



“Green Planet Architecture”—A Methodology for Self-Sustainable Distributed Renewable Energy Ecosystems

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Summary

This 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 (naturally, model-assisted, or genetically) 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 report 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 basic energy sources, feed, food, fuel, and waste recovery (recycling); this is natural green planet architecture. With the advent of modern agriculture, food and feed sources have become essentially dependent on four major crops: wheat, maize (corn), rice, and soybeans (Ref. 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 percent over the next 4 to 5 decades. This sets an anticipated peak at 2050 to 2060 of over 9 billion people demanding upwards of 650Q (650×10^{15} Btu, or 680×10^{18} joules) of energy (Ref. 2), with some variations based on future crop selections (Ref. 3). In addition, humanity is facing climatic change, loss of topsoils, increasing desertification with increasing soil salinity, warming oceans, and methane release from clathrate deposits around the world, among other concerns. By the same timeline of 2050 to 2060, half of all freshwaters will be concentrated in the cities (Ref. 4). Earth is 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 data from satellite surveillance and ground sources). 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 and 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 (Ref. 5): (1) the Middle East Cradle Two Project followed by (2) the Med-Dead Project (Mediterranean-Dead Sea Project) with principle and first product, Hope, through abundance instead of scarcity of resources. These principles are closely followed by Prof. Sachs (Ref. 6) who cites the inertia of getting started, not knowing everything, and the necessity of making decisions with uncertainties (taking risks). To overcome these obstacles, design to learn; gain knowledge; seek multiple solutions; and like Hodges educate, assist, and provide ways for communities to work their own way to prosperity.

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 (Ref. 1). Biomass residuals provide land-based power plants for general power and transportation.

This report 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. It will also provide a range of comparative results for the NASA GreenLab program and the potential for global food and 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: (1) the indoor or incubator facility, (2) the outdoor growth facility, and (3) 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 (Ref. 7). 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 (1) not use freshwater, (2) not compete with food crops, and (3) 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 (Ref. 7). Biomass-derived biofuels

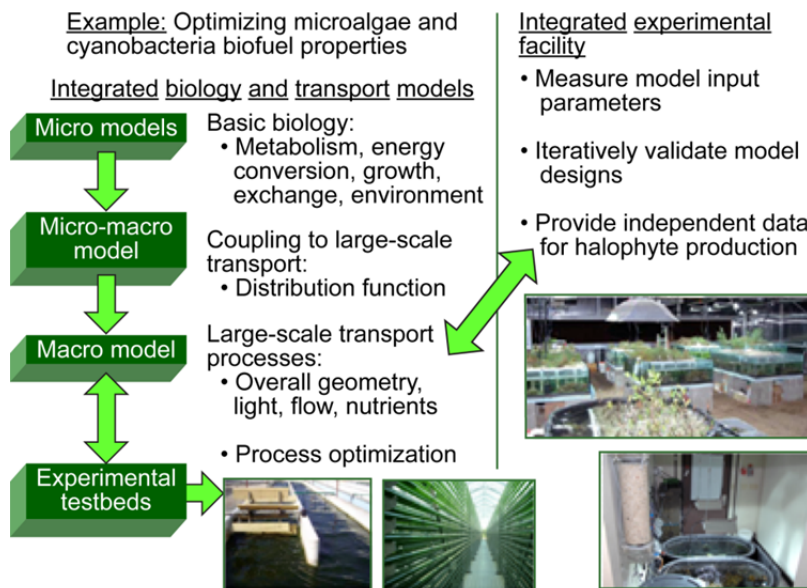


Figure 1.—Integrated iterative experiments and modeling: Efficient NASA-unique approach to production of aviation biofuels (Ref. 6).

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.

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 (Ref. 8).

In addition to the use of Earth observation (EO) remote-sensing satellite imagery, global positioning system (GPS) and differential GPS (DGPS) system use in U.S. agriculture is already well established for precision planting, fertilizing, and herbicide and 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) (Ref. 8). Constructing predictive models of the climate and growth conditions of biomass in remote areas, 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 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 that 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 Oceanic and Atmospheric Administration) to study an effective approach of space-observation systems. Table I summarizes the Decadal Survey missions (Ref. 9) and their possible applications to the model of Green Planet Architecture. Advances in technology further enable data collection and have been proven for water and snow distribution, ocean salinity, and wind patterns (Ref. 10) 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 I).

TABLE I.—NASA EARTH SCIENCE DECADAL SURVEY STUDIES

Satellite	Orbit ^a	Full title of satellite surveillance program	Applications to Green Planet Architecture modeling
ICESat II	LEO, non-SSO	Ice, Cloud, and Land Elevation Satellite	Cloud cover vegetation
SMAP	LEO, SSO	Soil Moisture Active Passive	Biomass productivity
DESDynI	LEO, SSO	Deformation, Ecosystem Structure and Dynamics of Ice	Vegetation, volcanoes, tsunamis, landslides
SWOT	LEO, SSO	Surface Water and Ocean Topography	Oceans and freshwater mapping
HypIRI	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
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	Gravity, 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 and photosynthesis spectra
3D-WINDS	LEO, SSO	Three-Dimensional Tropospheric Winds From Space-Based Lidar	Winds, weather pollution, pollen, and pathogen transport

^aLEO is low Earth orbit; SSO, sun synchronous orbit; and GEO, geosynchronous orbit.

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 (HPC) power; industry has 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. In 2010, the satellite EO 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 (Ref. 8). This project focuses on

- (1) Using an 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
 - (a) Problems of scale
 - (b) Simulation and modeling
 - (c) Difficult or “hard” problems
 - (d) Nondeterministic polynomial time (NP)
 - (e) 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 provide, 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, and so forth.

A successful interagency project (2007 to 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 (EOs) and the models required for processing. Geospatial intelligence utilized in a convergence-of-evidence methodology allowed the analysts to predict a 93 percent 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.

The capabilities of this project enable next-generation discoveries, advancements, and solutions for commercial, academic, tribal, and governmental stakeholders utilizing HPC applications and services. Users have immediate access to multiple sensors, analytics, and three-dimensional 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.

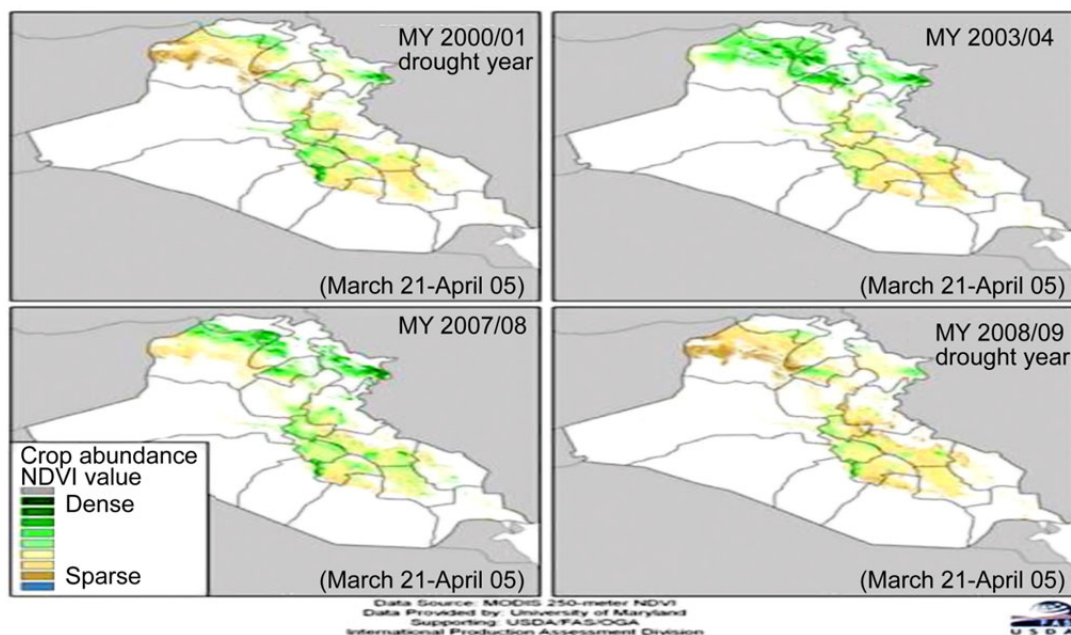


Figure 2.—MODerate-resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) chart displaying crop abundance in Ninewa Province, Iraq, from marketing years 2000/2001 (MY 2000/01) to 2008/2009 (MY 2008/09).

Enhanced Earth to satellite communication systems for emergency and remote applications (e.g., GATR, Ref. 11) lessen the impact of unanticipated events and harsh remote environments. Such communications centers can be rapidly deployed as nomadic bases.

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 reclaimed with sufficient nonsaline water and brackish or saline water irrigation. Halophytes grown with brackish waters require from the same to a 40-percent increase in water volume as do conventionally irrigated crops. With 50 percent 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 (Refs. 12 to 14). Life cycle analyses (LCAs) must be completed for environmental considerations as well as social, economic, conservation, climatic, growth, and development issues applicable to globally diverse localities (Ref. 15).

Computational Biomass Development

NASA is attempting to collaborate with outside partners to further algae development and other research into biomass production. Major collaborators include leading biofuel companies such as Seabiotic 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 for this NASA process is to be globally available, 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 (Ref. 16); the issues of scaling and industry inertia are a close second.

Potential Biomass Crop Sources

The following species are currently under research at the NASA GreenLab as biomass crop sources (Ref. 7):

- (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 jointed and succulent stems, indigenous to the United States (Refs. 12 to 14). The oil content that can be extracted from the seed is between 15 and 30 percent, 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 percent, similar to that of soybeans, and the fatty acid composition is similar to cottonseed (Ref. 17). 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 (e.g., as food supplements, fish food). 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 percent), 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: it is not yet suitable for feed, as trace amounts are toxic. Castor bean oils have been processed to a drop-in aviation fuel (classified as hydrotreated renewable jet, HRJ; hydrogenated esters and fatty acids, HEFA; and also at times as synthetic paraffinic kerosene, SPK) aviation fuels but have not yet flown as a 50:50 blend with Jet A-1 as have other biofuels, such as camelina and jatropha (Ref. 1).

Tables II and III 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. Halophytes 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 (Ref. 22).

In addition to alternate energy sources, water needs require brackish water recovery. This recovery includes the development of remediation systems that have applications for wetland and shoreline erosion control and remediation that includes integration of wastewater treatment and recycling with algae production, which offers economic advantages while providing a biomass feedstock (Ref. 23).

TABLE II.—COMPARATIVE COSTS AND FOSSIL FUEL REQUIREMENTS TO GROW AND HARVEST HALOPHYTES AND GLYCOPHYTES

[From Ref. 18.]

Biomass crop source		Water ^a		
		Fresh	Brackish	Sea
		Production costs, US\$(1990)/mt		
Halophyte ^b	Dry	-----	44	53
	Carbon	-----	175	211
Glycophyte	Conventional	30 to 40	----	----
		Fossil fuel required, kg/mt-carbon		
Halophyte	Salicornia	-----	225	300
Glycophyte	Conventional	130 to 180	----	----
	Corn to fuel ^c	300 to 970	----	----

^aType of water the biomass grows in.

^bProduction costs per dry tonne and per tonne carbon.

^cCorn grown as an energy crop.

TABLE III.—*SALICORNIA* CARBON BALANCE ESTIMATES BASED ON DATA FROM DR. CARL HODGES^a AND PROF. ED GLENN^b

Carbon sources	Estimate method	Carbon equivalent
<i>Salicornia</i> crop water pumping ^c	1.8 m ³ /ha H ₂ O = 18 000 m ³ /crop H ₂ O	
Fossil fuel required	3.8 m ³ /min H ₂ O requires 300 L/ha fuel = 225 kg/ha	
Fuel carbon content	85% C fuel @ 191 kg/ha C	191 kg/ha C
<i>Salicornia</i> oil seed	2000 kg /ha oil seed @ 30% seed-oil @ 600 kg /ha oil	510 kg/ha C
<i>Salicornia</i> straw returned to soil (cellulose)	20 mt/ha @ 70% cellulose @ 40% C @ 5600 kg/ha C	5600 kg/ha C
	Straw C:N @ 32:1 and humus C:N @8:1	1400 kg/ha C
	Optimistic @25% C-sequestration or 1400 kg/ha C Conservative @20% @ 1120 kg/ha C	
<i>Salicornia</i> roots (Hodges)	700 kg/ha C @ 30% @ 210 kg/ha C	210 kg/ha C
Table summary		
Fossil fuel consumed	0.191 mt/ha C	
Seed oil produced (and consumed)	0.51 mt/ha C	
Soil/root sequestration	1.3 to 1.6 mt/ha C	
Net carbon balance ^{d,e}	0.6 to 0.9 mt/ha C	

^aReference 19, private communication.

^bReference 20, private communication.

^cAssume 5-m pumping head (conventional fueled pump).

^dThe wastelands being advocated are mostly in very sunny regions. This means that solar-thermal or photovoltaic systems can be used 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.

^e25 percent of carbon in the atmosphere originates from deforestation, which is a glycophyte issue. This is not necessary for halophytes, a major benefit. The other major atmospheric carbon sources are coal (26 percent), oil (31 percent), and natural gas (15 percent) (Ref. 21).

Conclusions

NASA is exploring many species of biomass that target three major goals: not using arable land, freshwater, or food crops. The GreenLab Research Facility 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 it 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. Previous sections discussed the science and production, and steps are being made to bridge economics and markets with 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 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 (HPC) 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-mined information
3. 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.

Glenn Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 22, 2013.

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14. ABSTRACT This 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 <i>Salicornia</i> , seashore mallow, castor, mangroves, and perhaps <i>Moringa</i> can be modified (naturally, model-assisted, or genetically) 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 report 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.					
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