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Current Opinion in Biotechnology

Commercial feasibility of lignocellulose biodegradation: possibilities and challenges

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The main source of energy supply worldwide is generated from fossil fuels, which undoubtedly are finite and non-environmental friendly resources. Bioethanol generated from edible resources also has economic and environmental concerns. Despite the immense attention to find an alternative (inedible) source of energy in the last two decades, the total commercial production of 1st generation biofuels is limited and equivalent only to approximately 3% of the total road transport fuel consumption. Lignocellulosic waste represents the most abundant biomass on earth and could be a suitable candidate for producing valuable products including biofuels. However, cellulosic bioethanol has not been produced on a large scale due to the technical barriers involved that make the commercial production of cellulosic bioethanol not economically feasible. This review examines some of the current barriers to commercialization of the process.

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Current Opinion in Biotechnology 2016, **38**:190–197

This review comes from a themed issue on **Energy biotechnology**

Edited by **Andrew S Ball** and **Jamie H D Cate**

For a complete overview see the Issue and the Editorial

Available online 22nd March 2016

http://dx.doi.org/10.1016/j.copbio.2016.02.012

Introduction

One of the main contemporary issues facing society today is the development of sustainable energy from cheap, abundant and non-edible materials to enable its commercialization before the main energy sources are depleted. Throughout the twentieth century, fossil fuels (crude oil, coal and natural gas) were heavily exploited as the main source of energy. Currently, the main source (80–88%) of energy supply worldwide is generated from fossil fuels, which undoubtedly are finite and exhaustive resources and their current rate of consumption cannot be sustained in the long term [1,2,3••].

The majority of fossil fuel consumption is used in the transportation sector (60–65%) which is expected to increase dramatically as the world population increases [2,4]. In 2008, there were about 700 million light duty vehicles, automobiles, light trucks and minivans being driven on roadways around the world. This number is expected to at least double (to 1.3 billion vehicles by 2030) or perhaps triple (over 2 billion vehicles) by 2050. Although short-term prices of oil have currently dropped, the projected gap between the universal crude oil demand and the total actual production is probably to increase rapidly in future years leading once again to skyrocketing prices of fossil fuels in the long term. Furthermore, the overconsumption of these finite resources has also significantly contributed to security concerns of the oil supply and environmental pollution worldwide [5]. For example, transport vehicles account for a substantial percentage of air pollution globally, from each gallon of gasoline being burnt or used by a vehicle, about 8.16 kg of carbon dioxide (CO_2) is emitted. The adverse effects of using fossil fuels as the main source of energy are well documented and include environmental pollution such as increasing global carbon dioxide (CO_2) emissions [6].

It is not only that fossil fuels are the main source of air pollution, open-field burning of lignocellulosic waste (LCW) is a globally common practice as it represents a cheap, fast and practical means of preparing the field for the next crop. Air emissions from the burning process of wood, crop residues and other lignocellulosic biomass are not only a threat to public health but also wasting our natural resources. The burning process reduces the local air quality, creating a variety of health concerns from the discharge of carcinogenic oxides (NO_x, SO_2 and CO_x) into the atmosphere leading to asthma or pulmonary morbidity in humans. It has been estimated that annual emissions from open-field burning of lignocellulosic biomass were approximately 0.37 Tg of SO_2, 2.8 Tg of NO_x, 1100 Tg of CO_2, 67 Tg of CO and 3.1 Tg of methane (CH_4) [2,4,7,8].

Reducing the accumulated, atmospheric CO_2 concentration can be achieved whether by reducing the use of fossil fuels or utilising LCW in a more environmentally friendly manner [7]. The pressure on society to find suitable, renewable, less polluting and cheap sources of bioenergy and the desire to promote domestic rural economies are substantially increasing globally [4]. Therefore, there is an immense interest in the production of renewable biofuels from sustainable, cheap, plentiful and clean resources such as lignocellulosic biomass. A gradual shift from exhaustible fuels to sustainable biofuels will not only reduce the reliance on finite and expensive oil imports but will also help to maximise economic, environmental and social benefits [2,8].

Production of bioethanol from edible resources

Biofuels are derived from different sustainable feedstocks such as edible sugar or starch-based crops (corn in the USA and sugarcane in Brazil) and non-edible resources such as LCW which represent first and second generations of bioenergy substrates respectively [9]. Bioethanol produced from the 1st generation biofuels can be blended with current petroleum-based fuels either as a 10% (v/v) blend up to an 85% (v/v) blend, as well as being used as a pure hydrated ethanol [2,8,10]. The superior characteristics of edible bioethanol in the transportation sector also make it an excellent biofuel and suitable source for current and future advanced vehicles without major modifications [5,8].

Bioethanol has already been produced commercially in Brazil and the US beginning in 1975 using different edible feedstocks (sugarcane and corn respectively), and despite the problems associated with these bioenergy resources, it is still among the most promising renewable biofuels mainly for the transportation sector [8]. Although the 1st generation of biofuels offers great potential commercially as an alternative, sustainable, less polluting source compared to fossil fuel, it has considerable economic, food security and environmental limitations. The first generation of biofuels appears unsustainable on the basis of food-based feedstocks like corn, sugarcane or wheat as raw material, as it raises major nutritional and ethical concerns. Therefore, the first generation of biofuels (from edible resource) has been considered as socially flawed, as more than 800 million people suffer from hunger and starvation [11–13]. Moreover, the current production of 1st generation biofuels (less than 840 thousand barrels per day), although it has increased sevenfold since 2000, met only 2.3% of the total final transportation fuel demands [8]. Therefore, other cheap, plentiful and untapped feedstocks are urgently required for long term production [13].

Potential of LCW for biofuel production

Compared to fossil fuels, LCW are geographically evenly distributed globally and abundantly available. It was estimated that the annual production of these materials ranged between 10 and 50 billion tonnes worldwide, accounting for about half of the global biomass yield [3••,14,15]. Lignocellulosic material represents the most abundant biomass on earth and could be a suitable candidate for producing valuable products including biofuels. However, cellulosic bioethanol has not been produced on large scale due to the technical barriers involved such as commercial feasibility of lignocellulose biodegradation into fermentable sugars.

Wheat straw and rice straw are by far the most abundant agricultural wastes globally. The annual average production of wheat, rice and sugarcane straw worldwide is 354, 731 and 181 million tonnes, respectively (Table 1) [16]. Globally about 200 billion tonnes of plant biomass are produced annually and more than 90% of the total production of plant biomass is classified as LCW [17]. These waste materials are often available at very low cost and as a cheap substrate for commercial biofuel production. Previous studies suggest that LCW can be an ideal feedstock for biofuel production [8,16,18–21]. Different types of lignocellulosic residues could be used for biofuels production such as straws, crop residues, wood pellets, wood chips and agro-waste [22••,23•].

Because of the low price, availability throughout the year and wide distribution geographically, LCW is considered not only the most feasible option for biofuel production but also for fossil fuel replacement since these raw materials do

Table 1

Composition and potential of edible and non-edible feedstocks for bioethanol production

Biofuel resources	Carbohydrates (%)			Residue:crop ratio	Dry matter (%)	Average of worldwide production (1997-2001 in million tonne)	Bioethanol production potential (L per tonne of dry biomass)	Reference
	Cellulose	Hemicellulose	Lignin (%)					
Wheat straw	32.9–50	24–35.5	8.9–17.3	1.3	90.1	354.34	280–290	[8,24–28]
Wheat	**35.85**		NA		89.1	594.01	340–400	
Rice straw	36.2–47	19–24	9.9–24	1.4	88.0	731–900	280	
Rice	**87.5**		NA		88.6	590.87	430–480	
Sugarcane straw	40–41.3	27–37.5	10–20	0.6	71.0	180.73	280	
Sugarcane	**67**		NA		26.0	1266.60	70–500	
Corn stalks	35–39.6	16.8–35	7–18.4	1.0	78.5	203.61	225.7–290	
Corn	**73.7**		0.6		86.2	603.30	360–460	