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Review

The potential resource of halophytes for developing bio-energy in China coastal zone

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Fossil fuel is being consumed rapidly and large-scale development of energy plants is very promising to solve future energy crisis. However, it is impossible to grow energy plants in arable farmland extensively in order to ensure the national food security in China. This necessitates exploiting non-cultivated coastal saline lands to produce biomass that may be converted into biofuel. Halophytes which produce plenty of biomass using saline resources may be an important source for bio-energy. This study shows the natural distribution of halophytic energy plants in coastal zone in China. Also the assessment of the potential developing halophytic energy plants in China coastal zone is carried out. Finally, several practical suggestions are offered for the future exploitation of coastal energy plants in China.

Keywords: Bio-energy, Halophytic energy plant, Coastal zone in China

INTRODUCTION

Up till the present moment, fossil energy resources (oil, gas and coal) are the main fuel of our industrial economies and consumer's societies (Abideen *et al*. 2011). However, with rapid economic development, the increasing need and consumption of energy results in serious environmental problems such as environmental pollution, greenhouse gas emission and global climate change (Liu and Diamond 2005). Additionally, these resources are not sustainable and are depleting fast. For instance, oil which provides about 44% of the energy requirement along with gas at their current rate of consumption will last during about 35 years and coal is likely to be the only available source of energy for the next century (Shao *et al*. 2010; Shafiee and Topal 2009). Therefore, the world will face severe issue of energy crisis. Likewise, the demand for energy in China has been increasing progressively and has seen rapid growth in crude oil imports from 8163.2×10^4 tons in 2001 to more than 23900.0×10^4 tons in 2010. This puts China as the third largest importer of crude oil behind United States and Japan in the world. It was estimated that, from 2001 to 2006, China had suffered a direct economic loss of over 100.0 billion yuan because of the high prices of crude oil in the international market. The problem of energy loss has become a bottleneck that limits social sustainable development in China (Liu and Shao 2010). In order to meet the energy demand of social development and reduce our dependence on oil as a source of energy and environmental protection, exploiting the non-polluting green energy sources like bio-energy that is converted from biomass such as trees and various crops, switchgrass, agricultural and forestry residues has become an emerging task for human being. In China, although a lot of studies about bio-energy had been done in different aspects, such as fuel ethanol, biodiesel, and energy crop selection, etc (Yan and Chen 2007; Sha *et al*. 2005; Chen and Meng 2007), most of them focused on cultivation of traditional energy plants (sugar cane, sweet sorghum, potato, and cereal) and biodiesel extraction. There are few studies concerning the potential of halophytes on coastal saline land as source of bio-energy. Supplementing oil with ethanol made from food crops is playing an important role in the releasing of crisis of

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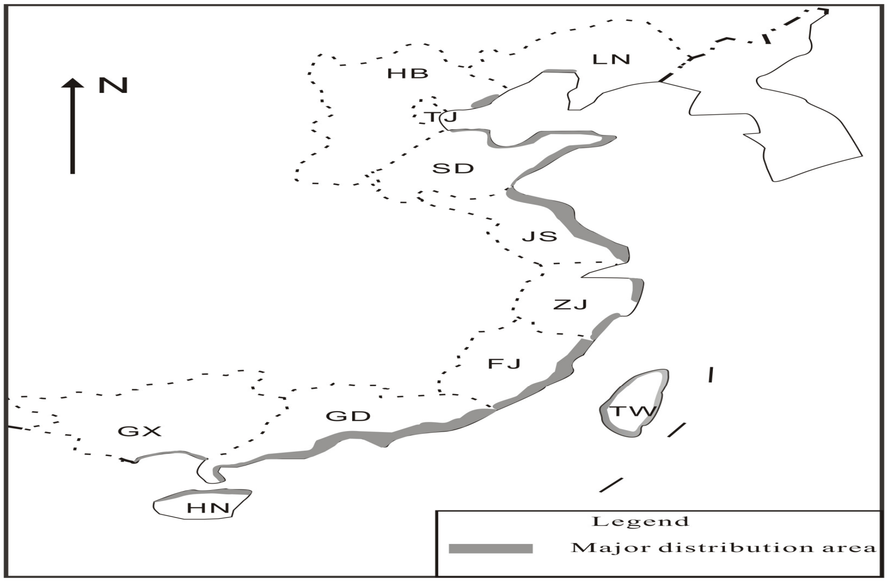

Figure. 1 The distribution of halophytic energy plants in China's coastal zone.
HN (HaiNan), GD (GuangDong), TW (TaiWan), GX (GuangXi), SD (ShanDong), JS (JiangSu), ZJ (ZheJiang), FJ (FuJian), HB (HeBei), TJ (Tianjin), LN (LiaoNing).

energy at present, but there exist a competition between food and fuel, particularly for the poor areas where population growth continues unabated. China has abundant biomass resources, which are estimated to be 2.61-3.51 billion tce (tons of coal equivalent) /for bio-energy feedstock, but the major biomass resources are crop straws and forestry residues. Moreover, China has fairly limited cultivated land resource for developing energy crops in a large scale in order to ensure the national food security. This had created a dilemma of choosing between food and fuel as ethanol is conveniently produced by fermentation of food crops. It is thus obvious that the best way to solve the shortage of energy is developing new energy plants which could not occupy the agricultural land. In fact, there are sources of material other than food crops having potential for conversion into fuel. As an example, in most halophytes, a number of them can produce appreciable compounds, which are similar to the petroleum or could be converted to fuel (Glenn et al. 1991; Abideen *et al*. 2011). Especial use of halophytes as biofuel crop is advantageous because they could tolerate extremely harsh conditions and do not compete with conventional crops for high quality soil and water and hence do not encroach on the resources needed for food crops (Rozema and Flowers 2008). This means that utilizing halophytes which are renewable and outside the human/animal food chain, and have high production may be a more desirable option for developing biomass energy in China.

Halophyte is a kind of native flora of saline soils, which is able to grow in habitats with a high concentration of salt and may be irrigated with saline water or even with seawater without any major ill effects on growth and production (Parida and Das 2005), as found in saline or alkaline semi-deserts, salt marshes, steppes, and sea coasts. The latter is considered as one of the most productive sources in terms of potential bio-energy. This is because that about 98% of water in the world is saline and over 800 million hectare of the world is coastal tidal flat affected by salinity (Rozema and Flowers 2008). Cultivation of halophytes on these vast coastal saline lands by using huge amounts of seawater in some cases would spare arable land and fresh water for conventional agriculture. By then, if the halophytic energy species are properly exploited, we would partly solve the energy crisis and halophytes would be hence a best choice for the above purpose. China has about 500 halophytic species, accounting for 24% of halophytes worldwide (Khan and Qaiser 2006), many of them could be used for biomass production as source of material for biofuel (Zhao *et al*. 2002). This paper is intended to introduce the natural distribution and energy potential of major halophytic species from the coastal zone of China, which will be useful for enhancing biomass energy industry in China and around the world.

Distributions of major halophytic energy plants in coastal zone of china

Based on the surveys from April 2009 to May 2010 and a number of previous studies on halophytes in China (Zhao *et al*. 2002; Duan *et al*. 2008; Mo and Li 2010; Ling 2010; Guo *et al*. 2011; Liu *et al*. 2008; Ma and Zhang 2006; Wang *et al*. 2008), 他he distribution of halophytic energy plants in coastal zone of China was shown in Figure 1,

Table. 1 Basic information of 27 halophytic energy plants in coastal zone of China

Species	Family	Distribution	Habit	Life form	Height(m)
Achnatherum splendens	Gramineae	TJ, LN	Herb	Perennial	0.5-2.5
Helianthus tuberosus	Compositae	GD, GX, SD, JS	Herb	Perennial	1.0-3.0
Ricinus communis	Euphorbiaceae	TW, HN, GX, JS, GD, TJ	Shrub	Perennial	1.5-2.0
Glycyrrhiza uralensis	Leguminosae	SD	Herb	Perennial	0.3-1.2
Phragmites australis	Gramineae	SD, LN, TJ	Herb	Perennial	1.5-2.5
Puccinellia distans	Gramineae	TJ, SD, JS, LN	Herb	Perennial	0.2-0.3
Xanthium sibiricum	Compositae	SD, JS, HB, GD	Herb	Annual	0.2-0.9
Tamarix chinensis	Tamaricaceae	GD, SD, HN, JS, ZJ, FJ	Shrub	Perennial	2.0-5.0
Calotropis gigantea	Asclepiadaceae	GD, GX, HN	Shrub	Perennial	2.0-3.0
Salicornia bigelovii	Chenopodiaceae	TJ,SD,JS	Herb	Annual	0.1-0.4
Panicum virgatum	Gramineae	SD,TJ, FJ, GD, HN	Herb	Perennial	1.0-2.0
Euphorbia tirucalli Linn	Euphorbiaceae	HN, GD, TW	Arbor	Perennial	2.0-6.0
Suaeda salsa	Chenopodiaceae	SD, JS, ZJ	Herb	Annual	0.5-1.5
Spartina alterniflora	Gramineae	TJ, JS, SD, ZJ, GD, GX, LN, FJ	Herb	Perennial	0.1-1.2
Sporobolus fertilis	Gramineae	JS, ZJ	Herb	Perennial	0.3-1.2
Hippophae rhamnoides	Elaeagnaceae	JS	Shrub	Perennial	1.0-5.0
Miscanthus sinensis	Gramineae	JS, ZJ, FJ, TW, GD, GX, HN	Herb	Perennial	1.0-2.0
Elaeagnus angustifolia	Elaeagnaceae	LN	Arbor	Perennial	2.0-3.0
Nitraria tangutorum	Zygophyllaceae	SD	Shrub	Perennial	1.0-2.0
Vitex trifolia	Verbenaceae	SD, GD, HN	Shrub	Perennial	1.5-5.0
Lycium chinense	Solanaceae	GD, GX, FJ, ZJ, SD	Shrub	Perennial	0.5-1.0
Glycine soja	Leguminosae	LN, GD, GX, SD, JS, ZJ, FJ	Herb	Annual	0.3-0.9
Kosteletzkya virginica	Malvaceae	GD, GX, JS, TW	Herb	Perennial	0.5-0.9
Suaeda glauca	Chenopodiaceae	TJ, SD, JS, ZJ	Herb	Annual	0.2-1.5
Stipa bungeana	Gramineae	JS, GD, GX, HN	Herb	Perennial	0.2-0.6
Rhizophora apiculata	Rhizophoraceae	FJ, GD, GX, HN, ZJ, TW	Arbor	Perennial	2.0-4.0
Sapium sebiferum	Euphorbiaceae	FJ, GD, GX, HN, ZJ, TW	Arbor	Perennial	12.0-15.0

HN (HaiNan), GD (GuangDong), TW (TaiWan), GX (GuangXi), SD (ShanDong), JS (JiangSu), ZJ (ZheJiang), FJ (FuJian), HB (HeBei), TJ (Tianjin), LN (LiaoNing).

and the information on twenty-seven halophytic species was summarized in Table 1. The 27 species, belonging to 13 families were distributed along the seacoast and nearby saline areas of different coastal provinces in China (Table 1). The majority of these species belong to the gramineae, compositae, chenopodiaceae and leguminosae, accounting for 50% of the total species. Among them, there are four arbor species and six shrubs, the rest are perennial or annual herbs. A wide variation in their height was also recorded (Table 1).

Also, Table. 1 and Figure. 1 clearly showed the unbalanced distribution of halophytic energy plants in coastal zone of China. Although there are rich oil halophytes with wide distributing range and better adaptability in coastal zone in China, the species distribution in families is not uniform and there is an obvious difference in their regional distribution. More coastal energy halophytes are distributed in southern provinces than in northern provinces. Therefore, we can conclude that halophytic energy plants in coastal zone of China decreased gradually from south to north and from tropical to temperate regions . For example, there are only a few halophytic energy plants (e.g. *Achnatherum splendens*, *Elaeagnus angustifolia*, *Glycyrrhiza uralensis*) that can grow in temperate zone (such as Shandong and Liaoning), where the temperature is the main limiting factor for them. However, most of halophytic energy plants are better adapted for tropical and subtropical regions like southern China. One probable reason is that southern China (e.g. Hainan, Guangdong) can receive more heat and light from the sun because of the lower latitudes and is thus more suitable for energy plants. So many halophytic energy plants are identified and developed on large scale due to the high temperature and marine climate in Hainan and Taiwan (Bhattacharya *et al.* 2003; Richardson 2006; Shao and Chu 2008).

Table. 2 Tidal flat areas of the coastal provinces and municipalities in China.

Provinces	Coastline length (km)	Tidal flat area ($\times 10^2 hm^2$)	Provinces	Coastline length (km)	Tidal flat area ($\times 10^2 hm^2$)
Liaoning	2620.5	1974.2	Zhejiang	6141.2	2444.0
Hebei	599.0	1167.9	Fujian	4830.0	2069.0
Tianjin	157.5	370.3	Guangdong	5300.9	2030.4
Shandong	3733.4	3223.6	Hainan	1528.0	518.8
Jiangsu	1011.4	5090.4	Guangxi	1437.5	1005.3
Shanghai	449.4	904.2	Taiwan	1576.0	143.0

Potential of developing bio-energy resources in coastal zone of china

Potential of halophytic energy plant resources

Considering the current land policy of China, development potential of bio-energy resource in China mainly depends on potential land area for cultivating fuel plants and unit-area yield as in other countries of the world. Without consideration of agriculture-forestry land used currently and salt-alkali land in inland, potential bio-energy resource in China only depends on coastal salt-alkali land for supporting halophytic energy plant growth. According to statistics, to date, China has a large tidal flat that spans 12 coastal provinces and municipalities from northern Yalu River estuary (Liaoning Province) to southern Beilun River estuary (Guangxi Province), with a total area of more than 2.0 million hm^2 (Table. 2). This number is rocketing in a rate of 13,300-20,000 hm^2 per year. On these non-agricultural coastal lands, it is not suitable for planting traditional crops due to extreme salinity and other adverse factors. However, the state of coastal land is appropriate for growth of halophytes or salt-tolerant plants. This will provide a solid basis of original materials for substituting fuels in near future in China. Moreover, the varied climatic conditions of the coastal provinces of China ranging from mild coastal to extremes of hot and cold have created a richly diversified flora of halophytes. A recent survey reports that China is one of the countries with the richest halophyte resources; there is about 500 halophytic species which are distributed in coastal salt marshes, accounting for 19.3% of halophytes worldwide (Khan and Qaiser 2006). Many of them have important economic value and could be used for biomass production as source of material for biofuel (Zhao *et al*. 2002).Therefore, the widely coastal tidal flat can offer excellent environmental conditions for fully utilizing and cultivating halophytic energy plants at a large spatial scale, which will have a great potential of supplying bio-energy resources to meet the demand of large-scale industrialization of bio-energy, with the co-benefit of fulfilling the demands of eco-society. For instance, only in Jiangsu province, there are about 5.09×10^5 hm^2 of tidal flat land for planting halophytes (Ling 2010), accounting for 25.0% of the total area of China's tidal flats. This number continues to grow at a rate of 0.13×10^4 hm^2 per year (Ma and Zhang 2006). It is highly advantageous to grow halophytic energy plants because of north-south obviously climatic differences resulted from the geographical feature with long and narrow in coastal zone of Jiangsu province. Most of energy halophytic species with the properties of drought tolerant, saline-resistant and high net productivity are found to be suitable for growing in these halomorphic soil conditions (Ling 2010; Ma and Zhang 2006; Liu and Shao 2010). Taking an example of cultivating *Helianthus tuberosus*, there are a production of 26.1×10^5 tons of bio-alcohol and 14.9×10^5 tons biodiesel / year in Jiangsu province. At present, applicable land resources for halophytic energy plants in coastal zone of China can reach 2.09×10^6 hm^2. Given that *H. tuberosus* is cultivated, there is a production of 6.13×10^6 tons biodiesel oil, and biomass production can reach 235.2×10^6 tons / year, which is equal to 1.57×10^6 tons of standard coal. In addition, it has no impact on agricultural land in plan. China has about 300 halophytes in coastal zone, many of which may produce good materials for transforming into biodiesel oil. The above is just a primary evaluation, which varies in different coastal provinces under different climatic conditions. Without doubt, land resources mentioned above will become an important base for developing biomass energy. (table 2)

Main halophytic energy species in China coastal zone

According to the research results of the former scientists (Zhao *et al*. 2002; Zhao *et al*. 2002; Duan *et al*. 2008; Duan *et al*. 2008) and our investigation, China has about

Table. 3 Main halophytes for ethanol production and their outputs and energy characteristics in China coastal zone

Species	Yield (t/hm^2)	Energy content (GJ/t)	Energy output (GJ/hm^2)	Data source
Helianthus tuberosus	75.0~105.0	17.6~20.0	1320~2100	Long *et al.* 2005
Tamarix chinensis	17.0~20.0	16.5~21.7	280~434	Xiao *et al.* 2005
Achnatherum splendens	7.5~10.0	17.2~18.1	129~181	Dong 2004
Phragmites australis	20.0~40.0	18.7~20.0	374~800	Yan et al. 2010
Panicum virgatum	9.4~25.0	15.5~18.0	145~450	Zhao *et al.* 2005
Miscanthus spp.	15.0~30.0	16.5~17.7	247~531	Xie *et al.* 2008
Spartina alterniflora	30.0~50.0	14.0~16.0	420~800	Mo *et al.* 2010

500 halophyte species. Of all the halophytes mentioned above, there are more than 300 native halophytes in coastal areas in China (Ling 2010). Most of them can produce some compounds, which compositions are similar to the petroleum or could be converted to flue. According to the composition of the energy carrier material, they can be classified into two kinds. The first is the halophytes for producing bioethanol. This type is the rich in carbohydrates. The carbohydrate can be converted to flue (methanol, ethanol, etc.) through thermochemical means or zymotechnics. The second is the halophytes for producing biodiesel. This type is rich in hydrocarbons and grease. The hydrocarbons in this kind of plants would be distilled and converted to the oil just like the fuel oil refined from the petroleum, and the grease would be converted to the flue oil (namely biodiesel) through the microbial or enzymatic catalysis.

Main halophytes for bioethanol production

Bioethanol is probably the most ideal approach to solve energy crisis in the future. At present bioethanol is mostly produced from carbohydrate-rich plants (mainly refer to sugar, stark and cellulose plants). Currently in coastal tidal-flat zone except for salt-tolerant glycophyte (e.g. Sugar beet) there are some halophytes such as *Helianthus tuberosus, Tamarix chinensis, Achnatherum splendens, Phragmites australis* and so on, which can be irrigated directly with seawater and have great potential to produce fuel alcohol (Table. 3).

Helianthus tuberous belonging to sugar-rich plants, are widely grown in coastal zones and utilized to produce biofuel because of its strong adaptability towards adverse conditions such as seawater *(H. tuberous* can grow well in the land of 0.7%~1.0% salt content), cold, malnutrition, drought and flooding. As perennial herbs, *H. tuberous* has rapid propagation ability and is capable of producing 75.0~105.0 tons of biomass / hectare annually (Long *et al.* 2005; Liu *et al.* 2008). More than 70% of its tuber is synanthrin and fructose content is also high (Guo et al. 2011). Their synanthrin productions can reach 8.5~15.0 tons/hm^2, if converted to ethanol, and the synanthrin above may produce 3.5~6.8 tons of alcohol, whereas the production of the same amount of alcohol will need to consume 17.0~45.0 t of maize or wheat (Denoroy 1996; Hay and Offer 1992). Helianthus Tuberosus is known as one of the most potential alternatives because of its high yield and amazing growth rate.

Tamarix chinensis, a typically perennial halophyte, is one of the dominant species distributed only in China coastal land. It also shows strong adaptability and can easily survive due to its tolerance towards extreme salinity, drought, flood, and barren soil. Recent investigation shows that the content of hydrocarbons is high within *Tamarix chinensis*, whose leaf is rich in protein, fat and sulfur. The heat value of 1.0 ton *Tamarix chinensis* fuelwood is equivalent to that provided by 0.7 ton of standard coal. Meanwhile *Tamarix chinensis* belongs to growing-fast-type shrub species with short cycle and long harvest period. It is capable of producing more biomass for bioethanol production than most other conventional shrub. The fuelwood production of *Tamarix chinensis* can reach 19.5 tons /hm^2 every year (Xiao *et al.* 2005).

Achnatherum splendens is a perennial halophytic herb growing in both coastal zone and hinterland in China. Its seeds can germinate at 240 mM NaCl and plant could subsequently grow under more saline conditions with the pH value from 8.0 to 9.5 and salt concentration of more than 3.0% because it tolerates high level of salinity and alkalinity. The biomass contains 16.7% lignin and over 40% fiber (Dong 2004), and energy content is approximately 17.2~18.1GJ/ton of biomass; these characteristics make it a good candidate for ethanol production.

Phragmites australis, a tall perennial halophytic herb with 1.5~2.5 m height, is found in highly saline soils where salinity is 2.8% because of its strongly survival competitiveness ability and splendid resistance of saline-alkaline, drought and flood. Generally, P. australis is used as a good raw materials for paper making but its chemical composition (50% cellulose in stalk and 17%

lignin) makes it a candidate for bio-ethanol production (Yan *et al*. 2010). P. australis has a very high productivity, the total biomass attains to 20~40 tons/hm^2, among which the aboveground biomass is more than 10 tons/hm^2, accounting for 25~50% of the total biomass while the underground biomass occupying over 50%. The high capacity to produce biomass means that *P. australis* could produce more bio-ethanol production than most other conventional grasses.

Panicum virgatum, commonly known as switchgrass, is a perennial warm season bunchgrass native to North America. Since its introduction in 2005, it had been cultivated in Northern China. Currently switchgrass can be found along the coastal zones in Shandong, Tianjin, Fujian, Guangdong and Hainan of China. Since the mid-1980s, Switchgrass has been researched as a renewable bioenergy resource, because of the ability to produce moderate to high yields on marginal farmlands, including coastal tidal flat. The main advantages of switchgrass as a bioenergy plant are its stand longevity, drought and salt tolerance, relatively low herbicide and fertilizer input requirements, ease of management, hardiness in poor soil and climate conditions, and widespread adaptability. It is reported that in some warm humid southern zones, switchgrass has the ability to produce up to 25t/hm^2 dry matter, which contains 45% cellulose, 31.4% hemi-cellulose and 12% lignin (McLaughlin and Kzos 2005). Given that it contains approximately 18.8 GJ/ton of biomass, the energy output-to-input ratio can be up to 20:1, and switchgrass hopefully has the potential to produce up to 380 liters of ethanol per ton harvested. This highly favorable ratio is attributable to its relatively high energy output per hectare and low energy inputs for production.

Miscanthus spp. is a very common grass with C_4 photosynthesis, which widely distributes in tropical, subtropical and temperate regions in the world. In China, there are six species, mainly found in south of the Yangtze River, especially in provinces such as Jiangsu, Zhejiang, Guangdong and Guangxi (Lewandowski *et al*. 2003; Xie *et al*. 2008). *Miscanthus* species are self-incompatibility plants with characteristics of high biomass productivity, strong adversity resistance, extensive adaptability, good fiber quality and low ash content, etc. In recent years, Miscanthus has received a considerable attention as an excellent potential biofuel. Nowadays *Miscanthus* plants have been widely studied and tested in Europe and North America as one of the most promising energy plants for biomass feedstock production. Studies at various institutions, such as the University of Illinois, indicate that Miscanthus dry biomass yield is about 15~30 tons/hm^2 / year, which is almost equivalent to 36 barrels of petroleum (Lewandowski *et al*. 2000). When harvested, Miscanthus plant contains more than 50% fiber with a mean length of 3.0 mm and only 20%~30% water, which makes it possible to be widely used as fuel directly or converted into bioethanol. For example, German has built a 120-thousand-KW power plant using Miscanthus plants as fuel. Recent reports claim that using Miscanthus to produce ethanol gives better results than using corn or switchgrass, and Miscanthus can produce the same amount of ethanol as corn, while using less than half of the amount of cropland as corn (Salvatore *et al*. 2006).

In addition, *Spartina alterniflora*, which belongs to Gramineae family and spartinaschreber genus, might be a potential bio-energy species growing in salinized beaches. This plant is native from the North American Atlantic coast, commonly found in both salt marshes of the Gulf of Mexico and coastal areas from southern Newfoundland to central Florida. It was introduced artificially to the Jiangsu coast in 1979 and then extended to the most coastal provinces and municipalities of China (such as Guangdong, Guangxi, Fujian, Zhejiang, Tianjin and Shanghai) due to widespread seeds of *S. alterniflora* carried by wind and waves (Mo *et al*. 2010). Now *S. alterniflora* has developed strong ability to resist salt, flood and seawater irrigation and can even live underwater. As C4 plants, S. alterniflora has a big biomass with over 30 tons / hm^2 dry matter in a year, because of its high rate of photosynthesis, high primary productivity (Zhao *et al*. 2005; Chen *et al*. 2011), and high energy storage (Qing *et al*. 2008). The percents of crude protein, crude fat and crude fiber are 11%, 2% and 25% respectively (Shen 2011).

Main halophytes for biodiesel production

The so-called biodiesel is a cleaner burning diesel replacement fuel made from natural, renewable sources such as new and used vegetable oils and animal fats. Thus, biodiesel, like solar energy, wind energy and tidal energy, is also known as the most promising renewable energy in the 21st century. According to the distribution of halophytes in China's coastal zone and the investigation of their economic traits, the following halophytes have great potential to produce biodiesel (Table. 4).

Salicornia bigelovii, a highly salt tolerant stem succulent annual halophyte widely growing on mudflats and saline-alkali soil in the coastal areas of China, was reported to be a first-choice plant of direct seawater irrigation without diminishing its yield. Its seeds can germinate at >200 mM NaCl and plants exhibit fairly good growth on saline soil near coastal areas of China (Hua *et al*. 2010). The seed oil content ranges between 27.2% and 32.0% and the amount of unsaturated fatty acids (USFA) can reach more than 73% of the total fatty acids as compared to those plants growing in non-saline soil (<0.1% salt), where about 36% USFA was present (Glenn *et al*. 1991; Leith and Mochtchenko 2003). *S. bigelovii* could produce seed yield of 1.7~2.3tons/hm^2 and oil production of 0.6 tons/hm^2, which makes it a good biofuel

Table 4. Main halophytes for biodiesel production and their productivity in China coastal zone

Name of Species	Seed yield (t/hm^2)	Seed oil content (%)	Oil production(t/hm^2)	Data source
Salicornia bigelovii	1.7~2.3	27.2~32.0	0.46~0.74	Hua *et al*. 2010
Suaeda glauca	2.3~3.0	25.0~30.1	0.58~0.90	Du *et al*. 2009
Kosteletzkya virginica	0.5~1.0	17.0~21.0	0.09~0.21	Guo *et al*. 2011
Suaeda salsa	1.3~2.4	22.4~28.5	0.29~0.68	Mo and Li 2010
Ricinus communis	3.7~4.5	47.0~50.0	1.74~2.25	Zhou *et al*. 2010
Helianthus annuus	2.5~3.2	35.0~52.0	0.88~1.67	Chen and He 2011

candidate. In recent years, a lot of experiments on introduction of *S. bigelovii* have been carried out and successful in China's coastal provinces and municipalities of Liaoning, Shandong, Jiangsu, Fujian and Tianjin (Wang *et al*. 2011).

Suaeda glauca, as another potential species for biodiesel, is widely found in inland and near coastal areas of China. It can tolerate flooding, reduced soil aeration conditions and high salinity (>0.3% salt). The seed oil content of *S. glauca* is up to 25% or more and the rate of oil-producing reaches more than 28%. The USFA and essential fatty acids for human body is occupied 91.8% and 80.0% of total fatty acids separately, which is helpful in dilating blood vessels, alleviating asthma, and in industrial oil (Qi and Zhang 2004; Du *et al*. 2009).

Kosteletzkya virginica (Malvaceae) first found in marshes along the eastern seashore of the United States, is another promising perennial halophytes for producing biodiesel with such biological characteristics as drought resistant and saline tolerant. This species can tolerate seawater irrigation and growth environment with salt content of 0.5~1.5% (Gallagher 1995; He *et al*. 2003; He *et al*. 2006) where most of the conventional crops can't survive. It was reported that K. virginica collected from saline soil (0.4%NaCl) contained equal amounts of seed oil and crude protein in comparison to soybean. Oil content of the seed reaches about 20.0%. Protein content of the seed is 22.7%~28.2% and fatty acid is 20%~30%. Seed production of natural and cultivated species is 0.5~0.96 tons/hm^2 (Ruan *et al*. 2004; Ruan *et al*. 2005; Guo *et al*. 2011).

Suaeda salsa, an annual dominant species of halophyte, is one of the wild resources in seashore salt marsh soil where direct seawater irrigation is inevitable. Experiments conducted by Mo and Li (2010) have identified that *S. salsa* can grow normally when the salt content of soil was about 2.5% ~ 3.6% in coastal zone of China. Fat content of the seed accounts for 36.5% of the total dry matter, resulting in an oil yield ratio of 26.1%.

Helianthus annuus (Compositae) is a facultative halophytic species that has a strong adaptability towards adverse conditions such as seawater, cold, drought, alkalinity and lack of nutrition. Now it has become the fourth important and stable oil plant in semiarid area and slight saline-alkaline coastal zone of China. Oil content of the seed reaches about 45.0% (Cui *et al*. 2011; Chen and He 2011). Generally seed yield of 3.15-4.80 tons/hm^2 can be obtained with little inputs, which indicates a huge potential for development and utilization.

Ricinus communis (Euphorbiaceae) is another facultative halophyte that grows well in saline-alkali soils with a salinity of 0.4~0.6% and PH <8.0, as found in salt marshes or other littoral habitats. The seeds of R. communis contained only about 6% water and 47.0%~50.0% oil whose composition was the major ricinoleic acid (87%). The data presented here clearly indicate a great potential to obtain high-quality biodiesel feedstock from R. communis seeds (Wang 2001; Zhou *et al*. 2010). At the same time，the energy value of castor oil in the development of coastal shoal is gradually paid more and more attention in recent years. It is reported that almost chemical products made from oil and coal as raw materials can be obtained from castor oil (Han and Deng 2007; Sun and Liu 2006). As one of ten famous oils in the world, therefore, the high oil *R. communis* has an expansive application prospect, and castor oil is also known as renewable oil resources.

As can be seen in Tab. 4, seed oil content of above halophytes showed a great deal of variation ranging from 17.0% in K. virginica to 52.0% in H. tuberosus. This indicated that the differences in oil contents of above halophytic herbs were significant.

Suggestions for exploitation of halophytic energy plants in china coastal zone

As mentioned above, producing bio-energy resources relying on halophytes from non-cultivated lands, such as coastal saline land, may be the best way to solve the problem of food or fuel in the future. However, the feasibility of halophytic energy plants development might vary greatly in different coastal regions, depending on different economic, environmental, and technological factors. Therefore, the following suggestions are very necessary:

First, as the base of biomass resource utility, a systematical investigation of coastal halophytes in China should be carried out urgently. Although some researchers have shown the general amount and distribution of halophytes in China (Zhao *et al*. 2002), they provided data based on generalizations of scattered investigations, rather than on systematic research. Thus further investigations and evaluations are still needed. For instance, the actual yield and the yield potential of many halophytes remain unknown because of absence of their domestication. Isolated field studies with *S*. europaea and *S*. bigelovii reported a production of 20 tons of total biomass per hectare, with a yield of two tons of seeds (Goodin *et al*. 1990; Glenn *et al*. 1991). While such reports are encouraging, actual yield in a commercial set up would probably be much lower and would require more manpower, material and financial input.

Second, it is essential to plant salt-tolerant energy plants according to local conditions. In most cases, the coastal zone is a new land by permanent recession of the seawater line. Its salt contents are quite different from place to place. For example, some places, wastelands inside the coastal levee are slight-alkali or saline and some salt-tolerant glycophyte such as sugar beet and sweet sorghum should be planted; for moderately saline lands, supralittoral zone H. tuberous L is ideal; for highly alkali or saline land (e.g. intertidal zone) we have to choose Salicornia bigelovii, Suaeda glauca, Tamarix chinensis or Achnatherum splendens. Other environmental factors such as water consumption, drought resistance, and light should also be considered.

Third, the screening and breeding of high energy halophytic species needs to be solved as soon as possible. At present, in China, there is no mature experience in selecting and cultivating halophytes on a large scale. Most halophytes are still wild and their yields are very low. Fortunately, some studies showed that salt-tolerant gene in halophytes could be cloned into glycophyte by transgenic methods (Liu *et al*. 2002; Kinney *et al*. 1996; Nanjio *et al*. 1999). Therefore, an experimental base should be set up, to utilize biotechnology, especially transgenic technology, to select or breed more salt-tolerant species with a high production, high heating value and high-starch/oil content, together with ecological benefits, which are suitable to be grown in coastal zones in China. Thus, the large-scale development and industrialized production of halophytic energy plants is expected to be a new agriculture pattern in coastal zone of China.

Fourth, halophytes have higher salt content and higher ash content compared to traditional crops. When they are regarded as biomass energy, the pre-desalination issue needs to be solved. Besides, the conversion of lingo-cellulosic material into ethanol involves hydrolysis of cellulose through cellulase enzymes. In the process of conversion, lignin may be a limiting factor that resists hydrolysis of biomass. So we should further advance the converting and extracting technology to enhance conversion efficiency of halophytes biomass energy and decrease production costs.

Fifth, Chinese governments should take various measures to promote the development of halophytes bio-energy, including financial subsidies, tax breaks, and project approval. Some departments have constituted these preferential policies, but they are not enough. In addition, China has no scientific developing plan of coastal halophytic energy plants nowadays. Therefore, it is needed to draw up developing planning of halophytic energy plants in China coastal zone and decrease the risk of large-scale plantations. Also, large industrial base should be established for the sake of exploiting the halophytic energy plants in China and making fuel products more competitive.

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