Renewable and Sustainable Energy Reviews 14 (2010) 530–534

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Comments: Main developments and trends of international energy plants

Liu Zeng-Hui [b], Shao Hong-Bo [a,b,c,*]

[a] State Key Laboratory of Soil Erosion and Dryland Farming, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Northwest A&F University, Yangling 712100, China
[b] Institute for Life Sciences, Qingdao University of Science & Technology (QUST), Qingdao 266042, China
[c] Yantai Institute of Coastal Zone Research for Sustainable Development,Chinese Academy of Sciences, Yantai 264003, China

ARTICLE INFO

Article history:
Received 26 June 2009
Accepted 10 August 2009

Keywords:
Energy plant
Planting
Biodiesel
Development
Suggestion

ABSTRACT

Energy plants play an important role in the development of bioenergy. In the world, there are many kinds of energy plants, but they are not utilized sufficiently. In the current paper, we discussed the situation of the research and development of traditional energy plants and some new energy plants in the world. At the same time, we focused on the distribution of some special energy plants and discussed their advantages in China. At last, we provided some suggestions for developing global energy plant field.

Contents

1. Introduction

With the development of the society, more and more energy is demanded. But at the same time, the pollution of environment becomes more and more serious and a large amount of crop is demanded. The problem of energy is the critical issue for social sustainable development. So many people and governments focus on the bioenergy, which is converted from biomass.

Bioenergy has the following advantages: first, the resource of biomass is abundant and widespread such as trees and various crops, switchgrass, agricultural and forestry residues. It is estimated that the solar energy absorbed by plants is equal to 60–80 billion tons of oil, which is roughly 10 times of the world's major fuel consumption [1,2]. Second, the raw material is reproducible. For example, vary kinds of algae are reproducing very fast. Third, the quantity of carbon dioxide produced by combustion is equal to the quality assimilated by plants. So it could not increase the content of carbon dioxide in air and would help to maintain the balance of ecosystem [1,3–5]. Therefore, bioenergy is named "green energy" too. It is estimated that 40% of the total consumption of energy would come from biomass energy in the world in 2015 [1,6].

In order to produce more and higher efficiency bioenergy, many researchers make great efforts to study energy plants. Energy plants are plants that can produce some compounds, which composition is similar to the petroleum or could be converted to flue [6,7]. They can be classified into three kinds: first type is the rich in hydrocarbons. Those hydrocarbons in this kind of plants would be distilled and converted to the oil just like the fuel oil refined from the petroleum; the second is the rich in carbohydrate. The carbohydrate can be converted to flue (methanol, ethanol, etc.)

* Corresponding author at: Institute for Life Sciences, Qingdao University of Science & Technology (QUST), Qingdao 266042, China. Tel.: +86 532 84023984.
E-mail address: shaohongbochu@126.com (S. Hong-Bo).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2009.08.009

through thermochemical means or zymotechnics; the third is the rich in grease. Through the microbial or enzymatic catalysis, the grease would be converted to the flue oil (biodiesel, etc.) [7–10].

In summary, the perfect energy plant should meet the following standards: first, it should bring huge economic benefit. The cost for cultivating it should be very low. Second, the plant must be cultivated easily. If it can grow in those terrifically environment, it must be the first choice. Third, the content of the available compound in plants should be high, and the best thing is that the compound is similar to the component of petroleum. So the converting technology would be very simple, which could make the application very wide.

According to the above points, many people are searching for the accordant plant or reconstruct the known plant by biotechnology. Since 1978, researchers in America have filtrated about 200 kinds of special energy plants and planted them in about 100,000 hm^2 [9,11,12]. In China, the research in energy plants began in 1994. According to statistics, there are 1554 species oil plants, belonging to 151 families and 697 genera, and accounting for 5% of the seed plants [9,13].

2. Major study contents and progress of energy plant in the world

The distribution of energy plants is widespread. It mainly includes traditional energy plants and new energy plants.

2.1. Traditional energy plants

Traditional energy plants are mainly crops that have been cultivated by people for about thousands of years. Sometimes, they are named energy crops too. It includes corn, sorghum, cassava, sugar beet, soybean, rapeseed and castor-oil plants. They were used to be planted for food and feed, but now a part of them are converted to flue used by vehicle.

The amylum is the mainly component of corn and cassava. The percentage is about 65% in the corn, but the content of amylum in the high starchy corn is above 70%. Cassava is usually planted in tropic and semi-tropical regions. The content of amylum is about 28% in fresh cassava and 70% in dry cassava. It can be hydrolyzed to glucose by hydrolytic enzyme which could be converted to ethanol through fermentation [11–13].

Sorghum was proposed as a potential bioenergy crop over 20 years ago. There are many advantages for sorghum as a potential energy plan: the first is yield potential and composition; the second is water-use efficiency and drought tolerance; the third is the established production system; the fourth is the potential for genetic improvement using both traditional and genomic approaches [14,15]. Starch, sugar and cellulose are the main components of sorghum. They could be directly used for biofuel production.

Soybean, rapeseed and castor-oil plants are planted widespread in the world. Because they contain the oil which could be converted to biodiesel by chemical or biological catalysis. Therefore, more and more countries make efforts to enlarge the planting acreage. The percentage of oil in soybean, rapeseed and castor-oil plants is usually about 20%, 42% and 50%, respectively. Through biotechnology methods, the percentage could be increased. For example, it is reported that the researcher have cultivated a kind of rape whose percentage of oil in its rapeseed is about 80% [13,15].

2.2. New energy plants

Because most traditional energy plants are crops, planting them must take a lot of agricultural land. In some countries, the area is very small, and the agricultural land is limited very much. What is more important, a lot of people in some developing or poor countries have no enough food for living. So developing special energy plants that could be planted in mountains or terrific environment is more important in these countries to solve the scarcity of energy. In other countries, developing special energy plants would help to national security.

The new energy plants focused on by researchers recently in the world main include the following species:

Jatropha curcas L.: It is a kind of frutex belonging to Euphobiaceae family and Jatropha genus. The height of trunk is usually 2.0–5.0 m. This plant is distributing in tropic mostly and coming of America. Its capsule is ellipse or roundness, whose flowering is usually from May to October [5,7,10]. The ellipse contains about 40% oil which quality is very good. The oil was tested in diesel engine and the result indicates that oil could be as a supplement or replacer of the flue [8,9].

Cladrastis lutea: It is a kind of ruderal, which grows in drought or half-drought areasand is mainly distributed in America. Through simple process, it could produce oil which has good combustibility just like the petroleum. It is estimated that it can produce about 1600 l per hectare [10,12].

Copaífera L.: It is a kind of arbor, which usually grows to 30 m high and 1 m thick and distributes in Amazon drainage area. It stockpiles a lot of oil in bole. When people bore in bole, it would discharge about 15 l oil in 2.5 h [7]. The component of the oil is similar to the fuel. So it can be as the transportation fuel directly.

Pistacia chinensis: It is a superior tree species for biomass energy. It bears fruits from September to November, producing inverted, egg-shaped globular drupes. It is reported that the oil content of its seeds and kernels is approximately 42.5% and 56.5%, respectively [8,9,16,17]. It is mainly distributed in China. The oil has a long history as the edible oil in China, but it is mainly used in industries. Recently, it can be as the good raw material of the biodiesel production [16,17].

Panicum virgatum L.: It is a biomass crop that is a perennial C4-type grass. Cellulose is the main structural substance of it. It can be converted to ethanol as fuel for vehicles. Production costs of switchgrass are much lower compared to annual fibre crops or compared to other biomass crops, which is mainly due to the low establishment costs and low input requirements. The grass has a wide range of adaptation and is usually developed in North America and Europe. It has been developed for energy in North America, Canada and more recently in Europe [18–21].

Pennisetum purpureum Schum: It is a kind of herbage. Because elephants like to eat it, so it is also named elephantgrass or Napier grass and regarded as forage crops. It is mainly distributed in tropic and semi-tropical zones and growing very fast. Owing to having the character of high biomass, perennial nature, pest resistance and better adaptability, it can be planted very easily and widespread. Besides, as forage for direct animal consumption and conservation fodder, this grass has potential industrial use for alcohol and methane production [9,11,12,22,23]. It is reported that the energy stored in elephantgrass per hectare is equal to the energy stored in 36 barrels petroleum. Now the researchers from Europe and America start to study it. If they can plant the grass in about 10% suitable land in Europe, it can offer about 9% electricity of whole Europewastage [12].

There are a lot of kinds of energy plants in the world, but mostly plants are not adapted to atrocious environment. In order to meet the social demand, we must utilize the land which is useless in agriculture, especially barren and droughty land and deserted mountains. So developing these special energy plants is necessary.

Table 1
Main energy plants empoldered by people in the world.

Species	Shape	Distributing	Production
Jatropha curcas L.	Arbor	China	Biodiesel
Eucalyptus spp.	Arbor	Australia	Bio-gasoline
Pennisetum purpureum Schum	Herbage	tropic and semi-tropical zone	Electricity
Panicum virgatum L.		America	Ethanol
Bombax ceiba Linn	Arbor	Australia	Heavy oil
Trachycarpus fortunei (Hook.) H.Wendl.	Arbor	Rain forest	Combustible oil
Energy grass	Herbage	Hungary	Compressed fuel
Pittoaporum tobira (*Thunb.*) *Ait.*	Arbor	Philippines	Bio-gasoline
Copaifera	Arbor	Amazon River Basin	Biodiesel
Pistacia chinensi	Arbor	China	Biodiesel

In addition, some hydrophily plants could be used as energy plants, especially those growing in ocean. In America, researchers have refined the biodiesel from gigantic algae which grows in the west coast of America. However, Canadian put a special kind of bacteria to the algae which grows very fast in ocean. They find that through chemical disposal, the algae can produce "petroleum". At the same time, Japanese has distilled the "petroleum" from algae grown in fresh water directly [9,18,24].

3. The application and development of energy plant in the world

The crisis of energy is more and more serious. In order to release the scarcity of energy, many countries start to cultivate some energy plants. At present, most countries mainly cultivate the traditional energy plants.

South America is the main region to cultivate soybean and sugarcane. The planting acreage of soybean in Brazil and Argentina is about 34,700,000 hm^2 and the yield is 96,500,000 tons in 2003. In Brazil, the yield of soybean is about 59,300,000 tons in 2007 and the yield will increase to 62,300,000 tons in the next year [25–29]. At the same time, Brazil is the country whose yield of ethanol is the most in the world. The yield is about 13,000,000,000 l in 1991 [3]. In 2004, the yield of sugarcane is about 390 million tons and the sugarcane used to produce ethanol is 190 million tons. In 2006, the yield is 372.7 million tons in Brazil. And the number will increase to 4.25 million in 2007 [25,27,28].

The main traditional energy plants in North America are corn, soybean and sorghum. The yield of corn in America is the largest in the world. In 2007, because of the development of bioethanol industry, the planting area is increasing to 90,459,000 acres and the yield would get to 12,500 million Bushels, which exceed the yield of 2004 with about 7 million Bushels. Approximately 15–20% of the US corn crop will be used to produce approximately 5.6 billion gallons of ethanol [7,27,28].

In Europe, the main energy plant is rapeseed. Germany is the country whose yield of biodiesel is the largest in the world. In Germany, there is about 1,000,000 ha-land for planting rapeseed specially [27].

In Asia, corn, soybean, rapeseed, sugar beet and sugarcane are the main energy plants. India is one of region where the largest acreages of sorghum are concentrated, and where it is a staple crop for providing food grain, feed grain and forage, and is even used in industry as a fuel source (combustion) [15,30]. In China, the yield of soybean, rapeseed and sugar beet is very high.

Traditional energy plants are playing an important role in the releasing of crisis of energy at present. But we must envisage the problem of population and foodstuff. The best way to solve the shortage of energy is developing new energy plants which could not occupy the agricultural land. The distribution and application of main new energy plants is shown in Table 1 [2,4,8–13].

Because the technology of cultivation and conversion is not perfect now, a lot of new energy plants are not utilized.

In China, there are many kinds of energy plants. With the acceleration of urbanization and traffic industry the development is very fast. For example, *J. curcas* L. is distributed in many places in China, which is the one studied at best by researchers. Sichuan Province is a main location for *J. curcas* L. planting. Recently, three foreign companies declared that they would invest to *J. curcas* and set up a factory to produce biodiesel in Sichuan Province [4]. The distribution of energy plant in China is shown in Fig. 1. Energy plants are mainly distributed in southwest provinces (Sichuan, Yunnan, Guangxi and Guizhou) in China. Only in Yunnan Province, there are about 17,000 species of higher plants and the number of energy plant contained oil is about 400 [4]. In addition, the development of bioenergy is very fast in Taiwan. It is reported that the potential of biodiesel production would achieve 100 million liters per year by 2010 and 150 million liters by 2020 [31].

4. Suggestions for the development of energy plants in the world

Environmental pollution becomes more and more serious and the energy consumption is increasing very fast. Biomass energy is the best way to solve these problems. In addition, because there are lots of biomass in the globe, and the price is very cheap. So biomass energy may be the main part of the energy in the future. In order to develop biomass energy preferably, we should take some measures to research and cultivate various energy plants according to different regions and conditions. From the current developing trend of energy plants and industry, we make some suggestions as follow.

First, governments must constitute various statutes to ensure the development of energy plants all right. Though some countries have constituted these kinds of rules, they are not enough. At the same time, the government must frame the plan to mark out the development of energy plants, and inspire people to plant these plants with competing effects. For example, there is an ethanol plan in Brazil, which can guide the development of ethanol industry [4,9]. In Europe, there are 15 members of European Union plan to cultivate *Pennisetum purpureum Schum* (elephantgrass) to generate electricity [12].

Second, enhancing the ability of scientific and developmental research is the linchpin of the development. Now, many researchers mainly focus on the search of new energy plants. Most new energy plants are wild. Besides, the yield is very low. So we should utilize biotechnology to reconstruct them and enhance the quality of production. In addition, advancing the converting technology may help develop energy plants.

Third, because most energy plants are woody plant, planting these plants could be considered with the forestation project. It is not only protecting the environment but also heightening the

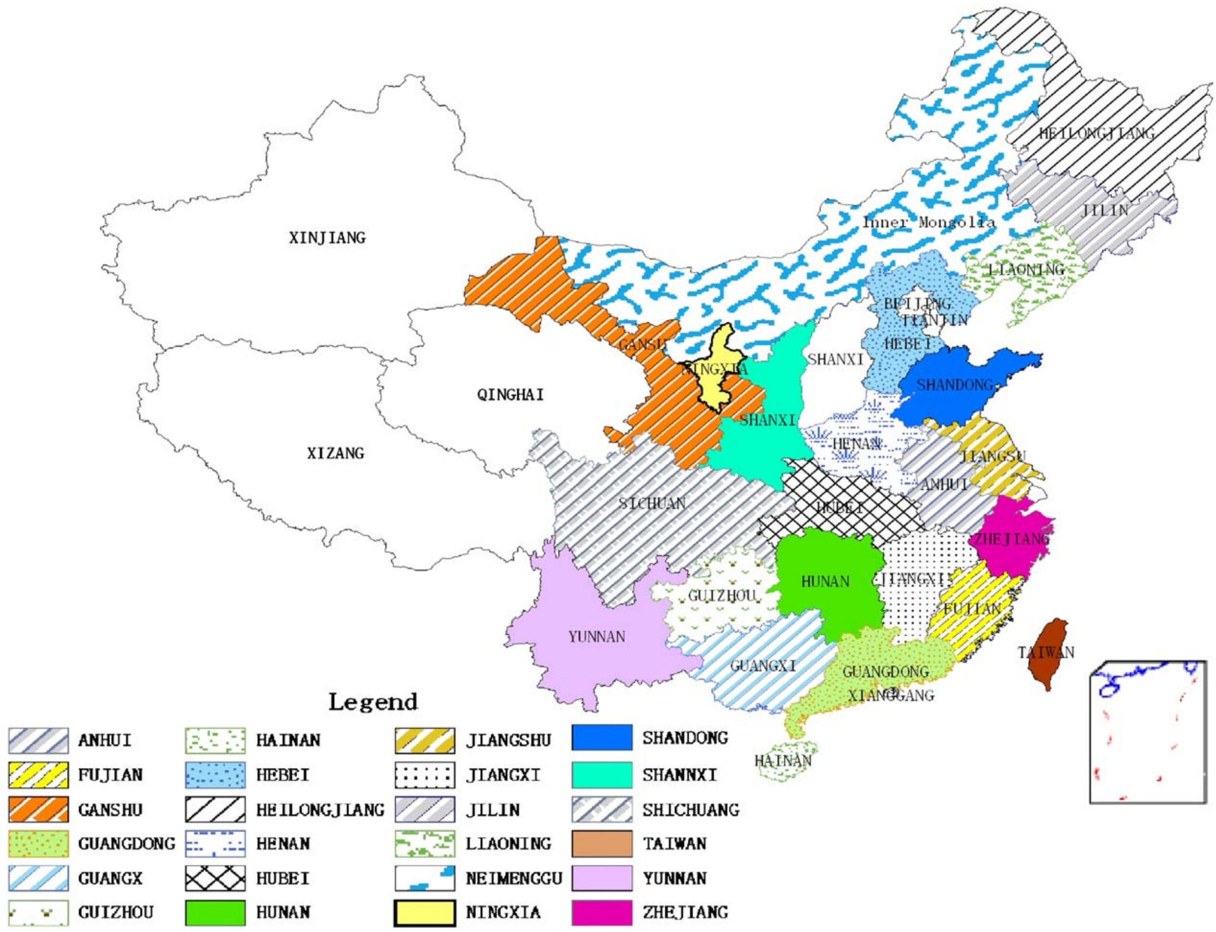

Fig. 1. The distribution of energy plant in China.

economic benefit. For these special plants which could grow in execrable environment, the benefit is more obvious.

Fourth, energy plants are not growing on the land only. In the ocean, there are many kinds of plants. We can look for new energy plants in the ocean. But there are few reports about this aspect.

Acknowledgements

This work has been jointly supported by One hundred-Talent Plan of Chinese Academy of Sciences, Shao M-A's Innovation Team Project of Education Ministry of China and Northwest A&F University, International Cooperative Partner Plan of Chinese Academy of Sciences the Cooperative&Instructive Foundation and Award Foundation of State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau(10501-HZ).

References

[1] Zhou DM, Meng FL. Biomass energy—the future sustainable energy. Civil Sci Technol 2007;1:73.
[2] Tan LW, Jian BQ. Exploitation and utilization of biomass energy. Agric Energy Technol (Renewable Energy Industry) 2007;1:18–27.
[3] Wang O. The development policies and the status quo and future trends of development and utilization of biomass energy in China. Chin Rur Eco 2007;7:10–5.
[4] Zheng W. Biomass energy development in the world and development possibility in Yunnan Province. J West China Forest Sci 2006;2:132–6.
[5] Wu GJ, Liu J, Lou ZP, Kang L. Research status and development proposals of Energy Plant. Sci Technol Soc 2006;1:53–7.
[6] Amigun B, Sigamoney R, Blottnitz HV. Commercialisation of biofuel industry in Africa: a review. Renew Sust Energy Rev 2008;3:690–711.
[7] Fei SM, Zhang XD, Yang GY, Zhou JX, Liu FY. On domestic and international situation of energy plant resources and their exploitation. J Sichuan Forest Sci Technol 2005;3:21–6.
[8] Sun HJ, Tan YH. Exploitation and utilization situation of energy plants resources and its prospect. J Anhui Agric Sci 2007;35:7900–8.
[9] Fu DQ, Huang HW. Brief introduction of exploitation and utilization of fuel plants resources. J Wuhan Bot Res 2006;24:183–90.
[10] Wang Y, Long CL, Chen ZY. Utilization of Jatropha Cuscas L., an "Energy Plant" for biodiesel. J Anhui Agric Sci 2007;35:426–7. 429.
[11] Graham RL. Forecasting the magnitude of sustainable biofeedstock supplies: the challenges and the rewards. Biofuels Bioprod Bioref 2007;9:1–9.
[12] Song YF. Progress of exploitation and utilization on energy plant. Biomass Chem Eng 2006;6:51–3.
[13] Shao HB, Chu LY. Resource evaluation of typical energy plants and possible functional zone planning in China. Biomass Bioenergy 2008;4:283–8.
[14] Burton GW. Biomass production from herbaceous plant. Biomass Energy Dev 1986;1:163–75.
[15] Rooney WL, Blumenthal J, Bean B, Mullet JE. Designing sorghum as a dedicated bioenergy feedstock. Biofuels Bioprod Bioref 2007;1:147–57.
[16] Li HL, Zhang ZX, Lin SZ, Li XX. Research advances in the study of Pistacia chinensis Bunge, a superior tree species for biomass energy. Forest Stud China 2007;9:164–8.
[17] Wang TA. Survey of the woody plant resources for biomass fuel oil in China. Sci Technol Rev 2005;5:12–4.
[18] Baer SG, Blair JM, Collins SL, Knapp AK. Plant community responses to resource availability and heterogeneity during restoration. Oecologia 2004;139:617–29.
[19] Clark RB, Zobel RW, Zeto SK. Effects of mycorrhizal fungus isolates on mineral acquisition by Panicum virgatum in acidic soil. Mycorrhiza 1999;9:167–76.
[20] Knee M, Thomas LC. Light utilization and competition between Echinacea Purpurea, Panicum virgatum and Ratibida pinnata under greenhouse and field conditions. Ecol Res 2002;17:591–9.
[21] Van Den Oever MJA, Elbersen H, Keijsers W, Gosselink ERP, De Klerk-engels RJA. B. Switchgrass (Panicum virgatum L.) as a reinforcing fibre in polypropylene composites. J Mater Sci 2003;38:3697–707.
[22] Bhandari AP, Sukanya DH, Ramesh CR. Application of isozyme data infingerprinting Napier grass (Pennisetum purpureum Schum.) for germplasm management. Gen Res Crop Evol 2006;53:253–64.

[23] Schmelzer GH. Review of Pennisetum section-Brevivalvula (Poaceae). Euphytica 1997;97:1–20.

[24] Liu ZT. Soybean production trends in the world and our response. Soybean Bull 2004;6:2–3.

[25] Lu ZM. Brazil's soybean production and research. Soybean Bull 2005;1:35–6.

[26] Chang RZ, Qiu LJ, Xu ZY, Li XH, Liu LH. Status of soybean research at home and abroad and the trend. Soybean Bull 2004;1:28–9.

[27] Liu LX. American corn economic development strategy. China Agric Inform Bull 2004;7:17–8.

[28] Yang XL, Wang K. Experience in the development of the corn processing industry and enlightenment in America. World Agric 2007;6:37–40.

[29] José CE, Electo SL, Osvaldo JV, Edgar EY, Edgar FC, Oscar A. Biofuels: environment, technology and food security. Renew Sust Energy Rev 2009;6–7:1275–87.

[30] Bhattacharya SC, Abdul Salam P, Pham HL, Ravindranath NH. Sustainable biomass production for energy in selected Asian countries. Biomass Bioenergy 2003;25:471–82.

[31] Huang YH, Wu JH. Analysis of biodiesel promotion in Taiwan. Renew Sust Energy Rev 2008;4:1176–86.