The population across the world is increasing rapidly and has crossed the seven billion mark. This population is projected to climb to nine billion by the year 2050 with most of the growth occurring in poorer countries, particularly in Africa and south Asia, according to present demographic trends [1]. Consequently, the resources of arable lands and good quality water are under pressure. Modern agriculture methods have increased per unit area yield of food crops and have so far managed to meet the demands. This increased supply, whose sustainability is uncertain in the long run, has been at the cost of over-exploitation of soil and water resources. High doses of chemical fertilizers, particularly nitrogenous, and excess quantities of irrigation water, needed for optimal yields of 'improved varieties' such as those of wheat and rice of the 'green revolution' of the 1960s, is causing pollution of underground water and has resulted in salinization of prime agricultural land. Over 800 million ha of the world is presently affected by salinity [101] and 45 out of 230 million ha of irrigated agricultural land has become saline [2]. This necessitates some forward planning and the need to look beyond the traditional resources to satisfy our needs, as all our field crops are sensitive to salinity. One solution may lie in making use of halophytes; plants of saline habitats, some of which may thrive even with seawater irrigation, can be put to an array of uses [3].

It has been realized that fossil energy resources, which are the main drivers of our economy, are not sustainable [4]; consequently, it may be worthwhile to explore the potential of halophytes as a source of fuel for the benefit of mankind through mobilization of salty water and saline land – both are plentiful on planet Earth. This article aims to review work done so far in this field, especially with reference to selection criteria for suitability of particular species and the bottlenecks in achieving desirable goals. The possibilities of utilizing halophytes are immense and some species from the Pakistan coast have been identified as needing attention as biofuel feedstock candidates. Similar or even better species may, however, be found elsewhere.

### Sustainability & environmental consideration

The use of plant biomass as fuel has been documented since early human history. Fossil fuels have gradually...
Hydrolysis: Decomposition of a chemical compound by reaction with water or acid (acid hydrolysis).

Pyrolysis: Thermochemical decomposition of organic biomass in the absence of oxygen.

Saccharification: Process of breaking a complex carbohydrate (as starch or cellulose) into its fermentable monosaccharide components.

Fermentation: Breakdown of sugar into an acid or alcohol.

gained popularity due to their high abundance and denser energy, making them the preferred fuels in many regions. The history of use of plant biomass as fuel is as old as mankind itself. In most developing countries however, wood is still a major source of energy [102]. It has also been realized that the fossil fuel resources are not sustainable and are depleting. According to some projections, we will have utilized all the available gas and petroleum reserves in this century, and coal will be the only fossil fuel left for use in the next [4]. Consequently, there is a resurgence of interest in biomass energy, which is sustainable. Some additional carbon from what was captured during photosynthesis may be released during the production of biofuel from biomass than if mechanical methods were used; however, through enzymatic digestion this release can be minimized, making it almost carbon neutral. Burning the fossil fuel releases enormous quantities of CO₂, which may result in a relatively higher increase in ambient CO₂, climate change and acidification of oceans [5,6].

**Halophytes as an energy feedstock**

The plant kingdom consists of about 400,000 flowering species [103], of which some 2600 are halophytic [7]. The halophytes have a diverse distribution but they are more common in arid/semi-arid regions of the tropics and sub tropics [8]. For instance, a large area starting from Rajasthan in India and extending through to Pakistan, the Middle East, North and Central Africa all the way to Morocco, is home to a variety of halophytes [3]. Other areas where diverse populations of halophytes occur include parts of Australia, China, the USA and South America. Pakistan alone has approximately 410 halophytic species distributed on the Sindh/Balochistan coast, and inland from coast to mountains in the north including the Indus basin [9]. These halophytes belong to 58 families with the highest number of species (90) present in the Chenopodiaceae (now called Amaranthaceae) followed by Poaceae (68), Cyperaceae (30), Papilionaceae (29), Astersaceae (24) and Tamaricaceae (23), while other families are represented by less than 10 species [9].

The Institute of Sustainable Halophyte Utilization (University of Karachi, Pakistan), with the mandate of exploring the potential uses of halophytes, is in the process of surveying the coastal region of Pakistan and has so far identified species suitable for biofuels [10] in addition to animal fodder [11], edible oil [12] and medicines [13]. It is noteworthy that a halophytic grass has recently been used on a commercial scale to make turf [14] and the use of halophytic grasses as animal feed is fairly common as a sole source or as a supplement to regular feed [Khan MA ET AL, Unpublished Data], but their usages have remained comparatively underexplored. This includes the use of halophytic biomass as a source of biofuel feedstock.

**Selection criteria for energy crops**

Various grains, such as corn, wheat, soybean and rapeseed, are currently major feedstocks for biofuel. According to a report, humans and livestock consume 48 and 35%, respectively, of the total grain produced annually, and approximately 17% is used for producing biofuels [15]. Faced with an increasing demand for energy and food, there is resistance against large-scale production of biofuel from food items, due to its impact on availability of food and inflation. The ideal feedstock for biofuel is hence outside the human food chain, such as the species of halophytes that do not infringe on prime agricultural land and good quality water resources. It is primarily important that a biofuel crop should be high yielding with few inputs, and have a wide environmental tolerance and ecological compatibility with desirable lignocellulosic content (discussed later). The species should be native to the area, have a fast growth rate and preferably be perennial to save cost of replanting. Further attributes include resistance to biotic and abiotic stresses, high water use efficiency and low fertilizer requirements. Integrating the quick check system [16] in the development of cash crop-halophytes may serve as a baseline study by facilitating data gathering on growth behavior and physiological/biochemical responses of plants under uniform salinity and controlled environmental conditions.

**Feedstock composition**

**Hydrolysis** of lignocellulosic biomass and further conversion into sugars is affected by feedstock characteristics; cellulose/hemicellulose in excess of 25–30% each and <10% lignin are desirable and cost effective [10]. A further consideration is the elemental composition of plant biomass, which generally consists of oxides, silicates, carbonates, sulfates, chlorides and phosphates of Ca, Fe, K, Mg, Na and Si, together with trace amounts of S, P, Cl and Mn [17]. Studies on the catalytic effect of mineral matter on biomass pyrolysis through various methods showed that even a small amount of certain minerals like Ca, K, Na, Mg and Fe may affect pyrolysis adversely and cause problems in saccharification [18]. Halophytes, especially those from the family Amaranthaceae, accumulate large amounts of salt in their biomass but they are also capable of excreting excess salts through specialized
salt glands, with halophytic grasses having the ability to block Na+ and Cl− at the root level. Information about the conversion process of biomass and optimization in saccharification of these halophytes is lacking to the best of our knowledge. The selection of the most suitable crops among halophytes should hence be done very carefully, keeping in mind not only the lignocellulosic composition but also their salt tolerance or avoidance strategies with special consideration of ion content.

- **Stress tolerance**
During growth, plants are exposed to a variety of biotic and abiotic stress, to which all conventional field crops are fairly sensitive. Salinity, being one of the more common hazards, attains special significance as it reduces yields considerably. Salinity tolerance ranges in halophytes widely with some species having tolerance to seawater or even higher salinity; for instance, *Arthrocnemum macrostachyum* survives in up to 1000 mM NaCl [19]. Many of these plants are not only salt tolerant but also possess osmo-tolerance because the primary effect of salinity is osmotic, which at higher salt concentrations also exerts ionic toxicity. These plants generally utilize the resources at their disposal efficiently (especially water) because they are programmed to live in hostile environments [20]. Depending on the quality of soil/water of a particular site, there is a wide array of halophytic plants to choose from for combining desirable attributes, such as high yields and suitable lignocellulose contents. It may be mentioned here that halophytes are generally not very susceptible to insect pests; however, that aspect needs attention in large-scale plantations.

- **Life strategy & maintenance**
Producing biomass becomes economical if the target crop is perennial. Further considerations include inputs, particularly fertilizers and water required for optimum yields. Obligate halophytes, *Suaeda fruticosa*, for example, require certain salt concentration for optimum growth; hence, those growing in the wild under specific conditions may produce large biomass. They are also mostly pest-free but these aspects require very careful monitoring for a wild plant that is being domesticated.

- **Yield & growth rates**
The potential of a crop, especially under stressful conditions, may be judged from seed germination, growth rates and height of the plants. These are therefore important criteria in deciding the suitability of a crop as a source of biofuel. In the absence of any systematic studies, information about exact yield and the potential of most halophytes is generally lacking; this will anyway be affected by the soil salinity and quality of irrigation water. However, it is noteworthy that the net primary productivity per unit area is reported to be highest in swamps and salt marshes where halophytes dominate, and where mangroves are the most productive plants growing submerged in seawater [24].

---

**Bioethanol production from lignocellulosic biomass**

Bioethanol has been recognized as a transportation fuel and can be used directly or blended with gasoline in various proportions [22,23]. The bulk of plant biomass contains varying amounts of lignocellulose (40–60% cellulose, 20–40% hemicellulose and 10–25% lignin) [24], which can be converted into a range of biofuels through various processing methods [5]. However, this is not as simple as it sounds because conversion of biomass into biofuel (bioethanol) involves hydrolysis of cellulose through highly specific cellulase enzymes and subsequent fermentation of the sugar formed by yeast or bacteria. Success in ongoing research in this direction would open up the opportunity of converting cellulose material from any source, such as timber or agriculture waste, into sugar. The halophytes, however, still have the edge in biomass production over other sources because of the availability of vast tracts of saline lands lying barren worldwide, where normal agriculture or forestation is not feasible but these plants of saline habitat can be grown with salty water irrigation. In coastal areas, biomass production of some halophytes may even be possible with sea water irrigation.

Currently, large-scale industrial production of bioethanol comes from sugarcane, corn, soybean and cereals; this is easier but leads to direct conflict with the food sector [25]. The focus of research has consequently shifted to use lignocellulosic biomass from nonfood plants as feedstock for biofuel. One bottleneck in this process is the presence of lignin–hemicellulose networks in cellulose fibers, which interrupt the enzymatic hydrolysis of cellulose, an important step in bioethanol production. To maximize sugar yield, this network has to be hydrolyzed [26]. Therefore, plants that have low lignin contents should be chosen for bioethanol production, in order to minimize cost of additional steps required for separation of lignin.

The acid hydrolysis of cellulose and hemicelluloses results in the production of both C₅ and C₆ sugars. While the hexose sugars may be more readily amenable to fermentation, the pentoses are recalcitrant in this regard and pose a major bottleneck [25]. Hence, the resulting sugar mixture must first be separated (which often involves complicated techniques and adds to the cost) and then fermented by different microorganisms known to ferment either hexose or pentose sugars alone. Not many effective microbial catalysts have so far been found that can directly metabolize oligosaccharides to
produce marketable products, exceptions being the production of xylanases by fungi (*Aspergillus niger* [27]) or actinomycetes [28].

- **Potential candidates for bioethanol**

  An initial study conducted by our research group on a number of halophytic species of our coastal area shows wide diversity in their lignocellulosic composition (Figure 1). These data exhibit a general trend of plant tissue composition and mineral contents which may vary with growth conditions and plant age. Characteristics of some promising species are presented in Table 1 and their other details are given below. The desirable features of these species include their salt tolerance, perennial growth, high water-use efficiency, fast growth rate and low energy input along with desirable lignocellulosic contents.

  **Phragmites karka** (Retz.) Trin. ex Steud (Poaceae)

  A perennial reed with creeping rhizomes that is commonly found in marshes and brackish water swamps. It is spread primarily by rhizomes and it produces numerous seeds that can germinate at 500 mM NaCl [29]; plants could subsequently grow under more saline conditions [Khan MA, UNPUBLISHED DATA]. The height of *P. karka* is comparable with the already reported biofuel crop *Miscanthus* [30], with a high biomass yield of composition similar to *Cynodon dactylon* [31].

  **Halopyrum mucronatum** (L.) Stapf. (Poaceae)

  This is a perennial grass growing on sand dunes in the coastal areas of Pakistan. It grows well while inundated regularly with seawater and produces dimorphic seeds twice in a year [32]. Its biomass, having 37% cellulose, 28% hemicellulose and 5% lignin, makes it a better candidate for ethanol production than switchgrass (*Panicum virgatum*) [31]. The grass can additionally be grown with seawater irrigation for dunes stabilization, checking land erosion, for carbon sequestration and so on.

  **Desmostachya bipinnata** (L.) Stapf. (Poaceae)

  This is a tall perennial grass distributed near coastal and inland areas of Sindh province. The seeds can germinate at >400 mM NaCl [33] and plants exhibit fairly good growth on saline and sodic soil where brackish water is available [Khan MA, UNPUBLISHED DATA]. Its fairly high salt tolerance on light textured soils [34] and ability to resist metal contaminations [35] have also been reported. The composition of its biomass (26% cellulose, 24% hemicellulose and 7% lignin) makes it a good biofuel candidate.

  **Panicum turgidum** Forssk (Poaceae)

  A perennial halophytic grass generally used as a fodder, but its chemical composition (28% cellulose, 28% hemicellulose and 6% lignin) also makes it a good candidate for bioethanol production. Essentially a desert grass widely distributed in Pakistan, *P. turgidum* can tolerate 200 mM NaCl at germination stage [36] and grows in dense bushes through tillers, reaching up to 1 m in approximately 30 days [31]. The identification and development of a more salt-tolerant *P. turgidum* may help address the scarcity of good quality water in many arid agricultural regions of the world.

  **Typha domingensis** Pers. (Poaceae)

  Found near coastal areas of Pakistan, this is a rhizomatous perennial with the ability to tolerate flooding and moderate salinity. Where perpetual supply of water and nutrients are available, it becomes an aggressive invader. However, its biomass containing 26% cellulose, 38% hemicelluloses and 4% lignin may challenge any second-generation species for biofuel production; for instance, water-hyacinth (*Eichhornia crassipes*), which has 35–50% of hemicellulose [37] but high (12%) tannin, which is undesirable for fermentation [31].

  **Urochondra setulosa** (Trin.) C.E. (Poaceace)

  A dominant species on the sand dunes, saline flats and saltwater creeks in the Indus Delta and near Karachi coast [38]. *U. setulosa* produces a large number of seeds, which could germinate at approximately 1000 mM NaCl [39] and can adapt in drought situations, making the plant very important ecologically in saline/waterscarce areas [40]. With 25% cellulose, 25% hemicellulose and 6% lignin, it is a suitable candidate for bioethanol. Its very slow growth rate, however, requires agronomic interventions and genetic breeding to make it more acceptable.

  **Aeluropus lagopoides** (Linn.) Trin. ex Thw. (Poaceae)

  A rhizomatous perennial grass that dominates the seasonally inundated coast as well as inland salt flats of arid Pakistan [41]. It appears to be propagating mainly through rhizomes in monospecific stands or through seeds while colonizing open niches [42]. It is a good candidate for a biofuel feedstock because of its perennial habit [43] and lignocellulosic biomass (26.67% cellulose, 29.33% hemicellulose and 7.67% lignin); however, this species does not grow very tall, which means it does not have enough unit area/time yield to be considered as a biofuel crop.

**Biodiesel production prospects**

Rudolph Diesel first proposed the use of plant oil as automobile fuel in the 19th century [104]. Subsequently it has been realized that biodiesel has a high potential as an environmentally friendly and renewable energy source for the future [44]. Biodiesel is a mono-alkyl ester derived...
from oils, which has characteristics similar to petroleum-derived diesel. The conversion of edible or nonedible oil from 'oilseed plant species' or animal fats into biodiesel may be relatively easy as it involves only hydrolysis and separation of glycerol. It may serve as a substitute for conventional diesel and can be used in existing diesel engines without significant modification [45]. Currently, approximately 84% of the world's biodiesel requirement is met by rape-seed oil and the remaining is from sunflower (13%), palm (1%), soybean and some other oils (2%) [105]. Incidentally, all of them are edible and their use for producing biodiesel may have adverse consequences on the price of food commodities. If biodiesel production is further increased, the world food situation would be adversely affected [46]. In order to meet this challenge, biodiesel should be produced from low-cost feedstocks such as nonedible oils, used frying oils, animal fats, soap stocks and greases. However, the available quantities of these waste oils and animal fats are not enough to meet the current demands for diesel. Additionally, biodiesel needs to have lower environmental impacts and ensure the same level of performance as of existing fuels [47]. This problem could be dealt with by using nonconventional oil sources, without compromising food resources and sparing good quality water and land for conventional crop production for essential food items.

Transition to a second-generation biofuel source, such as halophytes, can contribute to a reduction in land requirements due to their high energy yields per unit area, as well as to their nonrequirement of agricultural land.

**Potential candidates for biodiesel**

Seeds of many halophytes contain appreciable amounts of oil [12,48] and may serve as a source of

![Figure 1. Lignocellulosic contents of common halophytic species of local flora.](image)
Table 2. Seed composition of potential biofuel species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Oil (%)</th>
<th>Ash (%)</th>
<th>Na (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alhagi maurorum</td>
<td>21.9</td>
<td>2</td>
<td>607</td>
</tr>
<tr>
<td>Arthrocenmum macrostachyum</td>
<td>25.0</td>
<td>39</td>
<td>3573</td>
</tr>
<tr>
<td>Cressa cretica</td>
<td>23.3</td>
<td>7</td>
<td>310</td>
</tr>
<tr>
<td>Halopyrum mcrconatum</td>
<td>22.7</td>
<td>2</td>
<td>53</td>
</tr>
<tr>
<td>Haloxylon stocksii</td>
<td>22.7</td>
<td>20</td>
<td>3550</td>
</tr>
<tr>
<td>Salicornia bigelovii</td>
<td>30.0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Suaeda frutcosa</td>
<td>25.0</td>
<td>7</td>
<td>1623</td>
</tr>
</tbody>
</table>

Adapted with permission from [12].
**Table 3. List of halophytes species as potential sources of biodiesel.**

<table>
<thead>
<tr>
<th>Candidate species</th>
<th>Family</th>
<th>Site/province</th>
<th>Life form</th>
<th>C3/C4</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Arthrocnemum macrostachyum</em></td>
<td>Amaranthaceae</td>
<td>Clifton/SIN</td>
<td>NP</td>
<td>C3/C4</td>
</tr>
<tr>
<td><em>Haloxylon stocksii</em></td>
<td>Amaranthaceae</td>
<td>Hawksbay/SIN</td>
<td>NP</td>
<td>C3/C4</td>
</tr>
<tr>
<td><em>Salicornia bigelovii</em></td>
<td>Amaranthaceae</td>
<td>Manora/SIN</td>
<td>NP</td>
<td>C3/C4</td>
</tr>
<tr>
<td><em>Suaeda fruticosa</em></td>
<td>Amaranthaceae</td>
<td>KU Campus/SIN</td>
<td>NP</td>
<td>C3/C4</td>
</tr>
<tr>
<td><em>Cressa cretica</em></td>
<td>Convolvulaceae</td>
<td>KU Campus/SIN</td>
<td>SFC</td>
<td>C3/C4</td>
</tr>
<tr>
<td><em>Alhagi maurorum</em></td>
<td>Papilionaceae</td>
<td>KU Campus/SIN</td>
<td>NP</td>
<td>C3/C4</td>
</tr>
</tbody>
</table>

The species considered suitable are predominantly C4 type (Tables 1 & 3) with the potential of becoming aggressive invaders, harming the biodiversity of the area. This needs close observation in large-scale plantations, with care being taken to restrict species to their natural habitats. For instance, *P. karka* is a fast growing and invasive species among our research group’s studied plants with

---

A. *macrostachyum* (Moric) C Koch (Amaranthaceae)

A perennial, stem-succulent halophyte found in the intertidal zone of the Arabian Sea at Karachi, Pakistan [19]. The species is characterized by articu- lars stems with carnose segments, reduced and stem-united leaves [60]. Seed germination of *A. macrostachyum* was only inhibited at the highest salinity (4% NaCl, 5% MgCl2) but the ungerminated seeds showed a high recovery in distilled water (81 and 83%, respectively) [61].

A. *maurorum* Medic. (Papilionaceae)

A spiny, deciduous, perennial, saltmarsh under-shrub, native from Eurasia, commonly found in both inland and coastal areas of Karachi, Pakistan [12]. The perennial plant grows from a massive rhizome system, which may extend over 1.8 m into the ground. It has a wide soil tolerance, thriving on saline, sandy, rocky and dry soils. It does best when growing next to a source of water, such as an irrigation ditch. It is unpalatable to animals and irritating when it invades forage and grazing land. Seeds of *A. maurorum* may be used as a source of oil for biodiesel.

**Pitfalls & precautions**

Circumstantial and experimental evidence proves the superiority of halophytes over the present-day agricultural plants in tolerating salinity stress; however, detailed information concerning their growth behavior is largely missing compared with conventional crops, which are backed by thousands of years of efforts to domesticate them, with the process still ongoing. First and foremost is the availability of planting material, whether it be the seed or rootstock. The seeds of halophytes, which may be recalcitrant to germination, are generally of very small size and their availability is restricted to short specific periods of the year making it difficult to collect in large quantities.

Reliable estimates of seed or biomass yields of halophytes are not available, which require systematic cultivation of the target species in big plots with suitable cultural practices on aspects such as spacing, fertilizer doses, irrigation schedule and harvesting interval. Our research group has some information about the biomass yield of *P. turgidum* [Khan MA, Unpublished Data], but individual candidate species need to be similarly assessed. These studies are crucial before embarking on any commercial application. It is, however, noteworthy that because these are untested species of the wild, it is difficult to forecast the time and efforts needed for desirable outcome from the agricultural practices. As in any new venture, known and unforeseen problems may be encountered and will need to be solved over time. This was also the case with conventional agricultural crops, which now have greatly improved yields, with mechanization taking over manual harvesting and making the task much easier.

If rootstocks are being used as planting material, their availability, collection and transportation to planting site may also be problematic and costly. For commercial-scale planting, very large nurseries are needed requiring suitable infrastructure and involving expenses. Tissue culture techniques, if employed to meet the demand, will require technical know-how and prior assessment of economic feasibility.

For reasons mentioned earlier, a low salt load in biomass is desirable for efficient pyrolysis and saccharification. Halophytic grasses thus become preferable because they restrict ion uptake at the root level and reduce salt buildup in foliage. This advantage, however, carries the hazard of increasing soil salinity, especially when soil is already saline and being irrigated with brackish water. One remedy may lie in combining a salt excluder (a grass) for use as biofuel, and a salt accumulator, *S. fruticosa* for instance, in the same land at suitable intervals and separately harvested [11]. This, however, needs further study.

The species considered suitable are predominantly C4 type (Tables 1 & 3) with the potential of becoming aggressive invaders, harming the biodiversity of the area. This needs close observation in large-scale plantations, with care being taken to restrict species to their natural habitats. For instance, *P. karka* is a fast growing and invasive species among our research group’s studied plants with
water-logging tolerance; therefore, we should target it to be cultivated in similar conditions where it can flourish and produce the lignocellulosic biomass, without harming the ecosystem.

**Concluding remarks**

Biofuel from plant biomass has the advantage of being sustainable. However, considering the energy demand and the quantity of biomass likely to be available for conversion, it would be very optimistic to suggest that the biofuels will fully meet our future needs. These second-generation fuels can, at best, be expected to serve as a supplement to fossil fuel, such as the current blending of ethanol with petrol and thus helping in making the fossil fuel last longer than predicted. Cultivating halophytes in saline lands will spare fresh water and good agricultural lands for food, and provide lignocellulosic biomass of desirable quality for conversion as biofuel. Perennial grasses appear as better feedstock due to their high yield and low salt load in foliage; however, the salt buildup in soil needs close observation.

**Future perspective**

Keeping in view the current pace of land degradation and competition between food and fuel crops, diversification through halophyte utilization to suit particular soil conditions seems a viable alternative. A number of halophytes can be found that have desirable characteristics for biofuel production. Saline culture of halophytes is not a large challenge, but care is needed to use native plants to avoid any hazardous ecological consequences and restrict such planting to areas where soils are already saline and the irrigation water is brackish. The knowledge of some of the mechanisms adopted by plants to cope with salinity and the methods to deal with salt buildup in root zone are available and more information is accumulating. There is a need to explore the possibility of optimizing growth of candidate species through rigorous agronomic trials and to produce lignocellulosic biomass of suitable composition in quantities higher than that mentioned above. A better understanding of ecophysiological and agronomical responses of these species will help in efficient management and manipulation of plant growth characteristics suited to the prevailing conditions.

**Financial & competing interests disclosure**

The work was supported by the Higher Education Commission of Pakistan and the University of Karachi, Karachi, Pakistan. Z Abideen is recipient of a scholarship from HEC offered under their indigenous PhD programs. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

No writing assistance was utilized in the production of this manuscript.

---

**Executive summary**

**Sustainability & environmental consideration**

- Fossil fuels are depleting fast and require a more sustainable alternative, such as biofuel from halophytic lignocellulosic biomass. This approach is environmentally sound and addresses the food versus fuel debate.

**Halophytes as an energy feedstock**

- Although halophytes are a small fraction of the plant kingdom, their abundance in saline soils and tolerance to salty water irrigation, both of which are abundant worldwide, warrants investigation of their potential use as a source of biofuel.

**Selection criteria for energy crop**

- A candidate species should preferably be perennial, high yielding, requiring low inputs and cost effective in conversion into biofuel. It should have low lignocellulosic recalcitrance and be amenable to fermentation.

**Bioethanol production from lignocellulosic biomass**

- It is theoretically possible to convert cellulose from any source into sugar, which can be fermented into ethanol, if low-cost methods are available for this purpose.

**Biodiesel production prospects**

- Converting seed oil into biodiesel is relatively straightforward as it involves only hydrolysis of oil and separation of glycerol.

**Pitfalls & precautions**

- Collecting large quantities of feedstock, seed or biomass, will require small-scale field trials for growth maximization before embarking on large-scale cultivation. Large nurseries and tissue culture techniques may meet the demand of commercial-scale planting if technical know how for low-cost production is available.

**Conclusion**

- Research is needed to yield maximization of candidate species through agronomic trials and breeding for desirable traits such as low lignin and high cellulose content.

- Replacing fossil fuel completely with biofuel is highly unlikely in the foreseeable future. Therefore, developing a mix of techniques to use solar, wind and water as an energy source, along with fossil and biofuels, may provide a viable solution to meet demands.
References

Papers of special note have been highlighted as:

- of interest
- of considerable interest


23. Provides initial information about the oil content and fatty acid profiles of the local halophytes, which may help in their utilizations for human consumption.

24. Provides information about the influence of mineral matter on pyrolysis of biomass.

25. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

26. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

27. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

28. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

29. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

30. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

31. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

32. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

33. Provides information about the screening of some local halophytes for lignocellulosic contents to demonstrate the huge potential of halophytes as biofuel feedstocks.

Websites
101 FAO. FAO land and plant nutrition management service. 
www.fao.org/ag/agl/agll/spush
102 MNRE. Ministry of new and renewable energy booklets on renewable energy. 
www.Mnes nic.in
103 Edwards L. Estimate of flowering plant species to be cut by 600,000. 
www.physorg.com/news204438872.html
104 Knothe G. Historical perspectives on vegetable oil-based diesel fuels. 
105 FAO Commodities and Trade Division. Biofuels and commodity markets – palm oil focus. 