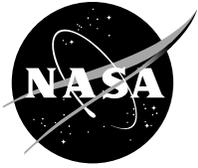


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# Alternate-Fueled Flight: Halophytes, Algae, Bio-, and Synthetic Fuels

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Prepared for the  
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Space Administration

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# Alternate-Fueled Flight: Halophytes, Algae, Bio-, and Synthetic Fuels

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## Abstract

Synthetic and biomass fueling are now considered to be near-term aviation alternate fueling. The major impediment is a secure sustainable supply of these fuels at reasonable cost. However, biomass fueling raises major concerns related to uses of common food crops and grasses (some also called “weeds”) for processing into aviation fuels. These issues are addressed, and then halophytes and algae are shown to be better suited as sources of aerospace fuels and transportation fueling in general. Some of the history related to alternate fuels use is provided as a guideline for current and planned alternate fuels testing (ground and flight) with emphasis on biofuel blends. It is also noted that lessons learned from terrestrial fueling are applicable to space missions.

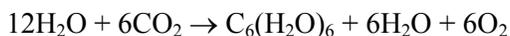
## Introduction

These materials represent an update (to 2009) and additions to the Workshop on Alternate Fueling Sustainable Supply and Halophyte Summit at Twinsburg, Ohio, October 17 to 18, 2007 (ref. 1).

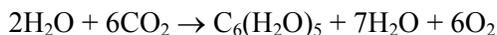
In the brief discussion herein, we will look at reasons why halophytes and algae are being investigated as fuel, food, and energy sources.

To produce biomass fuels, sources of carbon, hydrogen, oxygen, nutrients, and sunlight are required. Basically for fuels we need glucose,  $C_6H_{12}O_6$ , or cellulose,  $(C_6H_{10}O_5)_n$ .

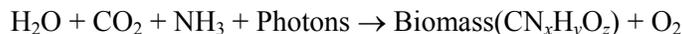
In this respect (stoichiometrically), glucose ties up six waters and six carbons for every unit of glucose produced. When the carbon input is from  $CO_2$ ,



Cellulose ties up five waters and six carbons in form of a polymer:



In round numbers, to make 2 kg of biomass one ties up about 1 kg of water and 3 kg of  $CO_2$  plus nutrients (fertilizer), which complicates matters. So to actually produce the biomass, in addition to water and  $CO_2$ , one needs nutrients and photons (400 to 700 nm)—all in the proper proportions.



This elementary notion of conversion points out that sustainable biomass sources require sunlight, suitable “soils,” nutrients,  $CO_2$ , water, symbiosis, and a lot of care—all of which become major concerns. How do we address these major concerns? Do we pump water from freshwater aquifers, use waste and brackish waters, use seawater, or what? Do we use open-air  $CO_2$  capture, exhaust stack capture, well capture, ponds, reactors, or what? Do we locate in hot dry, hot humid or cool, moist climates for growth or what? Do we pump water,  $CO_2$ , or nutrients to the “fuel factory,” use conventional farming techniques, grow in vertical arrays, or what? Should we really process biomass into fuels at the expense of our food supply or what? Should we permit climate changing deforestation to produce biomass fuels or what?

While these questions are both scientific and political, they also require a paradigm shift in our production and use of energy, water, and food resources.

From this very simple illustration of biomass needs, questions, and major concerns, we will show that common food crops and grasses (some also called “weeds”) have already been processed into aviation fuels in limited quantities. We then show why halophytes and algae are better suited as sources of aerospace fuels and transportation fueling in general. We will then provide some of the history related to alternate fuels use as a guideline to some current and planned alternate fuel testing, both ground and flight, with emphasis on blended biofuels.

We will not discuss, to any extent, the coal-to-liquid (CTL) or gas-to-liquid (GTL) synthetic fueling processing to S8 (synthetic JP8 or now being referred to as synthetic paraffinic kerosene (SPK) and used interchangeably herein) or JP900 techniques, as these have been addressed (e.g., refs. 2 to 6).

## **Glycophyte Crop and Grass Fuels**

Glycophytes are sweet water (freshwater) plants, and they represent common sources of food.

UOP-Honeywell, University of North Dakota (UND), General Electric (GE), and Inventurechem (ref. 7) all have processing technologies to convert common food-based crops and grasses to biojet. Three of these (UOP, UND, and GE) were sponsored under DARPA proposal BAA06-43, for crop and weed conversion to JP8. These common crops include plant nuts, fruits, and seeds, for example, with palm oil, canola oil, and waste fats having potential for processing to S8 (synthetic JP8) (ref. 8). The same process could be applied to a variety of bio-oil-based feedstocks, yet sustainability, transport logistics, and costs require consideration.

It appears that all cited processors have provided fuels to Boeing and the Air Force Research Laboratory (AFRL) for testing, most under the designation of fuel 1, 2, 3, and so forth. Jet fuels will benefit from commercialization of the Department of Defense (DOD) need for JP8 and S8.

The major problems with glycophyte crop and grasses conversion to fuels are

- (1) Lack of sustainable sources, as assessments and processes assume feedstock availability
- (2) Lack of realistic business (commercialization) model for total biomass product
- (3) Competition with demands for (i) arable land that produces food and (ii) freshwater
- (4) Process is energy intensive

Potentially sustainability and commercialization issues could be overcome, yet human energy, food, and water demands are inevitable sources of conflict with using crops for fueling.

## **Halophytes, Algae, and Cellulosic Feedstocks**

In view of the competitive nature of glycophyte fuel sources with the Triangle of Conflicts (energy, water, and food), we seek alternatives in plants that thrive in brackish and saltwater with the ability to survive in arid lands. These represent major concerns that are raised in the Introduction. A nice summary is given by Whitfield (ref. 6).

Of the Earth’s landmass, ~43 percent is arid or semi-arid, and 97 percent of the Earth’s water is seawater. Halophytes are salt-tolerant plants (micro and macro) that can prosper in seawater or brackish waters and are currently common feedstocks for fuel and food (fuel-food feedstocks) in depressed countries. Two types, broadly classed as coastal and desert, can be found in marshes, coastal plains, inland lakes, and deserts. Major arid or semi-arid halophyte agriculture problems include pumping and draining the required high volumes of irrigation water from sea or ocean sources. Also, not all arid or semi-arid lands are suitable for crops. Benefits of halophyte agriculture include freeing up arable land and freshwater resources, cleansing the environment, decontaminating soils, desalinating brackish waters, and carbon sequestration. Sea and ocean halophyte agriculture problems include storms, transport, and diffuse harvesting. Benefits include available nutrients along with ample water and sunlight.

Careful attention to details and use of saline agriculture fuel feedstocks are required to prevent anthropogenic disasters. In theory the potential for fuel-food feedstock halophyte production is high; based on test plot data, it could supply 421.4 Quad, or 94 percent of the 2004 world energy consumption and sequester carbon, with major impact on the Triangle of Conflicts (ref. 9).

While theory points the way, applications and development of these plants become the work of the day. We investigate the work on seashore mallow, a halophyte grass, and some halophyte work in Israel along with a note on other sources for algae oils and conversions along with potential halophyte and algae projects. Many other saltwater-tolerant plant projects are supported through the International Center for Biosaline Agriculture (ref. 10).

### **Halophyte: Seashore Mallow**

Seashore mallow (*Kosteletzkya virginica*) (KV) is among the many saltwater-tolerant plants that grow in the wilds of coastal marshlands or inland brackish lakes. Halophyte plants can remediate soils, capture carbon, free up freshwater, and produce fuel-food feedstocks, with seed production similar to that of soybeans. With the rise of sea levels due to glacial melt imperiling seashores, halophytes and salt water algae are being looked upon as major sources of fuel-food feedstocks (Hendricks and Bushnell, refs. 1 and 9).

Saltwater irrigation of plants is foreign to most agricultural minds, yet Hodges (ref. 11) proposes that a complete community life-cycle system can be developed to grow plants, collect freshwater, free coastal lands for human occupation and at the same time provide all the attributes cited prior (Dr. Carl Hodges, ref. 12).

Schill (ref. 13) reports on the seashore mallow and the work of Dr. John Gallagher at University of Delaware, where in 2007 a 2.5 acre test plot produced 13 bu/acre in a very dry season where conventional soybeans averaged only 24 bu/acre (normal is 40 to 50 bu/acre). The near spherical seeds (fig. 1), similar



Figure 1.—Seashore mallow seeds (ref. 13; see also ref. 14).

in size to wheat seeds, are planted and harvested using conventional farm machinery with adjustments for planter plates and combine operating speeds. The oil content of seashore mallow is also similar to that of soybeans (about 18 percent) with fatty acid composition more like cottonseed.

A very concise summary of the Gallagher and Seliskar halophyte work, background, halophytes merits, and recent successful harvest is seen on their one-page summary (fig. 5 in the appendix) (ref. 14) and a more complete discussion of the seashore mallow (KV) work is found in (ref. 15). See the appendix.

In correspondence with Prof. Gallagher regarding seashore mallow, more agricultural details evolved. Considering about 13 percent scatter-loss before harvest, replicate plot yields were 14 bu/acre. This reasonably good yield was without irrigation on Delaware farmland at a time when the county agent estimate on soybeans without irrigation “at least a 75 percent reduction in normal yield” because of 2007 summer drought. The previous year (2006), soybeans yielded about 40 bu/acre. Prof. Gallagher did not think KV would have benefited as much as beans with freshwater irrigation because of its drought tolerance. The KV would have benefited from salt-water irrigation for two reasons: (1) weed control and (2) a boost in growth from some salt. Very little fertilizer was used on the replicate plot in the spring so as to not encourage the weeds since farming was no-till and they did not have salt water to control the weeds. The older plants grow quickly in the spring, and the plant-canopy closes quickly. Except for the mare’s tail, which is roundup resistant, weeds really did not cause a lot of problems.

An objective of growing seashore mallow is low-maintenance, twice-in-the-field equipment (plant and harvest) biomass production. Higher productivity can result from irrigation, monitoring, insecticides, and nutrient care.

In the first year of Prof. Gallagher’s field trials, a single KV shoot emerges that fills out into multiple shoots the following year and eventually the rows become indistinguishable (ref. 13).

The first time KV was planted, the soil was tilled before planting and eventually weeds took control. The next time, conventional no-till agriculture was practiced: weeds were just sprayed, and KV was planted in the spring. The second year for the no-till crop (Spring 2007), the KV was sprayed and a little fertilizer spun on just before the shoots broke the surface in late April. The next time Prof. Gallagher took machinery to the field, it was to combine (harvest). The third-year plant shoots look very promising and are becoming an established crop.

Prof. Gallagher feels that KV agriculture would thrive on the coastal plains and that the potential for rapid increase in yield from just simple (KV) selection is very good. Future work includes testing within and between the established lines and collecting more samples from the range of genotypes in the wild. When comparing soybeans grown in the 1950s to the modern beans, keep in mind that we do not want to go from today’s KV to a plant that needs the water, fertilizer, and insecticide pampering the sweet corn farms around Delaware require.

### **Halophyte: *Salicornia Bigelovii***

*Salicornia bigelovii*, a leafless annual salt-marsh plant with green jointed and succulent stems, is indigenous to the Arabian Sea coasts of Pakistan and India on the margin of salt lakes and Celon (Sri Lanka) (ref. 16), the U.S. Southwest, and other parts of the world. Similar varieties have been developed and are grown by Hodges (ref. 11) and Yensen (refs. 17 and 18). See also Hendricks and Bushnell (ref. 1) and reference 19.

*Salicornia bigelovii* (author’s hybrid variety sos-10) seed collected from field trials in five areas on the Arabian Sea coast were processed by hexane extraction, producing 27.2 to 32.0 percent oil. The oil acid content is given in table I; it has a refractive index of 1.4680 and a density 0.9054 g/cm<sup>3</sup>. It can be seen many parameters were found to be quite compatible with those of safflower oil, which had slightly higher oil (4 percent), fiber (2 percent), and ash (0.5 percent), with 2 percent lower protein (ref. 16). The safflower seeds were from four different harvests (MSDS oil density, 0.921 g/cm<sup>3</sup>).

TABLE I.—PERCENTAGE ACID CONTENT OF SEED OILS  
[After ref. 16.]

Fatty acids	Salicornia bigelovii	Safflower	Soybean <sup>a,b</sup>	
			Commercial	Refined
C16:0 palmitic	7.52±0.24 (7.00–8.50)	6.70±0.25 (6.03–7.81)	11	11.76
C18:0 stearic	1.45±0.07 (1.24–1.69)	2.50±0.10 (2.05–3.00)	4.1	4.64
C18:1 oleic	13.42±0.56 (12.33–16.83)	12.30±0.70 (9.50–15.70)	22	24.98
C18:2 linoleic ω <sup>6</sup>	75.50±2.04 (74.66–79.49)	78.00±3.50 (73.60–80.04)	54	55.41
C18:3 linolenic ω <sup>3</sup>	1.98±0.09 (1.50–2.30)		7.5	3.8

<sup>a</sup>reference 20, <http://chinese-school.netfirms.com/soybean-composition.html>, soybean commercial products.

<sup>b</sup>reference 21, [http://www.scielo.br/scielo.php?pid=S0103-90162005000300014&script=sci\\_arttext](http://www.scielo.br/scielo.php?pid=S0103-90162005000300014&script=sci_arttext), soybean refined oil.

Both salicornia bigelovii and safflower seed have greater oil content than cotton (15 to 24 percent) and soybeans (17 to 21 percent). Salicornia bigelovii saponin detoxification can be accomplished by pre-extraction soaking the seed in 1% NaOH permitting use of protein residual as animal feed.

### Sustainable Halophyte Grasses (*Distichlis Spicata*)

Many arable land areas are at risk or affected by salinity, due to shallow or rising water tables, underground pumping, and climate changes. For example, in the year 2000 Australia had an estimated 5.7 million saline-affected hectares, with potential to reach 17 million hectares (170 000 km<sup>2</sup>) by 2050 (ref. 22). According to Sargeant, Tang, and Sale (ref. 23), these sites are generally regarded as degraded from a chemical and physical perspective, with high concentrations of dissolved salts within the root-zone, and are commonly waterlogged. There are very few ways that landholders can use these degraded areas for commercial use. In most cases, they are abandoned and lost from the farming system.

*Distichlis spicata* (fig. 2) is the only C4 species most suited to the high temperatures and high-radiation regimes during the warm summer months of southern Australia (ref. 23). This species not only has the ability to grow and spread in saline waterlogged soils, but it also produces valuable green feed in moist saline discharge soils during the summer period. Such forage has real value for a mixed farming system.

Sargeant, Tang, and Sale (ref. 23) have found that *Distichlis spicata* var. yensen-4a is sustainable in saline and seasonally waterlogged sites and becomes a productive option for landholders as a way of utilizing an otherwise abandoned unproductive land. They found significant improvements in soil conditions for *Distichlis spicata* (var. yensen-4a (NyPa Forage) is a halophytic pasture grass) growing in saline discharge. Fields planted 2 to 8 years were investigated at three different sites. The fields have been under landowner observation, where the largest improvements are found in the 8-year sward within soil depths of 0.1 m. Soil measurements included saturated hydraulic conductivity, water-stable aggregates, root length and dry weight, electrical conductivity, pH, and soil nitrogen and carbon. Results showed a 12-fold increase in saturated hydraulic conductivity, with increases in both nitrogen and carbon without noticeable increases in salt accumulations in the rooting zones. The magnitudes varied between soil type, age topography of field. The baselines were adjacent no-grass zones.

These improvements are consistent with the results of research conducted in Pakistan, where the salt-tolerant Kallar grass (*Leptochloa fusca*) was shown to improve the physical properties of saline-sodic soils (refs. 25 and 26).

Seashore saltgrass is also native to the United States.



Figure 2.—Halophyte grass (*Distichlis spicata*), reference 24.

### **Further Halophytes and Algae Research**

A variety of halophyte and algae work is being carried out in Israel with a recent biomass and biofuels meeting held in Haifa, Israel. The meeting was entitled “The Energy Forum—Energy from Bio Fuels (16.10.2007)” held at the Samuel Neaman Institute, Haifa. There were no proceedings, but topics of discussion are provided (ref. 27).

In communications, Prof. Amram Eshel (ref. 28) (and Prof. Yoav Weisel), Tel-Aviv University Department of Plant Sciences, writes that they are studying the potential of desert halophytes as sources of biofuel or biodiesel. They started testing certain desert plants mentioned in the literature as potential biodiesel plants. The basic idea is to develop methods for biofuel or biodiesel production that will not compete with agricultural resources devoted to food production. Therefore, they search for desert halophytes that could be grown on marginal soils using marginal quality waters and serve as sources of biofuel or biodiesel. In the deserts of the world there are large areas that are not currently under cultivation, and saline or reclaimed water would enable arid land productivity. Even the so-called second-generation plants—Castor beans and *Jathropha*—will not grow well under such conditions.

They have also achieved over 25 t/ha/y dry tree biomass production under desert conditions and reclaimed water irrigation. Until efficient methods for cellulose degradation are available, these could be used for earning Clean Development Mechanism (CDM) credits by afforestation projects in third-world countries. It may turn out that even though algae production is much greater than that of halophytes, the investment costs could mean that halophytes would be better? The algae issues are very nicely covered by Prof. Ben-Amotz (ref. 29).

### **Algae Commercial Food, Medicine, and Fuels-Potential**

Algal processors need to know the process and methods to reduce costs as cited per the model in reference 29. Inventrechem.com has an agreement with Seambiotic and Israel Electric. AlgaTech, Israel (ref. 30) and Earthrise Nutritionals LLC, Calipatria California USA, (ref. 31) are commercial food suppliers with a large industry in Indonesia supplying food supplements to Japan.

A nonfood algal production analysis presented at the San Francisco Algal Summit, Ben-Amotz (ref. 29) shows 50:1 cost reduction using CO<sub>2</sub> stackgas. Ben-Amotz cites FGD Power Station, Ashkelon, Israel (431 mt CO<sub>2</sub> /hr, 10 344 mt CO<sub>2</sub> /day) with average mid-large station at 4000 mt CO<sub>2</sub>/hr. In round

numbers, 2 kg biomass requires 1 kg water and 3kg CO<sub>2</sub> plus maybe up to 1 kg nutrient fertilizers (questionable). For complete capture and stoichiometric conversion, a natural-gas-fired 4000 mt-CO<sub>2</sub>/hr powerplant has the potential to produce 2660 mt biomass/hr while consuming 1330 mt water/hr (16 000 mt biomass, 7980 mt water, and about 8000 mt nutrients, assuming 6 hr/day production).

In a Vertigro system, a flat-surface greenhouse is essentially turned into a series of vertical surfaces. Plants can be grown in containers attached to vertical transparent sheets suspended from an overhead conveyor system. In the algal growth system, the suspended sheets become vertical multipass horizontal tubular plastic-encased bioreactors. The fluid containing algae is pumped up, and it cascades down through the series of horizontal tubes with a high degree of mixing at the end turnaround and entry to the next horizontal passage. The arrays are spaced to allow maximum light penetration and flow rates, CO<sub>2</sub>, and nutrients adjusted to provide optimum algal growth. The algae are reported to consume up to 90 percent their weight CO<sub>2</sub> with 50 percent dried weight as lipid or oil content. The system conserves both land and water, as little or no water is lost to evaporation and is somewhat immune to foreign algal strains. Estimates are that a fully operational plant may produce to 4000 bbl bio-oil/acre/year, three orders of magnitude more than soybeans (refs. 32 and 33). A similar scaleable modular photobioreactor system concept is discussed by Kodner (ref. 34).

The 2007 Algae Biomass Summit in San Francisco was like a road map of potential ways, along with partnerships, to make cellulosic and algal oils for processing into JP8 (ref. 35).

### **Other Research and Developments**

North Carolina State University has developed a process to turn virtually any lipidic compound (e.g., algae) into fuels for aviation (includes oil from algae) (ref. 36). The process is licensed to Diversified Energy Corp. (ref. 37) of Gilbert Arizona. Principles in the North Carolina group include Profs. William Roberts, Henry Lamb, Larry Stikeleather, and Tim Turner of Turner Engineering in Carrboro, N.C.

Aquaflow Bionomic Corporation (New Zealand) (ref. 38) harvests algae directly from settling ponds with significant oil yields. Similar efforts are found at Solix Biofuels and Colorado State University (ref. 39; see also ref. 40) for commercializing algae to biodiesel. Solix photobioreactors and ponds are based on the National Renewable Energy Laboratory (NREL) Aquatic Specie Program. Both Aquaflow and Solix should be massively scalable.

GreenFuel Technologies Corporation (ref. 41) and Arizona Public Service Company (APS) (ref. 42) were able to grow algae successfully at APS's Redhawk natural gas power plant. GreenFuel Technologies also has an agreement with Institut fur Getreideverarbeitung Potsdam (ref. 43) Germany for algae production.

Trident Exploration Corp. (ref. 44) and Menova Energy Inc. (ref. 45), are to develop a photobioreactor. Menova systems are applicable to photovoltaic, solar thermal, or light piping.

The National Science Foundation (NSF) has published a roadmap for the production of hydrocarbon biofuels, liquid transportation fuels derived from lignocellulosic biomass that are close analogs to their petroleum-derived hydrocarbon counterparts (refs. 46 and 47).

The Bali Indonesia Red Cross volunteers are planting tens of thousands of mangroves to inhibit costal soil erosion (ref. 48). It would be good if the project also envisioned aqua- and agriculture similar to that of Hodges (ref. 11) to enhance regional development, conserve freshwaters, and provide energy and food to fracture the Triangle of Conflicts (energy, food, and water).

### **Potential for Dead Sea and Death Valley Community Projects**

Several prospective algae-oil consortiums are investigating the nutrient rich Sultan Sea in California for algae growth, there other areas that could benefit from seawater agriculture and aquaculture. Basically most areas near oceans or seas could benefit from the work of Hodges (ref. 11).

## Cellulosic and Algal Fuel Goals

### Cellulosic

- Phase I: 30-percent conversion efficiency and <\$3/gal (500 ml test samples in 6 to 8 weeks)
- Phase II: 50-percent conversion efficiency and <\$2/gal seeking <\$1/gal 4000 liter fuel, scalable to 50M gal/yr
- Note: U.S. Department of Agriculture will have a say, as corn stover for example cannot be taken from field as it builds soil, prevents erosion, and offers wild animal protection

### Algal

- Genetic engineering not part of program...unless well known and established product
- Phase I: 100 liters fuel, \$2/gal demonstrated (500 ml test samples in 6 to 8 weeks ?)
- Phase II: 4000 liters fuel, \$1/gal demonstrated, scalable to 50M gal/yr
- Note: open ocean farms may be impacted by international law

Figure 3.—Basic DARPA proposal BAA08–07 goals.

In the conceptual reclamation of the Dead Sea by sea-water pumping (ref. 49), the concept of Hodges (ref. 11) could readily be adapted to supplementing the Sea with even more make up water, freeing up freshwaters, and building seashore communities. Rather than harvesting minerals these communities could enable harvests of food and fuel feedstocks from halophytes and algae resulting in sustainable independence of energy, water, and food when combined with solar photovoltaic (PV) systems (e.g., ref. 50).

A similar project with sustainable growth of halophytes and algae could be envisioned for Death Valley 282 ft (86 m) below sea level in southwestern United States. The necessary water could be supplied by pumping seawater through a suitable land route or combined with gravity feed through tunneling. Both the Dead Sea and Death Valley could use similar pumping and gravity feed systems. In both cases one could learn how arid land plants survive, from plants unique to the harshest of deserts. (As a note, Los Angeles freshwater comes from three aqueducts, one of which is the Sierra Nevada-Los Angeles Aqueduct).

Although there are many commercial and potential sources for halophytes and algae, the cost and sustainable productivity are major factors. For algae the production can be very high, at a current cost of about 10× that of conventional biomass oils. This issue is being aggressively addressed by many algae proponents and DARPA proposal BAA08–07 (fig. 3) (ref. 51), which addresses commercialization of both algae and cellulosic biomass conversion to JP8. The essential requirements of the BAA directed toward sustainable commercial production of JP8-biojet are set forth as goals, not absolutes.

## Cellulosic Conversion to Fuels

DARPA BAA08–07 also seeks biomass fuels from algal and cellulosic material feedstocks (ref. 51). Evers Tech, Indiana-Purdue Lugar Energy Center (Mike Hudson, Andrew Hsu, Richard Wagner principals) (refs. 52 and 53), and Ventech Engineering (ref. 54) are working on a process for converting waste materials to biofuels as originally cited by Evers Tech in Atlantic Greenfuels (ref. 1). The following list provides examples of wastes with potential conversion to energy-fuel resources:

- (1) Local
  - livestock waste
  - landfill waste
  - sewage sludge waste
  - algal waste (ponds ? + summer pond algae)
- (2) Regional
  - solid wastes (municipal)
  - forest wastes
  - tire wastes
  - others classified above under Local that can be shipped inexpensively

A recent alliance between ICM Inc., and Coskata, Inc., has set an ethanol price target at \$1/gal with plant production in 2010. Coskata (ref. 55) is a next-generation ethanol developer using biological fermentation technology, and ICM (ref. 56) designs and constructs commercial ethanol plants. The Coskata three-step conversion process turns cellulosic material and carbon based feedstocks into ethanol. The patents are claimed and may be similar to those issued to University of California (UC), Berkeley, and Evers Tech. Using patented microorganisms and efficient bioreactor designs, Coskata uses a unique three-step conversion process that turns virtually any carbon-based feedstock, including biomass, municipal solid waste, and other agricultural waste, into ethanol (ref. 57). See also cellulosic and processing work of Downing (ref. 58).

Combining cellulosic feedstocks along with halophyte and algal feedstocks and their oils will enhance total energy cycle efficiencies and in some cases prove more efficient than delaying harvests to extract the oils. For example in a very wet or very dry season, seed oils may be too expensive to harvest yet biomass could salvage the agriculture expenses.

Cellulosic and biomass conversion is being investigated by the Joint Bio-Energy Initiative (JBEI), a consortium of UC Berkeley, UC San Francisco, UC Davis, Stanford University, Lawrence Livermore National Laboratory, and Sandia National Laboratory with potential for State support (ref. 59).

The Department of Energy- (DOE-) JEBI bio-energy proposal lead is Jay Keasling of the Lawrence Berkeley National Lab (LBNL). Prof. Keasling is director of Berkeley Lab's Physical Biosciences Division and an expert in synthetic biology, and UC Davis's Prof. Rodman is an expert on rice genome.

The DOE also supports two other centers, the BioEnergy Research Center (Oak Ridge National Laboratory is the lead center) and the Great Lakes Bioenergy Research Center (University of Wisconsin-Madison lead and with Michigan State University).

The DOE's Samuel Bodman feels these centers will provide cellulosic ethanol technology for standard crops, crop Stover and wastes by 2012 to decrease petroleum-based gasoline consumption by 20 percent in 10 years (refs. 59 and 60).

The JBEI research is housed within a single location with major objectives: development of feedstock's, feedstock's conversion to sugars and aromatics, conversion of sugar and aromatics to biofuel, data analysis and imaging, and experimental natural and synthetic biology. Major areas of investigation include plant cell synthesis (genomics, lignin polymerization, enzyme, and chemical depolymerization), pretreatment methods (lignocellulolytic enzymes microbial communities nurtured for degradation of lignin), conversion of sugar monomers from depolymeriztona or lignocellulosic biomass of selected feedstocks, and yeast pathways.

Many of these areas are also being worked on at NREL; however, whereas ethanol is the initial fuel molecule of JBEI interest, butanol, isopentanol, hexadecane, and geranyl decanoate ester are potential substances for biodiesel and biojet fuel (refs. 59 and 60).

The NREL is also developing processes and genetically engineered microorganisms to more efficiently convert starch, sugar crops (sugarcane), and cellulosic biomass principally to ethanol. In the presence of new catalysts, vegetable oils derived from high-lipid, genetically modified seed react with methanol or ethanol produce biodiesel. Other prolific biomass such as algae can also provide the oils that can be further refined to biojet (ref. 61).

Many of the production processes are self-limiting in that they develop inhibitors (too much alcohol) or byproducts that are toxic to the conversion of cellulosic ethanol, requiring significant investments in research. Biochemical pretreatment methods include hydrolysis and fermentation, which involve chemicals, enzymes, and fermentative microorganisms. The thermochemical processes requires catalysts and process optimization tradeoffs between pressure and temperature, for example, in hydrolyzing hemicellulose, where in a dilute acid pretreatment is used to fracture the sheath that surrounds the cellulose and lignin. A proper mix of enzymes can enhance the process in treating stover for example and new yeasts are now available (ref. 62). The Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI) shares production information (refs. 63 and 64). Among the new tools being developed is a molecular dynamic biomass model (cellulose-cellulase system) based on surface imaging

visualizing the biomass structure and near-infrared spectroscopy to provide biomass composition (ref. 62).

With such recent advances in cellulosic wastes conversion, it is suggested that local biomass and alternate fueling journals be closely monitored along with the activities of Atlantic Greenfuels (ref. 1).

The lessons we learn in synthetic and biomass developments for terrestrial fueling, including water conservation and food production, are applicable to space missions, where very harsh environments will require processing and reprocessing of wastes as sources of energy. While we have much to learn even about our own Earth habitat, knowing how to use algae, halophytes, and symbiotic bacteria (e.g., cyanobacteria) on space missions will enable greater mission independence and potential for survival (perhaps even a space colony?). Such efforts require experimentation and mission demonstrations some of which could be carried out by the NASA Life Science Group (ref. 65). We suggest a close partnership with these groups in order to integrate knowledge gained in alternative fueling for aviation.

Dr. Nicholas Yensen, in conjunction with Agriculture Research Services U.S. Salinity Laboratory of the United States Department of Agriculture and NyPa International, has assembled a searchable database of halophytes and salt-water plants and their uses (ref. 66). The Web site also contains an information section with a wealth of resource books and papers. Other biomass oils and productions characteristics are provided in references 67 and 68.

Whitfield (ref. 69), summarizing the Future Fuels Aviation Conference in London on April 14 and 15, 2008 (ref. 70), breaks down the fueling issues according to consumer (upper), supplier (middle), and producer (lower), (table II) The roles played by each are in turn driven by consumer demands, some of which are illustrated in table III. Consumer demands reflect those of the public community as a whole and in this case in response to climatic changes associated with environmental affects of aviation emissions.

We now turn our attention to applications of alternative fueling with respect to aviation and will provide some background and recent, current, and planned activities.

TABLE II.—ALTERNATE FUELING: ROLES OF CONSUMERS, SUPPLIERS, AND PRODUCERS

Tier	Represented by	State
Upper	Airlines, aircraft manufacturers and those representing demand	A straight forward role of encouragement, facilitation, and leadership.
Middle	Those at the interface: fuel developers and converters, engine companies, and the certification community	Under stress, being pressured from both sides to deliver, each with roles to play in an old game being played with new players, and possibly new rules.
Lower	Feedstock suppliers	Keen to offer their proposals—but seeking agreement that their product is sustainable

TABLE III.—ROLES OF CONSUMER DEMANDS REFLECT PUBLIC COMMITMENT TO CLIMATE CONTROL

Criteria	KLM <sup>a</sup>	Virgin <sup>b</sup>
Water	No use of drinking water	Should not divert water away from food agriculture or drinking water
Deforestation	No deforestation or forced relocation of people	Should not lead to deforestation
Soil	No soil degradation	Should apply sustainable agronomy principles (e.g., equivalent of FSC <sup>c</sup> )
Land and food	No competition with food or use of arable land	Should not conflict with staple food crops
Other	No negative influence on biodiversity	Should have lower life cycle carbon emissions

<sup>a</sup>Refers to KLM Royal Dutch Airlines, reference 71, [http://www.klm.com/travel/klm\\_splash/splashpage.html](http://www.klm.com/travel/klm_splash/splashpage.html).

<sup>b</sup>Refers to Virgin Atlantic (Airlines), reference 72, <http://www.virgin-atlantic.com/en/us/index.jsp>.

<sup>c</sup>FSC is Forest Stewardship Council, reference 73, [www.fsc.org](http://www.fsc.org).

## Alternative Fueling Demonstration Projects

The use of alternate fueling is neither new nor novel, yet the feedstock and fuel conditioning can be. Prior to the discovery of cheap oil, synthetic fuels and lubricant plants dotted the U.S. eastern landscape. In the late 1930s, the war machines realized the necessity of secure sustainable fueling and developed new processes for making synthetic fuels based on ample supplies of coal. Synthetic fuels have been used to power both piston and gas-turbine engines. The point is that synfuels powered aircraft over 60 years ago without adverse effects, but the “know-how” technology has been lost.

### Historical Ground and Flight

Prior to the 1860s, some 50 coal-to-liquid (CTL) fuel plants produced oil, gas, grease, and waxes for Americans. Boston had five low-temperature carbonization (LTC) plants. The Titusville Drake well in 1859 ushered in cheap oil, however, that by 1873 forced the CTL plants to shut down (refs. 74 and 75).

Von Ohain’s 1939 He.S3B jet engine was designed for gasoline, whereas Whittle’s 1941 (Gloster/Whittle) engine used illuminating kerosene. Some advocates claimed that jet engines could run on any fuel from whiskey to peanut butter (oil) (refs. 76 to 78). (See also recent biofueled jet flight, ref. 79.)

In early 1944, 25 synfuel plants produced more than 124 000 barrels per day largely from coal. By February 1945, however, that level had “bombed” to 620 bbl/day. Ninety-two percent of Germany’s aviation gasoline came from synthetic fuel plants.

In 1944, General George Patton used ersatz gasoline (substitute gasoline), synthetic fuel manufactured from coal, to operate his armored vehicles (ref. 80).

In November 1943, Congressman Jennings Randolph flew from Morgantown West Virginia to Washington, DC, in a synfueled airplane inaugurating a U.S. synfuels program in 1944 (ref. 80).

In 1944, Whittle’s kerosene fueling approached standardizing with the specification for JP-1 with  $-60\text{ }^{\circ}\text{C}$  freezing point. Because of the limited availability of such fuels, mixtures of naphtha and kerosene distillates came into use and eventually evolved into military JP8+100 and commercial Jet-A.

JP-7 is an example of a nondistillate blended fuel (ref. 81). It is a very clean blend of hydrocarbons, low in aromatics (typically 3 percent), with a low vapor pressure and excellent thermal oxidative stability and nearly devoid of the sulfur, nitrogen, and oxygen impurities. The mixture consists of alkanes, cycloalkanes, alkylbenzenes, indanes/tetralins, and naphthalenes, with addition of fluorocarbons to increase its lubricant properties. With  $<3$  percent highly volatile aromatics like benzene or toluene, triethylborane (TEB) has to be injected through the engine and afterburner in order to light-off the combustor.

### Recent Flight

Prof. Expedito Parentee, Tecbio, Fortaleza Brazil, from 1980 to 1984—The first applicability trials using biodiesel and the development of PROSENE, an alternative combustible lipofuel (vegetable oil) used as an alternative to aviation kerosene. The first flight was taken using pure biokerosene in an EMBRAER turbobiokerosene turboprop-powered aircraft, between the cities of São José dos Campos dos and Brasília. This accomplishment was considered to be of strategic national interest, and the results could not be published (ref. 82).

Dr. Max Shauck (at that time, the Baylor Institute Director) reported that in the 1990s, Baylor University in Texas Institute for Air Science flew a Beech King Air turboprop for 60 hr with a Pratt & Whitney Canada PT6A running a 20:80 blend of biodiesel and kerosene and the other, 100 percent Jet-A. The aircraft was flown to 25 000 ft (7600 m) and appeared to have no problems (ref. 83).

In response to the 1980s oil embargo, South Africa picked up the German Fischer-Tropsch (FT) technology, and Sasol became the leading producer of synfuel from coal and more recently from gas. South African Airlines used blended fuels, and international aircraft flying in and out of Johannesburg

Airport were refuelled with 18 to 25 percent blends and in some cases to 50 percent of Jet-A and synfuel. There are no reported (public) maintenance or aircraft limitations due to the fueling regime.

Cliff Moses, Southwest Research Laboratories, has tested Sasol synjet and found these fuels to behave similar to Jet A and certification to be eminent (ref. 84). On April 12, 2008, Sasol Ltd. received approval from the global aviation fuel specification stakeholders to supply airlines at 100 percent CTL synjet fuel. Sasol's high-temperature Fischer-Tropsch (HTFT) is used to convert coal into four primary streams: isoparaffinic kerosene; heavy naphtha kerosene with 10 percent aromatics; light distillate #1 with 24 percent aromatics; and naphtha #2 with 39 percent aromatics. Synjet is low in sulfur (<5 ppm) with 8 to 25 percent aromatics (to protect fuel line sealing) (refs. 85 to 87). Aircraft ground emissions testing is planned for 2008 to 2009. (Note that the military specification MIL-DTL-83133F approves both CTL and GTL fuels, see below.)

See also the subsequent section on Airbus-Quatar Airways flight test where GTL fuel was used.

On 11 April 2008, military fuel specification MIL-DTL-83133F (ref. 88) was released, which specifically states in section 3.1.1 "...up to 50 volume % of the finished fuel may consist solely of Synthetic Paraffinic Kerosene (SPK) derived from a Fischer-Tropsch (FT) process meeting requirements of Appendix A..." The blend is designated as JP8/SPK. The specification allows for SPK to be derived from a FT process without feedstock restraints, which is important for fuel suppliers for two reasons: (1) feedstocks could include GTL and CTL, as well as ShaleTL, TarSandTL, and biomass as long as the liquid fuel satisfies the FT requirements and meets the specifications set forth in MIL-DTL-83133F, Appendix A; and (2) commercial aviation has a propensity to follow military designations because many of the engines have similar cores. The downside of this is it will be difficult to certify other fuels and engine configurations and aircraft that would use these fuels.

While commercial aviation could adapt MIL-DTL-83133F, currently (2008) there is no world-wide consensus on specifications on alternate fueling for commercial aviation. Roots for the alternate fueling for commercial aviation program grew out of discussions between NASA and Boeing. Subsequently, FAA and Boeing inaugurated meetings that later became the Commercial Aviation Alternate Fuels Initiative (CAAFI) group (ref. 89), which is also supported by military aviation. The Air Transport Association of America's (ATA) Earth Day release underscores its commitment and principles for the adoption of alternative fuels (see also Whitfield (ref. 69) and tables II and III) while entrusting CAAFI as the focal point to address sustainable secure fuel supplies with price stability (ref. 90).

### **Current and Planned Testing**

*First certification of Synthetic Fuel JP8 Blends:* On August 8, 2007, a B52H was certified to fly on JP8 + synjet blends (50:50). There are engine and aircraft maintenance records but unavailable. (For reports contact William Harrison and James "Tim" Edwards, Edwards, James T Civ USAF AFMC AFRL/RZTG, AFRL Wright Patterson Airforce Base, Ohio (James.Edwards@WPAFB.AF.MIL).

The United States Air Force (USAF) plans tests with C17 and other aircraft in a manner similar to B52H flight and ground tests with certification of all aircraft by 2010 on blended fuels; the B52H is powered by Pratt & Whitney TF33 engines (refs. 79, 83, and 91 to 96). (Recall that commercial flights in and out of Johannesburg have flown uncertified synthetic-Jet-A blends for many years.)

#### ***First Biofueled Jet Flight***

On October 2, 2007, Green Flight International's Chief Pilot Carol Sugars and Douglas Rodante successfully completed the world's first biofuel jet aircraft flight (ref. 79). The test program included various blends of Jet-A and biofuel up to 100 percent biofueling. They flew their L-29 aircraft at 25, 50, and 100 percent biofuel to 17 000 ft (5.18 km) without difficulties. The Czechoslovakian L-29 is a retired military aircraft. The powerplant, Motorlet M-701C, is an early-generation single-stage centrifugal compressor and single-stage axial-flow turbine capable of operating on different fuels including heating oil (refs. 92 to 94). The L-29 airframe underwent recent certification along with a new engine (25 hr).

The aircraft has heated fuel tanks that maintained 24 °C with an environmental ambient at -4 °C; an additive to the fuel enhanced the margin of safety by 20 °C. The biofuel was recycled restaurant oils consisting of assorted cooking oils such as canola, sunflower, palm, soy, and so forth (ref. 95) with no reported flight difficulties, yet the time at 17 000 ft (5.180 km) was short. The fuels were preblended and loaded into the aircraft. The fuel filtering indicators, indicative of fuel plugging, never even blinked.

One of the major issues, as with the B-52 flights, centers on sealing. Rubber “O” rings are used in the fuel pump, and neoprene is used in some lines. Here the issues are degradation and lack of aromatics for swelling, which are added to synfuels to maintain seal swell. Fuel leaks can lead to fires in areas not covered by extinguishing equipment or air fire-walls in military aircraft. These issues are being watched carefully as will be fuel injector coking and component wear.

In general, biofuels and blends are more viscous than Jet-A, and at power levels less than 55 percent the L-29 combustors ran rich with higher smoke emissions. Ground and flight testing on the L-29 was carried out at 25, 50, and 100 percent biofueling where it was noted that smoke emissions increased with increased biofueling. These results differ from those cited by Dr. Max Shauck (ref. 83) for the PWC-PT6A Beech King Air: Shauck noted a decrease in smoke with increase in biodiesel. These inconsistencies may be due to the fuel refining, Shuck’s biodiesel and Sugars-Rodante’s recycled restaurant oil. In an effort to operate the L-29 with a lower fuel-to-air ratio (*f/a*) at low power, the fuel nozzles will be changed with smaller injection holes. Future flight plans call for a U.S. cross-country flight in early November 2007, followed by an around-the-world flight of 22 000 miles, most likely in a Learjet or Gulfstream.

At the Paris Air Show, CFM displayed their CFM56-7B green engine program with methyl ester fuel blends (no hard data has been released). The CFM56-7B used on the Boeing 737 models has had an initial test in which it ran off a mixture of 30 percent biofuel (methyl ester) and 70 percent standard jet fuel (refs. 96 and 97).

On October 22, 2007, a C-17 Globemaster III took off from Edwards Air Force Base in California on a successful 4-hr flight using a blend of synthetic and JP8 fuels. This is the first time a C-17 using PW 2040 engines has flown using a FT JP8 fuel blend in all four tanks. On October 19, 2007, the C-17 flew with the fuel blend in one tank to validate engine and fueling performance. The C-17 and PW 2040 turbofan engines are similar to the PW 2037 commercial turbofan-engines used in the Boeing 767, for example. The mission included ground operation of the auxiliary power unit and evaluations over the C-17 operational envelope (ref. 98). The synfuel was supplied by Shell UK. Shell’s commercial low-temperature FT GTL plant at Bintulu, Malaysia, open in 1993, produced 14 700 barrels per day (in 2005) of high-quality liquid products (ref. 99).

The USAF is still on track for fleet certification by first quarter 2008, with all USAF aircraft certified by 2011. Note that 50-50 blends provide sufficient aromatics from the JP8 to contain fuel swell. (The alternate fuel specification is now at 8 percent aromatics, and it may be relaxed if 100 percent synfuel tests prove satisfactory.)

The AFRL Arnold Air Force Base in Tullahoma, TN, is also planning testing sequence with alternate fuels.

Pratt & Whitney (Florida) and NASA will be in a co-operative venture to test engines with blended fuels. “Flight International” reports that NASA Glenn is going to purchase a PWC308 engine for synthetic fuels testing. The basic engine configuration is a single-stage fan, driven by a three-stage low-pressure turbine, supercharging a four-stage axial, single-stage centrifugal high-pressure compressor, driven by a two-stage high-pressure turbine. An annular combustor is featured. Some versions have an unmixed exhaust, but the PW306 and PW308 (7 klbf, fan diameter 33.2 in.) include a forced mixer. A full-authority digital engine control (FADEC) system is incorporated. Applications of the 300 series include the Learjet 60, Cessna Citation Sovereign, Gulfstream G200, Hawker 1000, Dassault Falcon 7X, Fairchild-Dornier 328JET, and White Knight Two (ref. 100).

## Commercial Alternate Fueled Flight Tests

Boeing and Virgin Atlantic Fuels plan a 747 test scheduled for 2008 with biofuel to be selected. Initially, one engine will be run on alternate fuel (refs. 101 and 102). Boeing and Air New Zealand have also scheduled similar 747 tests in 2008 with biofuel to be selected (ref. 103).

On February 24, 2008, Virgin Atlantic became the first commercial carrier to fly on biojet fueling of one of four GE CF6-80C2B5F turbofan engines. The fuel blend was 80 percent Jet-A and 20 percent processed babassu nut-coconut oils (Parente biojet) provided by Imperium Renewables (ref. 104) and was based on the work of Parente (ref. 82). Ground tests to 60 percent Jet-A and 40 percent biojet showed no discernable problems (ref. 105). The 747-400 flew from London Heathrow to Amsterdam Schiphol (320 km or 200 miles), reaching altitudes of 25 000 ft (7.6 km) in 40 min. Full-up-engine tests are planned in 2008. The collected flight data will be analyzed to assess engine performance, emissions, and maintenance issues (ref. 106). Engine alternate fueling tests with algae oils processed to biojet are anticipated to occur in 2008 (ref. 105), and Continental and General Electric plan CFM56-7B biofuel flight testing with 737 aircraft in 2009 (ref. 107).

Air New Zealand 747 testing in 2008 will be more directed toward fuel sustainability issues. Air New Zealand engines are usually Rolls-Royce RB211-524H turbofan engines (ref. 108).

On October 31, 2007, Qatar Airlines announced it would fly on “natural gas,” which is most likely Shell GTL.

On February 1, 2008, an Airbus A380 flew from Bristol to Toulouse (a 3-hr flight) on one of four Rolls-Royce Trent 900 engines fueled with 50 percent Jet-A and 50 percent Synjet to assess the environmental impact of alternative fuels. The GTL synthetic fuels program is part of a November 2007 fuels consortium agreement between Airbus, Qatar Airways, Qatar Petroleum, Qatar Fuels, Qatar Science & Technology Park, Rolls Royce, and Shell International Petroleum Company. The goal is regulatory approval of 50:50 blended fueling by 2009 with 100 percent GTL fueling by 2013 (ref. 109).

JP8 represents about 60 percent of the DOD fuel consumption, and with rising fuels costs the USAF estimates cost increases of at least \$60 million/\$bbl-oil-increase. The DOD is currently (2008) committed to alternate fuels, and in March 2008 the B1B flew supersonic on a 50:50 blend (50 percent JP8 and 50 percent Synfuel), emphasizing that commitment.

Fuel 100, low-lead (LL) aviation fuel (avgas), has been a stable, dependable piston-engine aircraft fuel and the only allowable fuel approved by the FAA that contains carcinogenic tetra-ethyl lead. A 1990 memo states the lead is to be phased out. The FAA has certified a blended fuel, AGE85 (85 percent ethanol and 15 percent high-octane petroleum (not specified)), for use in several Cessna models with Continental engines (ref. 110). The FAA also approved AGE85 for the Piper Pawnee powered by Lycoming IO-540 engines, (ref. 111). Ethanol-fueled cropdusters have logged thousands of hours in Brazil (ref. 112).

The piston engine fuel market is 600 to 700 million gallons per year and will require sustainable secure supply of the AGE85 fuel to become effective.

## Summary

Halophytes and algae are fast becoming biomass plant matter of interest in aviation fueling studies. The potentially high oil yields of algae are up to 150 times that of soybeans and advanced halophytes promise yields beyond soybeans on saltwater- (or brackish-water-) irrigated, otherwise arid land, conserving both freshwater and arable crop lands.

Synthetic fueling has been used for many years and was heavily used during wars. The most recent application is with South African Airlines and all commercial flights out of Johannesburg, where blends up to 30 percent have fueled commercial aircraft without noted detrimental effects. A commercial flight demonstration with one of four engines operating on blended synthetic fuels (50% synthetic: 50% JetA) has been accomplished. The United States Air Force has certified the B52H (turbojet engines) to fly on

blends of 50 percent synthetic fuel and 50 percent JP8 and has flown the C117 on the same fueling blends (turbofan engines).

Biofuels derived directly from waste oils have been used to fuel the L-29 bioflight. However, normally these triglyceride fuels, biodiesel, must be processed with freezing point suppressants to enable them to withstand the low temperatures of high-altitude flying. Several commercial flight demonstrations with one of four engines operating on blended biojet fuel (20 percent) with 80 percent JetA have been accomplished. Other follow-up flight demonstrations are eminent.

A series of laboratory and flight testing demonstrations are planned. These tests are designed to validate the usefulness of biofuels and synthetic fuel blends with petroleum-based fuels in commercial aviation. The major impediment at this point in time is a secure, sustainable, renewable economically beneficial supply of these fuels.

Developments for synthetic and biomass terrestrial fueling, including water conservation and food production, are applicable to space missions where very harsh environments will require processing and reprocessing of wastes as sources of energy. While we have much to learn even about our own Earth habitat, knowing how to use algae, halophytes, and symbiotic bacteria (e.g., cyanobacteria) on space missions will enable greater mission independence and potential for survival.



## Appendix—Profs. Jack Gallagher and Denise Seliskar Documents

The halophyte seashore mallow grows in the coastal shallows of Maryland. The small seeds require a few seasons to become established and be a productive field that can be profitably harvested. This appendix illustrates some of the features of seashore mallow and presents a concise view of the potential impact halophytes could have as a fuel feedstock (figs. 4 and 5). See also reference 15, <http://www.ceoe.udel.edu/Halophyte/Growing%20Seaside%20Biodiesel%20proposal%20FINAL.pdf>

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# Growing Biodiesel Fuel and Animal Feed with Saline Irrigation

**Seashore Mallow (*Kosteletzkya virginica*) has the evolutionary history and genetic potential for the task.**



### Seashore Mallow features

- Grows with saltwater irrigation
- Perennial
- Morphology similar to soybean
- ~18% oil for biodiesel
- Residual seed meal ~30% protein
- Cellulosic stems for alcohol
- Large fleshy roots sequester CO<sub>2</sub>
- Grown with traditional farm equipment

Figure 4.—Seashore mallow (*Kosteletzkya virginica*), reference 15.

## AN OIL-SEED BIOFUEL MULTI-USE CROP GROWN WITH SALTWATER

### The Idea

Grow a salt-tolerant, oil-seed, multi-use crop on saline land or dry land that can be irrigated with brackish water or seawater, thus freeing fresh water and high quality soil for food and feed and bringing poor land into production.

### The Problem

- Fossil fuel dependence - Dwindling fossil fuel reserves at a time of escalating worldwide demand coupled with issues of security of foreign supply raises concerns.
- Impending food and feed shortage - Food supplies for humans and livestock will become more stressed as human population increases and we supplement fossil fuels with biofuels.
- Freshwater shortage - Increased population and per capita water demand are limiting available freshwater. Increased upstream river water withdrawal and ground water pumping exacerbate salinization problems.
- Increasing amounts of salty soil worldwide – Saline soil may be due to traditional crop irrigation, geologic origin, sea level rise, or saltwater intrusion. Rising sea level is salinizing rivers, coastal ground water & farmland.
- Global warming - Changes in rainfall patterns associated with global change create waterlogged soils in some places and drought conditions in other places, both of which limit most crops.
- Annual planting - A substantial amount of energy is consumed by the annual planting and cultivation of the most commonly used bio-fuel crops.
- Farm to market transportation - Transporting biofuels long distance from producers to users reduces net energy gain. Populations are concentrated in coastal areas.

### The Solution

- Seashore Mallow - *Kosteletzkya virginica* is an oil-seed halophyte.

### The Plant's Features

- Perennial (10 years)
- Salt-tolerant, drought-tolerant, & waterlogging-tolerant
- Seeds do not shatter readily & no known diseases
- Not invasive
- Plants can be sewn and harvested with traditional farm equipment
- Stores carbon belowground in large perennating carrot-like root



### The Potential Products from the Plant

- Oil from seed for biodiesel fuel - The seeds are similar to those of cotton in fatty acid composition. Seeds are ~ 18-20% oil. Highest yield to date was ~22 bu/acre with saltwater irrigation and no selection/breeding.
- Protein-rich animal feed from seed meal cake - Residual seed meal is ~30% protein.
- Alcohol from stems - Stems are robust and a potential feed stock for alcohol production. First year plants typically produce one stem and second year four to seven. Older plants may produce many more per plant each year (record is 44).
- Carbon credits – Carbon storage takes place in the perennial roots.

### Research Needs

- Refine agronomic and production techniques – Evaluate techniques to maximize yield (seeding density, salinity, and harvest refinement), irrigation techniques (flood, sprinkle, drip, etc.) and frequency, fertilization; evaluate halophytic winter annuals as cover crops; explore herbicides (needed when salinity is low).
- Crop improvement – Initiate a breeding program to increase yield. Assess plants grown from seeds collected from its range along the mid-Atlantic, Southeast, & Gulf coasts. Refine tissue culture & transformation protocols.
- Biofuel Testing – Extract oil and convert to biodiesel for testing. Test stems for alcohol production.



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Figure 5.—Single-page summary of halophyte work (ref. 14).

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<b>14. ABSTRACT</b> Synthetic and biomass fueling are now considered to be near-term aviation alternate fueling. The major impediment is a secure sustainable supply of these fuels at reasonable cost. However, biomass fueling raises major concerns related to uses of common food crops and grasses (some also called "weeds") for processing into aviation fuels. These issues are addressed, and then halophytes and algae are shown to be better suited as sources of aerospace fuels and transportation fueling in general. Some of the history related to alternate fuels use is provided as a guideline for current and planned alternate fuels testing (ground and flight) with emphasis on biofuel blends. It is also noted that lessons learned from terrestrial fueling are applicable to space missions. These materials represent an update (to 2009) and additions to the Workshop on Alternate Fueling Sustainable Supply and Halophyte Summit at Twinsburg, Ohio, October 17 to 18, 2007.				
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