viable fuels are a premium in the aviation industry [1]. Biomass residuals provide land-based power plants for general power and transportation.

This paper reviews ways in which the application of geospatial intelligence could be synergistic with the development of *Salicornia*, seashore mallow, castor, *Moringa*, and other plants as crops that can

serve as energy sources for use as premium fuels, such as those required for aviation. We will also provide a range of comparative results for the NASA GreenLab program and the potential for global food/feed production improvement through modeling. Biomass fuel research and development will benefit fueling and energy in the near term, but freshwater food and feed in the far term. The opportunities are of enormous proportions to provide humanity with freshwater, food, feed, and energy.

NASA Greenlab Data and Resources

The GreenLab Research Facility at NASA Glenn Research Center comprises three complementary components hoping to optimize biomass feedstock: (i) the indoor or incubator facility, (ii) the outdoor growth facility, and (iii) computational modeling. Each possesses a variety of climatic adaptive ecosystems and power and energy sources, with a long-term goal to enable commercialization and close the production and demand gap for alternative fuel sources [6]. The computational modeling tools are being developed to enable process development and optimization of key production processes, and will be further discussed in a later section.

The unique integrated approach, Fig. 1, is directed to the achievement of optimal biomass feedstock through climatic adaptation of balanced ecosystems. The three founding principles are that the crops are to not use freshwater, not compete with food crops, and not use arable land. The incubator laboratory screens seeds, seedlings, waste treatment, and ecosystems, varying parameters such as controlled saline, lighting, and nutrients. They are transitioned to the outdoor laboratory, and eventually implemented in comparable climates throughout the world. Biomass plants adapted include *Salicornia*, seashore mallow, and mangroves to some degree. In terms of algal varieties, native algae species remain the most sustainable algal form [6]. Biomass-derived biofuels represent viable alternative fuel resources for fields such as aviation. Their byproducts can be used for feed or food, and their residuals can be converted to other energy sources or products.
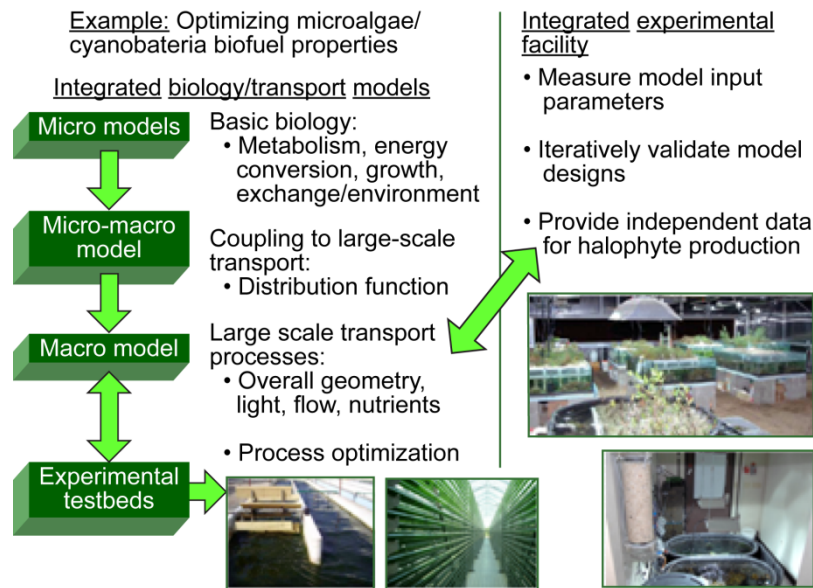
Fig. 1 Integrated iterative experiments and modeling: Efficient NASA-unique approach to aviation biofuels [6].

Geospatial Intelligence

To provide food, feed, energy, and freshwater needs on a global scale, it becomes necessary to model and predict the availability of resources and the conditions that provide for sustained biomass growth and development. Whether current, potential or virtual, these models often require high volumes of satellite imagery from collaborative data sets between government agencies and private industry [7].

In addition to the use of Earth observation remote sensing (EO) satellite imagery, global positioning system (GPS) and differential GPS (DGPS) system use in U.S. agriculture is already well established in precision planting, fertilizing, and herbicide/pesticide placement. It has been able to improve water use, night farming, and disease monitoring. Precision farming is based on geospatial intelligence information from a combination of the GPS and geographic information system (GIS) [7]. Constructing predictive models of the climate and growth conditions of more remote areas of biomass research, as well as applying the technology to weather patterns of more populated areas, can provide enormous societal benefit.

Geospatial intelligence data are being used globally for virtually thousands of unique and complementary agricultural crop management, water management, carbon management, and applications. NASA satellite data in particular is of high value in these projects since it is those sensors such as MODIS which provide the most frequent global coverage.

There is much work being done both within NASA and with external companies to further the potential of geospatial intelligence. NASA's Earth Science Decadal Survey brings together the work of many different agencies such as NASA and NOAA (National Oceanographic and atmospheric Administration) to study an effective approach of space-observation systems. Table 1 summarizes the Decadal survey missions and their possible applications to the model of Green Planet Architecture [8]. Advances in technology further enable data collection and have been proven for water and snow distribution, ocean salinity, and wind patterns [9] as well as data ingest. Combining these technologies with results from the Decadal missions could expand capabilities to learn about soil condition, moisture, nutrients, pathogens, other invasive species, and more (Table 1).

The difficulties with ingesting, processing, and managing these large data sets are being addressed by both NASA and industry in the form of low-cost, highly accessible, high-performance computing power; industry has high-performance computing (HPC) centers. These advancements represent the way forward in order to utilize NASA data and commercial data sets to address the global environmental and societal problems.

Table 1 NASA Earth Science Decadal Survey Studies

Satellite	Orbit	Full Title of Satellite Surveillance Program	Applications to Green Planet Architecture
ICESat II	*LEO, non SSO*	Ice, Cloud, and land Elevation Satellite	cloud cover, vegetation data
SMAP	*LEO, SSO*	Soil Moisture Active Passive	biomass productivity
DESDynI	*LEO, SSO*	Deformation, Ecosystem Structure and Dynamics of Ice	vegetation, volcano, tsunami, landslide prediction
SWOT	*LEO, SSO*	Surface Water and Ocean Topography	oceans and freshwater mapping
HyspIRI	*LEO, SSO*	Hyperspectral Infrared Imager	carbon cycle ecosystem, soil, nutrients, water
ASCENDs	*LEO, SSO*	Active Sensing of CO_2 Emissions over Nights, Days, and Seasons	atmospheric CO_2 data
GEO-CAPE	*GEO*	Geostationary Coastal and Air Pollution Events	aerosols and particulate tacking
ACE	*LEO, SSO*	Aerosol-Cloud-Ecosystems	aerosol and clouds
LIST	*LEO, SSO*	Lidar Surface Topography	land shift, water runoff
PATH	*LEO*	Precision and All-Weather Temperature and Humidity	temperature, humidity, weather forecasting
GRACE II	*LEO, SSO*	Gravity Recovery and Climate Experiment	experiment measurements of gravity and large-scale water movement
SCLP	*LEO, SSO*	Snow and Cold Land Processes	snow/ice/water runoff
GACM	*LEO, SSO*	Global Atmospheric Composition Mission	mission weather, photosynthesis spectra
3D-WINDS	*LEO, SSO*	Three-Dimensional Tropospheric Winds from Space-based Lidar	winds, weather pollution, pollen, pathogen transport

In 2010, the satellite Earth observation data sets such as that from MODIS, TRMM, NCEP, AFWA LIS, Landsat 5 and 7, PET, and SPOT-Veg NDVI were loaded into the HPC system [7]. This project [7] focuses on

1. Using a HPC cloud to perform difficult computational analytics necessary for hosting and managing multiple satellite sensor datasets for (near) real-time data assimilation products
2. Developing an information platform in a high performance environment addressing multiple sensor integration problems, which include
    i. Problems of scale
    ii. Simulation and modeling
    iii. Difficult or "hard" problems
    iv. Nondeterministic polynomial time (NP)
    v. Adaptive systems (artificial and natural)
3. Demonstrating sustainability improvements in dataset modeling all in one database (keeping their native resolutions) to look at responses to all variables

This list clarifies what signals the data provides, in order to view entire regions of the world at one time and make quicker, more accurate land use predictions (such as global food security) while working with multiple data sources for rainfall, temperature, etc.

A successful interagency project (2007–2010) between the National Geospatial-Intelligence Agency (NGA) and the U.S. Department of Agriculture (USDA) utilizing NASA Earth Science data and other data sets observed drought and agricultural production (e.g., Fig. 2). This project required a petascale cloud to deliver the computations and data volumes required to ingest, manipulate, and analyze these Earth observations and the models required for processing. Geospatial intelligence utilized in a convergence-of-evidence methodology allowed the analysts to predict a 93% wheat crop shortfall due to drought; this provided a 10-month advanced famine early warning window, allowing the associated parties to divert the famine and potential societal unrest.
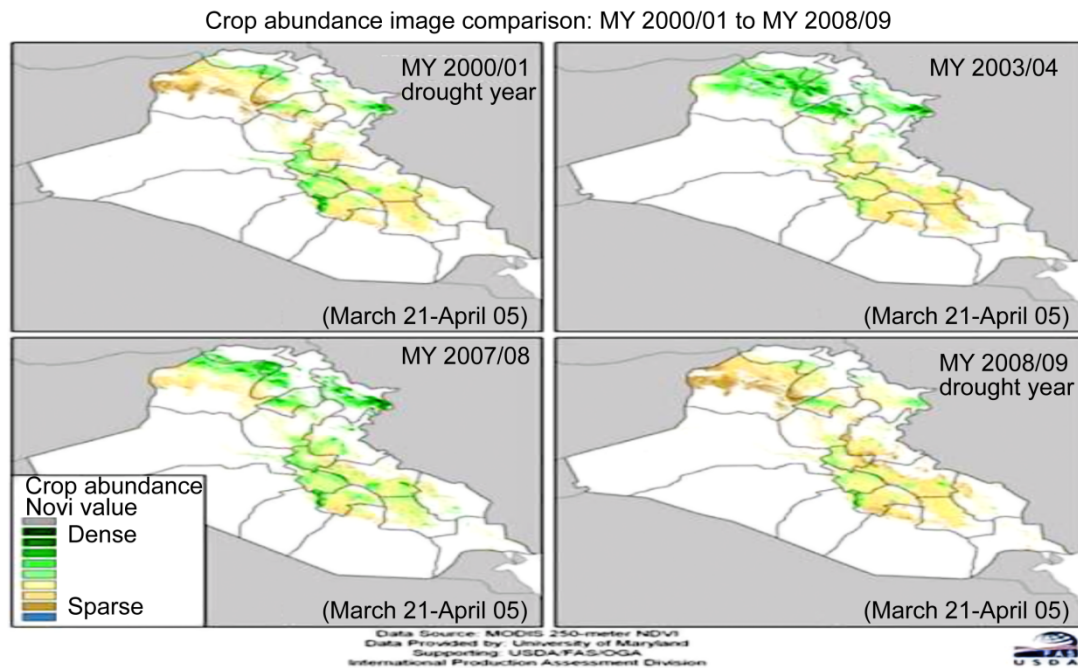
Crop abundance image comparison: MY 2000/01 to MY 2008/09

Fig. 2 MODerate-resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) chart displaying crop abundance over time in Ninewa Province, Iraq.

The capabilities of this project enable next-generation discoveries, advancements, and solutions for commercial, academic, tribal, and governmental stakeholders utilizing high-performance computing applications and services. Users have immediate access to multiple sensors, analytics and 3D visualizations of any monitored region. This vision integrates a secure cyber infrastructure and a near real-time, "on demand" product environment to detect and prevent looming humanitarian crises. This same process can be utilized to address food, feed, energy, natural resource and freshwater needs on a global scale.

Halophytes and Growth Demands:
The anticipated increase in demands for natural resources makes it necessary to exploit Earth's arid and semi-arid landmass that can be can be reclaimed with sufficient nonsaline water and brackish or saline water irrigation. Halophytes grown with brackish waters require from the same to a 40% increase in volume of water as conventionally irrigated crops. With 50% of the population residing within 50 km of a shoreline, halophytes, such as *Salicornia bigelovii* (which thrive in salt water), and salt-tolerant plants seem natural for crop selection [10–12]. Life cycle

analyses (LCA) must be completed for environmental considerations as well as social, economic, conservation, climatic, growth, and development issues applicable to globally diverse localities [13].

Computational Biomass Development:
NASA is attempting to collaborate with outside partners to further algal development and other research into biomass production. Major collaborators include leading biofuel companies such as Seambiotic USA, Evogene, Transalgae, Phycal, and BioEcoTek; Government laboratories such as the National Renewable Energy Laboratory and Sandia National Laboratories; the U.S. Air Force; and multiple academic partners. These partners provide feedback to the GreenLab for optimal biomass growth, control, and development. As previously mentioned, the goal is for this process to be unique to NASA, consisting of numerical models that are validated by experimental studies in the GreenLab, capable of extending productivity to large-scale systems, thereby taking advantage of optimization and cost scaling. Cost remains the main impediment to biomass fueling [14]; the issues of scaling are a close second.

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Potential Biomass Crop Sources

1. *Salicornia* and Mangroves
2. Seashore Mallow
3. Halophyte trees and shrubs
4. Algae Systems
5. Castor Beans

The halophyte *Salicornia* has been studied for food, feed, fuel, and salt retention. Previously mentioned *Salicornia bigelovii* is a leafless annual salt-marsh plant with green joined and succulent stems, indigenous to the United States [10–12]. The oil content that can be extracted from the seed is between 15% and 30%, and its fatty acid oil is comparable to that of safflower oil. Mangroves are well known as coastal water refuges for aquatic life and sources of building materials and fuels. Seashore mallow is a perennial that grows on coastal marshlands or brackish lake shorelines. The seed-oil content is 18%, similar to that of soybeans, and the fatty acid composition is similar to cottonseed [15]. Trees and shrubs can be energy and carbon credit resources. Algae are currently too expensive to be considered as a fuel source, but as a niche market source, algae are very productive and profitable. Castor is a crop for semi-arid to arid lands; it is not a true halophyte, and its climatic adaptation is currently being tested. Because of their high seed-oil content (up to 45%), castor beans are being developed by Evogene as a transportation fuel. The ricin cellulosic material can be denatured by heating and used as an energy

or product source, but is not yet suitable for feed, as trace amounts are toxic. Castor bean oils have been processed to SPK-HEFA (HRJ) aviation fuels, but not yet flown as a 50:50 blend with Jet A-1, as have other biofuels, such as camelina and jatropha [1].

Tables 2 and 3 compare different halophyte and glycophyte sources (e.g., the four major crops rice, soybeans, corn, and wheat) for fuel. Halophytes are generally more expensive to produce; however, they have the advantage of being able to grow on land that has not been previously farmed or forested, whereas glycophytes must be grown on arable land. They also require less fossil fuel for production.

There is a great deal of industry need and opportunity related to alternative fuel sources such as aviation fueling. Projected growth of aviation depends on fueling where specific needs must be met in terms of safety and particulate emissions [19].

In addition to alternate energy sources, our water needs require brackish water recovery. This includes the development of remediation systems which have applications for wetland and shoreline erosion control and remediation including integrating wastewater treatment and recycling with algal production, offering economic advantages while providing a biomass feedstock [20].

Table 2 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 3 Carbon balance estimates based on data from Dr. Carl Hodges [16] and Prof. Ed Glenn [17]		
Sources	Estimate method	Carbon equivalent
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	510 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, 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 any form of fossil fuels to raise halophytes.
[c]25% of 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% [18].

Conclusions

NASA is exploring many species of biomass that target three major goals: not using arable land, freshwater, or food crops. The GreenLab serves as a testing and development site for these crops, and further computational work is being done to analyze their effectiveness. Geospatial intelligence has also been applied to crop work, productivity, and patterns, and should be expanded for further societal applications. As in most cases, science is ahead of production, which is ahead of economics, which is ahead of markets, all of which are ahead of profits. In previous sections, we have discussed the science and production, and steps are being made to bridge economics/markets and production, as well as profitability and societal benefits. Many of the satellite data and modeling techniques described can be applied to societal disasters such as fire, earthquakes, and droughts. These techniques can also be applied to mature and maturing markets and to determine the viability of a market candidate's potential. Biomass sources, geospatial intelligence, alternative fueling, and other areas highlighted in this paper are important ideas to be explored and united in order to target some of today's largest global problems.

Today, distribution of geospatial intelligence in the form of space-based data is spread among global space agencies, science investigators, government agencies, nongovernmental organizations, universities, and private sector organizations. The access and usability of Earth science data through high-performance computing capabilities focus on the future of e-science-based discovery (and access) through technology development that

1. improves and automates the discovery of data
2. improves users ability to find access and download data
3. mines information
4. increases users' ability to utilize multiyear measurements

The GreenLab work supported by geospatial intelligence and current HPC technology can be expanded to support global societal applications.

References

[1] Hendricks, R.C., Bushnell, D.M., Shouse, D.T. (2010) "Aviation Fueling: Greener, Cleaner Approach," ISROMAC13–2010–48, 13th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, HI, April 4–9. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100017410_2010018359.pdf

[2] Parker, John (2011) The 9 billion-people question, The world's population will grow from almost 7 billion now to over 9 billion in 2050. John Parker asks if there will be enough food to go round. The Economist, Thursday, February 24th, 2011 A special report on feeding the world

[3] Edgerton, Mike, Creating Virtual Acres: Near Term Feedstock Opportunities, High Yield Pathways for Production, A center for Evergreen Energy Symposium on Biodiesel Feedstock, Donald Danforth Plant Science Center, St. Louis Missouri www.centergreen.org

[4] 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.

[5] Hodges, C., 2011, Seawater Foundation, private communication.

[6] B.M. McDowell Bomani and R.C. Hendricks, Malik Elbuluk, Monica Okon, Eric Lee and Bethany Gigante, NASA's GreenLab Research Facility: A Guide for a Self-Sustainable Renewable Energy Ecosystem NASA/TP—2011-217208, Internal #E-17888 [see also http://www.youtube.com/user/TEDxNASA#p/c/5/GCOc31fQi7A]

[7] Johnson, Shawana P., Philp, Alex (2011) Successful Global Food Security Inter-Agency Project Leads to High Performance Computing Model to Address Analytical Difficulties Utilizing Multiple Satellite Sensor Datasets. IEEE, IGARRS, Honolulu, Hawaii. July 2010.

[8] http://decadal.gsfc.nasa.gov/index.html

[9] Simons, Rainee N. Microwave & Optical Technologies for Aerospace Communications at NASA Glenn – Past, Present, and Future. Presentation at HBCU/OMI Collaborative Research Symposium, Cleveland State University, July 26–27, 2011.

[10] Anon (1990) Saline Agriculture: Salt-tolerant Plants for Developing Countries. National Academy Press, Washington, DC, USA.

[11] 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.

[12] Ho, M.- W., and Cummins, J., 2009, "Saline Agriculture to Feed and Fuel the World Institute for Science in Society," ISIS Report 24/02/09, The Institute of Science in Society, London. http://www.i-sis.org.uk/SalineAgriculture.php

[13] 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/

[14] Hendricks, R.C., and Bushnell, D.E., 2009, "Synthetic and Biomass Alternate Fueling in Aviation," *Mechanical Engineering Today*. http://www.asme.org/NewsPublicPolicy/Newsletters/METoday/Articles/Synthetic_Biomass_Alternate.cfm

[15] Hendricks, R.C. and Bushnell, D.M., 2008, "Halophytes, Algae, and Bacteria Food and Fuel Feedstocks," Evergreen Energy Symposium, High Yield Pathways for Production: A Center for Evergreen Energy Symposium on Biodiesel Feedstock, 21 November 2008, St. Louis Missouri. www.centergreen.org

[16] Hodges, C., 2009, Seawater Foundation, private communication.

[17] Glenn, E.P., 2009, University of Arizona, Tucson, AZ, private communication.

[18] Dembo, R., 2009, "Keynote Address BCNET Green Technologies for Research and Learning," Zerofootprint, Toronto, Canada. http://www.zerofootprint.net/

[19] Hendricks, R.C. and Bushnell, D.M., 2011, "Particulate Emissions Hazards Associated With Fueling Heat Engines," ISROMAC13–2010–62, 13th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, HI, April 4–7. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100017283_2010018364.pdf

[20] BioEcoTek-Hawaii, 2009. www.bioecotek.com