Are salt-tolerant halophytes the answer to an aviation industry increasingly focused on renewable fuels? Charlotte Niemiec looks at this "game changer" in the biofuels industry and how an ecosystem could be put in place to make it even more sustainable

HALOPHYTES CONTAIN 30% OIL, ARE SALT TOLERANT AND CAN BE GROWN ON ARID LAND

Halophytes: a biofuel b

Has the biofuel problem finally been cracked? A team of scientists at the MASDAR Institute in Abu Dhabi firmly believes it has found the answer to indirect land use change (ILUC) concerns and food versus fuel debates in the form of halophytes.

Unlike most plants, halophytes are salt tolerant. They can therefore be grown in arid places such as the desert and watered with sea water. They grow in saline water, such as saline semi-deserts, mangrove swamps, marshes and sloughs. There are thousands of species of halophytes – most of the plants on the beach are halophytes, for example – and they grow in most tropical and moderate climate, are perennial and very hardy.

Some species are edible, such as *salicornia*, which is currently marketed in the USA as a gourmet food product. It tastes like asparagus or green beans and contains salt. Halophytes do have natural predators, such as beetles, but these pests can be controlled by introducing spiders to the crop. Goats are also rather fond of halophytes as they can tolerate higher salt contents.

Halophytes have other uses, too. They are excellent at cleansing the environment, decontaminating soils, desalinating brackish waters and carbon sequestration.

They have been put to the test in land remediation; in 2007, hurricanes salinated soyabean fields, rendering them barren. Scientists introduced a native species of *salicornia* into the fields, which produced usable crops of halophytes and desalinated the soil in the process.

In companion work with Professor Gallagher at the University of Delaware, a soyabean field fallowed by hurricane floodwaters was planted with sea-shore marrow that produced useable seed, even in a dry season. The halophyte remediation technology could also be applied to aquifer irrigated land farms, which are becoming more salinated each year.

There are numerous organisations investigating the potential of biofuel derived from halophytes, with strong interest shown from the aviation industry. Darrin Morgan, director of sustainable aviation fuels at Boeing, explains in an interview with Zachary Shahan, director of the CleanTechnica website, how his company is involved in these projects. Boeing is the world's largest aerospace company and is a leading manufacturer of commercial jetliners and defence, space and security systems. It produces tailored services including commercial and military aircraft, satellites, weapons, electronic systems, defence systems, launch systems, advanced information and communication systems, and performance-based logistics and training.

Boeing is part of the Sustainable Bioenergy Research Consortium (SBRC) and is a member of the Sustainable Aviation Users Group, formed in September 2008 with support and advice from leading environmental organisations such as the National Resources Defense Council and the Roundtable on Sustainable Biomaterials (RSB). The group is focused on accelerating the development and commercialisation of sustainable aviation biofuels, including biofuels derived from halophytes.

Also partnered with the SBRC is the MASDAR Institute of Science and Technology, the world's first graduate-level university dedicated to providing real-world solutions to issues of sustainability; Etihad Airways, the flag carrier airline of the United Arab Emirates (UAE); Honeywell UOP (formerly known as Universal Oil Products), a multinational company developing and delivering technology to the petroleum refining, gas processing, petrochemical production and major manufacturing industries; and Safran, a leading international high-technology group with three core businesses in aerospare, defence and security.

Biofuels top traditional fuels in the air

Morgan explains that biofuels are technically superior to kerosene, which took the aviation industry somewhat by surprise. This is because biological sources lend themselves better to the creation of hydrotreated fuels – those devoid of oxygen – which function better in plane engines. Tar sands and shale crude oil contain contaminants that interfere with aviation and create inefficiencies in the system, but mineral oils are cleaner.

Nevertheless, says Morgan, the problem for the industry is that aviation itself has a relatively small carbon footprint, which makes investors reluctant to invest in biofuels.

A new path had to be found, which would not utilise fresh water and expensive farmland as first-generation biofuels had done. It was also important not to create a fuel that required a change in plant engines; the fuel had to fit the plane.

It is important to remember that (most) modern aircraft cannot run solely on biofuels. In an interview by Sander Olsen with Dr Bilial Bomani, the head of NASA's green lab research facility, Bomani explains: "The seals and fuelling systems

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reakthrough

of legacy aircraft aren't designed for biofuels and will leak if loaded with pure biofuels. So, we have created a 'bio-blend' consisting of 95% aviation fuel mixed with five percent biofuels. However, current specifications ASTM D 7566 allow up to 50% blends and some demonstration flights have shown it can be done even to near 100% alternative fuelling." At some point, he admits, a plane will need to be designed that can run purely on biofuels and legacy aircraft would be fuelled using a 50/50 bio blend.

Two birds with one stone

Halophytes provided a big breakthrough in the development of a biofuel derived from renewable sources using deserts (which constitute 20% of the world's land) and salt water (70% of the world's water).

The MASDAR team researched over 30 species of halophyte out of the thousands available, and finally settled on four optimal species: *salicornia virginica*, *salicornia bigelovii*, *salicornia europea* and *salicornia subterminalis*.

The scientists and researchers involved realised it was more sustainable – and made solid financial sense – to create a halophyte ecosystem by merging aquaculture with halophyte farms. Aquaculture has come under fire for returning the fish waste it produces to the ocean, but the nutrients in this waste are exactly what halophytes need to grow and make natural, non-chemical fertiliser.

In an interview with Dr Alejandro Rios, director at the Bioenergy Research Consortium at MASDAR, he explained to *Oils & Fats International* that SBRC scientists were in the process of building a lab-scale, pilot facility on two hectares of land within Masdar city. The next step will be to create a test ecosystem on 200ha in western Abu Dhabi.

The pilot facility will use grid energy but it is hoped that, when the ecosystems are in place, the energy produced by the halophyte farms will be used to power all infrastructure, making it a self-sustaining system.

The plants currently produce two tonnes of seed/ha, which equates to 600-700 litres of oil. With agricultural engineering, however, the team hopes to increase the yield up to four or five tonnes of seed/ha.

Furthermore, the 40 tonnes/ha of biomass produced, Rios says, contains "extremely interesting properties" such as chemicals and sugars that have attracted the interest of the pharmaceutical and cosmetic industries.

The halophyte ecosystem will use flood irrigation in a similar way to that used in the growing of rice. An engineered system will use gravity to irrigate the plants, which will be grown in the open air rather than in greenhouses. Waste seawater from a fish and shrimp farm will nourish halophytes that clean the water as they grow. The water will next flow into a field of mangroves before returning (cleansed) to the ocean. The project will investigate the scaleability and viability of an integrated seawater energy and agriculture system, known as the ISEAS concept (*see Figure 1, previous page*).

Commercially viable in just five years

But what is rather remarkable is how quickly these systems could be put in place and producing competitive biofuel. In as few as four to five years from now, Morgan envisions thousands of hectares being used as, he notes, the land on which halophytes can be grown is up to 20% of the world's land mass.

Bomani explains that there is already a 'halophyte city' in Mexico, where halophyte farms are in abundance. He claims there have also been large-scale farms in Eritrea, Africa with current trials in the Middle East; all have been under the direction of Dr Carl Hodges, the founder of the Seawater Foundation, an organisation dedicated to greening the desert coastlines of the world to generate wealth in poverty stricken areas, eliminate famine and improve the global environment. These farms are producing sustainable food and fuel.

Contributing to his bullish outlook is the fact that the halophytes being used are very amenable to having sugars removed. Bomani explains that the major cost for cellulosic biofuels is extracting the sugars and ridding them of lignin. Halophytes are low in lignin and high in sugars, and they require lower temperatures to heat and process the fuel.

Concluding, he states that halophytes are a "game changer for biofuels" and the "biggest breakthrough for biofuels ever", relevant not just to the aviation industry but everywhere.

Replacing other renewable fuels

How much land, then, would it take to fuel the entire aerospace industry? Bomani comments: "If we dedicated the land mass of Maryland to growing advanced algal technologies, along with halophyte optimisation, we could almost supply the entire aerospace industry in the USA. If we had the land mass of the Sahara desert, we could meet the aviation fuel needs for the entire world using primarily advanced halophyte plants. We are trying to use under-utilised NASA land in Florida to grow halophytes. We actually see beach sand as our soil, which normally has no nutrients. The beach sand gets its nutrients from the water below. With the projection that the aerospace industry will grow about four percent per year, currently fuelling requirements – based on current aircraft designs – are expected to double by 2020."

It is worth remembering, however, that the aviation industry accounts for just eight percent of world oil consumption, according to IFFP Energies Nouvelles' website, therefore it is questionable whether there is enough suitable, available land to cover entire world oil use with halophyte-derived biofuel.

In terms of yields, halophytes are competitive with soyabeans. In a paper written by R C Hendricks of the NASA Glenn Research Center in Cleveland, Ohio, and D M Busnhell of the NASA Langley Research Center in Hampton, Virginia, titled '*Halophytes energy feedstocks: back to our roots*', published in February 2008, the authors discuss the viability of halophytes as a biofuel feedstock.

They note that experimental farms yield 1.7kg/m^2/yr of total biomass and 0.2kg/m^2/year of oil, similar to soyabean seed oil yields. To compare-the yield from soyabeans is about 19% oil and 48% protein. It produces 10.9lbs/bushel, 468lbs/acre or 61 gallons/acre of oil with an average crop of 43 bushels/acre. Halophyte seeds provide 30% oil and yields are 0.2kg/m^2 (two tonnes/ha). These yields equal or exceed the yields of soyabeans and other oilseeds using freshwater irrigation," the authors state. At 30% oil, this implies 6.67 tonnes/ha of seed. This is, the authors conclude, nearly four times that produced by the average crop of soyabeans in the USA.

Meeting US demand for biofuels is no easy task, but all other feedstock contenders are wiped off the map when halophytes are introduced (*see Table 1, above*). But halophytes are only in second place; algae is the top contender by a large margin.

"The land fractions for freshwater and micro halophyte agriculture (algae) are even more impressive than those of halophytes, requiring between 0.08% and 5.6% of total US land to replace oil or oil and gas consumption."

In terms of cost, it currently costs around US$18/gallon for alternative fuels. Although halophyte-derived biofuels are not yet currently commercially viable, the SBRC aims to eventually make the cost comparable to that for conventional aviation fuels but, in order to make that happen, international agreements would need to be drawn up to free up millions of acres of non-arable lands. ▶

TABLE 1: FUEL FEEDSTOCK PRODUCTION RELATIVE TO US LAND FRACTIONS (ASSUMES NO CONVERSION LOSSES IN PROCESSING OR LAND USE[A]

Feedstock crop	Fuel	Production rate (kg/ha)	US total land		US arable land	
			Oil fraction	Oil & gas fraction	Oil fraction	Oil & gas fraction
Halophyte[b]	Biodiesel	2,000	0.711	1.202	3.741	6.324
Projected		21,685	0.066	0.111	0.345	0.583
Algae[c]	Biodiesel					
Lower limit		43,090	0.033	0.056	0.174	0.294
Upper limit		172,360	0.008	0.014	0.043	0.073
Jatropha (India)	Biodiesel	3,000	1.066	0.801	2.494	4.216
Palm oil (Malaysia)	Biodiesel	5,000	0.284	0.481	1.496	2.529
Switchgrass[d]	Ethanol	2,375	0.543	0.918	2.857	4.829
Sugarcane[e]	Ethanol	2,790	0.461	0.780	2.428	4.105
Miscanthus giganteus[f]	Ethanol	11,290	0.114	0.193	0.601	1.016
Seashore dropseed	Ethanol	6,970	0.145	0.245	0.764	1.292
Saltgrass	Ethanol	6,020	0.168	0.284	0.884	1.496

[a] Energy ratio to No.2 diesel: B100, 0.82% to 0.85%; ethanol, 0.63% to 0.67%
[b] Glasswort species of salicornia bigelovii
[c] (5,000 to 20,000 ga/acre-yr) x (0.92 x 8.34)/(0.4047 x 2.2) = kg/ha
d 1,236 gal/ha x 0.645 energy conversion = 798 gal/ha x (0.785 x 8.34) lb/gal/2.2lb/kg/ha
e 1,454 gal/ha x 0.645 energy conversion x (0.785 x 8.34) lb/gal/2.2 lb/kg = 2,793 kg/ha
f 5,878 gal/ha x 0.645 energy conversion x (0.785 x 8.34) lb/gal/2.2 lb/kg = 11,289 kg/ha

Source: 'Halophytes energy feedstocks: back to our roots', R C Hendricks, D M Bushnell, 17-22 February 2008

A future in halophyte fuel?

Any real scale-up of the technology can only be achieved with "international cooperation", states Bomani. There is a huge amount of low-quality, unused land that could effectively be used for halophyte production, and which will not compete with arable/high value land at all. If inclined, one could even grow a halophyte garden on a rooftop, if one lived by the sea, he explains.

Hendricks and Bushell conclude: "Supposing that the production, logistics and political issues could be overcome, the total energy for arid land sources scattered over the earth would be sufficient to meet the world's energy demands. As such, if humanity chose and if we became committed, it could be accomplished. As a final note, while research by the SBRC is focusing on clean, natural halophyte-derived energy, other halophytes could theoretically be genetically engineered to produce gasoline. According to Bomani, other groups are looking into this technology, which he describes as "prohibitively expensive".

If the technology is successful, it has the potential to populate the deserts of the world with plants-cum-fuel-pumps full of oil. ●

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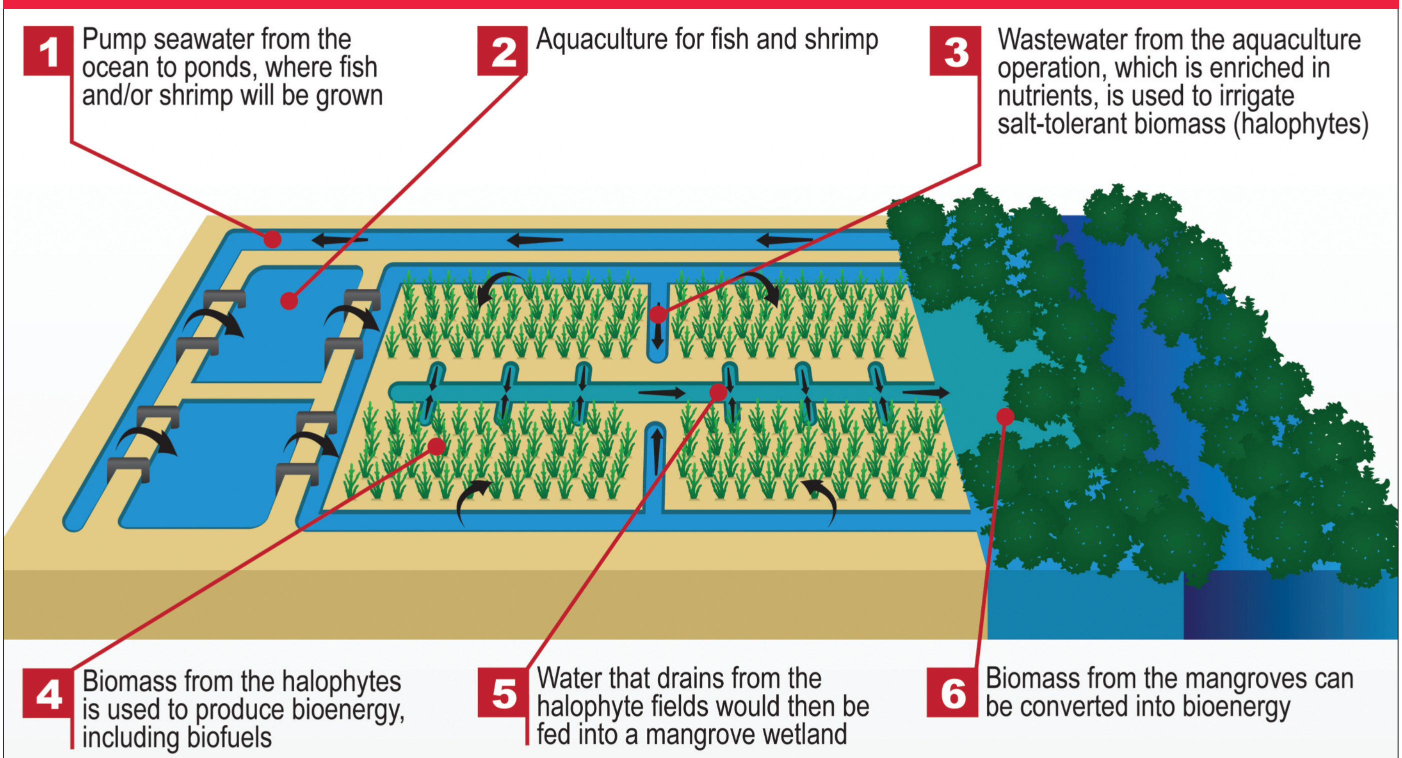
FIGURE 1: THE ISEAS CONCEPT



The goal of this project is to demonstrate that the integrated process is sustainable and environmentally responsible with respect to land use, carbon emissions and discharge of by-products such as aquaculture waste products

Source: MASDAR Institute, UAE