



ELSEVIER

Contents lists available at ScienceDirect

## Biotechnology Reports

journal homepage: [www.elsevier.com/locate/btre](http://www.elsevier.com/locate/btre)

## Short Communication

## Prospective technologies, feedstocks and market innovations for ethanol and biodiesel production in the US



Jadwiga R. Ziolkowska\*

*The University of Oklahoma, Department of Geography and Environmental Sustainability, 100 East Boyd St., SEC 650, Norman, OK 73019-1081, USA*

## ARTICLE INFO

## Article history:

Received 19 May 2014

Received in revised form 2 September 2014

Accepted 2 September 2014

Available online 4 September 2014

## Keywords:

Biofuels

Second generation biofuels

Biofuels feedstocks

## ABSTRACT

In recent years, production and consumption of biofuels has become controversial, mainly due to the competitive use of natural resources for food/feed and fuel production. Second generation biofuels (with cellulosic ethanol being on top of developments nowadays) have a great potential to provide an economically feasible solution. However, high processing costs related to breaking down cellulosic plant material and converting it to sugar (and fuel), missing infrastructure and environmental impacts can be detrimental.

This paper discusses various biofuels technologies and feedstocks that have a potential to emerge as prospective feedstocks for second generation biofuels production in the future on the US market. It also emphasizes existing challenges that could hinder the development of these technologies and their commercialization in the long-term.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).

## 1. Introduction

For the past 30 years, the number of promising feedstocks for biofuels (ethanol and biodiesel) production in the US has increased considerably, and so have prospects for the biofuels technologies of the future. With the strong support of the US Government for renewable energies, second generation biofuels have become one of the major prospective investments of the biofuels industry sector as well as biotechnology R&D.

First generation biofuels from edible crops (e.g., corn, soybean, canola) (also called conventional biofuels) have been criticized for their competing with food and feed production, especially in the face of unexpected weather events and climate change [1]. The currently investigated and produced second generation biofuels (belonging to the group of advanced biofuels) are not competing with food/feed production in a direct way. They comprise: ethanol from cellulosic plant material, e.g., switchgrass, miscanthus, poplar, and biodiesel from oil plants, e.g., jatropha, oil palm as well as biofuel from algae.

According to the Renewable Fuel Standard (RFS) that has mandated biofuels production in the US since the establishment of the Energy Policy Act of 2005, 36 billion gallons (136 billion l) of biofuels are supposed to be supplied to the market by 2022. Advanced biofuels need to constitute 58.3% of the total mandate. In

2010, the RFS was extended by RFS2, setting new standards for conventional and advanced biofuels in terms of production volumes and life cycle greenhouse gas (GHG) emissions. Thus, for instance, cellulosic ethanol is supposed to be supplied at the volume of 16 million gallons (60.5 million l) by 2022 and to guarantee 60% CO<sub>2</sub> savings compared to fossil fuels [2]. Due to a mismatch between the mandate requirements and the actual production of cellulosic ethanol, the mandate has been adjusted and downsized by the Environmental Protection Agency (EPA) via waivers in all previous years. Despite that, both policy makers and scientists agree that second generation biofuels represent a prospective solution of the future and can be more viable in the long-term than conventional biofuels.

One of the major problems that did not allow for the advanced biofuels technology (especially cellulosic ethanol) to develop on a large commercial scale yet is the technological impediment of breaking down plant biomass (lignin in the plant walls) and releasing carbohydrate polymers (cellulose and hemicellulose) that can be converted into fermentable sugars and further refined into fuels. In addition, new highly efficient feedstocks are being unveiled as a sustainable biofuel source that could potentially outperform the currently applied second generation biofuels feedstocks.

This paper provides a brief overview of potential biofuels feedstocks and technologies of the future that are currently being investigated for higher effectiveness and commercialization as well as for reducing economic impediments. The paper does not aim at providing a quantitative analysis on the presented

\* Tel.: +1 405 325 9862; fax: +1 405 325 6090.

E-mail address: [jziolkowska@ou.edu](mailto:jziolkowska@ou.edu) (J.R. Ziolkowska).

feedstocks, which would be difficult at this stage of the current technological development and knowledge about those feedstocks. Rather, it has the aim of indicating potentials of little-explored feedstocks that could theoretically prove to have long-term benefits for advanced biofuels production.

## 2. Biofuels technologies

The fundamental problem for the advanced biofuels industry is that, despite many attempts, none was successful yet with identifying a commercially viable way to produce advanced biofuels at a cost-competitive level with petroleum fuels or first generation biofuels. The main difficulty with refining second generation biofuels relates to extracting enzymes capable of breaking down lignin and cellulose in plant walls and converting biomass to fermentable sugars. The high costs of those processes determine the final costs of the second generation biofuels that are not competitive with traditional gasoline at this point of time. Several studies have been undertaken to address this problem and provide a viable solution.

One possible solution, which would also allow for reducing costs of the second generation biofuels, has been introduced by Berka et al. [3]. The authors suggested two fungi strains (*Thielavia terrestris* and *Myceliophthora thermophila*), with their enzymes active at high temperatures between 40–75 °C, to be able to accelerate the biofuel production process. They can also contribute to improving the efficiency of biofuels production to the extent that would be sufficient for large-scale biorefining. In addition, the fungi could be theoretically exposed to genetic manipulation in order to increase the enzyme efficiency even more than it is possible with wild types [4,5].

A similar solution has been investigated by the scientists from the US Department of Energy (DOE), the BioEnergy Science Center and the University of California who developed the *Clostridium cellulolyticum* bacteria capable of breaking down cellulose and enabling the production of isobutanol in one inexpensive step [6]. Isobutanol can be burned in car engines with a heat value higher than that of ethanol (and similar to gasoline). Thus, the economics of using *Clostridium cellulolyticum* bacteria to break down cellulose is very promising in the long-term [7]. Furthermore, DOE researchers found engineered strains of the *Escherichia coli* bacteria (certain serotypes can be responsible for food poisoning in humans) to be able to break down cellulose and hemicellulose contained in plant cell walls, e.g., switchgrass. In this way, expensive processing steps necessary in conventional systems can be eliminated which could subsequently reduce the final biofuels price and allow a faster commercialization process for second generation biofuels.

The presented processes of using bacteria for breaking down cellulose and lignin, if applied on a large scale, have a high potential to substitute traditional gasoline on a one-to-one ratio. This clearly makes them superior to the current ethanol blends [8].

## 3. Feedstocks for second generation ethanol

In addition to enzymes that have the ability to digest hard woody plant material, experiments are also on the way to provide more efficient feedstocks for second generation biofuels production.

The most prospective feedstock for cellulosic ethanol nowadays is corn stover. Due to the abundance and unlimited accessibility of the feedstock that is considered as a waste product of corn production, cellulosic ethanol from this feedstock could become an affordable substitute and a blend for gasoline. However, the feedstock poses challenges related to breaking down lignin at a low cost. Several companies have undertaken efforts to improve the

technology. For instance, using a sequence of chemical processes, the Virent Company (connecting Honda, Shell and Cargill) has recently developed a biogasoline (a 'drop-in' high octane fuel) that can be used as a direct substitute for conventional gasoline [9,10]. According to FAPRI-ISU [11], corn stover for ethanol production in the US was used for the first time on a commercial scale in 2008 with 0.43 thousand metric tons being supplied on the market. The supply has been growing to date with an estimate of 713.2 thousand metric tons projected to be used by the end of 2013. Further projections foresee a continuous increase of the corn stover use for second generation biofuels production up to more than 3.8 million metric tons by 2025. Since the price of ethanol from corn stover (or any other feedstock) depends on the scale of production, it can be expected that with commercialization of the process, the costs of producing cellulosic ethanol would also decrease. Other challenges related to commercialization of corn stover ethanol include, among others, the collection and storage costs of the feedstock and the opportunity cost of the land and other resources being used for the plantation of the feedstock. Natural scientists debate about the amount of corn stover that can be removed from the field and still maintain a healthy biotope without negatively impacting soil fertility or causing excess erosion. Also, the costs of collecting other crops and feedstocks from the field and transporting them to the processing plant might turn out to be greater than growing and harvesting costs. In such a case, certain crops could be abandoned and displaced by cheaper ethanol feedstocks, which could create considerable market changes.

An alternative feedstock approved by the legislation for commercial cellulosic ethanol production under the advanced biofuels mandate is switchgrass and miscanthus. Due to high processing costs, the switchgrass feedstock has not yet been successful enough to be commercialized on a large scale, and it is still in the experimental or pilot production stage. Under current technological limitations, the US Department of Agriculture (USDA) in collaboration with the University of California at Berkeley are trying to develop a genetically engineered switchgrass variety that contains up to 250% more starch than conventional varieties [12,13]. This would allow for increasing the economic efficiency of sugar yields and minimizing the final switchgrass-based biofuels costs. If combined with the enzymatic modifications as described above, the production costs of cellulosic ethanol could be reduced substantially.

Another feedstock to be potentially used for cellulosic ethanol production in the future is elephant grass (napiergrass) (*Pennisetum purpureum*) that was introduced to the US from Africa in 1913. This tropical plant is fairly drought-tolerant, grows well on marginal lands and filters nutrients out of runoff in riparian areas. In addition, it does not require irrigation and is capable of producing biomass until the first frost. The main technological requirement and challenge to make napiergrass an efficient and competitive feedstock is to improve its yields and increase disease resistance [14,15].

Poplar has been considered for a long time as a viable and prospective feedstock for cellulosic ethanol production in the US. Poplar is drought-tolerant and capable of growing on marginal lands. If indeed grown on abundant or marginal land, it does not compete with other crops for food and animal feed. If cultivated on a biofuel farm, poplar trees create favorable wildlife habitats and provide recreational services. By removing contaminants from soil, poplar has a valuable potential of soil remediation (phytoremediation) [16], which clearly benefits other parts of the ecosystem chain. Growing poplar trees is said to be more fuel efficient and generates a lower carbon footprint than other annual food crops. Its growth rate is considerably slower than that of biofuels oil crops (e.g., crambe and camelina) [17]. However, this problem could be

mitigated by applying biochemical modifications, as discussed in the previous section, or nocturnal photosynthesis that allows poplar to absorb carbon dioxide also at night. This feature allows the plants to reach a higher growth rate with lower water requirements (8–16 inches = 203–406 mm) of precipitation annually as compared with traditional biofuel crops that require 20–40 inches/year (508–1,016 mm/year) [17]. Another possibility to increase poplar growth rates, which also constitutes a major challenge nowadays, is growing genetically modified poplar species that would hold the nocturnal photosynthesis mechanism and thus constitute a feedstock even more tolerant to drought than the conventional poplar species [18]. One of the possible limitations could be harvesting, transport and storage costs.

Another feedstock theoretically considered for ethanol production is orange (citrus fruit) peels. Global agriculture produces about 15.6 million tons of orange and other citrus waste annually. The discarded peels could potentially be used to produce both biofuels and other products: bio-based solvents, fragrance, pectin for cosmetics, pharmaceuticals and foods jellies, or cellulose used as a thickening agent. In this way, GHG emissions could be mitigated that are otherwise released while landfilling or burning orange peels. An international Orange Peel Exploitation Company in collaboration with the University of York, the University of Sao Paulo and the University of Cordoba launched a “zero waste” biorefinery project to explore possible developments in this field [18]. Also, researchers at the University of Central Florida have developed a method for breaking down the cellulose and refining ethanol from orange peels by means of a tobacco enzyme. The tobacco enzyme is derived by cloning genes from fungi and bacteria. This process is considerably less expensive than using synthetic enzymes [19]. Hydrocarbon molecules from tobacco can also be converted directly into a fuel that could be used as a drop-in substitute for petroleum fuels, as suggested by UC Berkeley researchers. To ensure a cost-effective process, highly efficient varieties of tobacco need to be used, which have a capacity to bind high amounts of sunlight and convert carbon dioxide to hydrocarbon molecules. To accelerate this process, tobacco can be enhanced with genes from cyanobacteria that, next to algae, are already a very efficient feedstock for biofuels production. Tobacco bears potential advantages over other non-food biofuel plants like miscanthus, switchgrass and camelina [20]. Currently, a large area of land is already used for tobacco farming, which could be used for biofuels production without additional technological costs. However, this practice would significantly impact the tobacco industry and cigarette prices. Given the high value of tobacco, it is hard to anticipate an alternative use of this plant at an economically feasible level, even though biological and technological potentials already exist.

Another possible way of producing ethanol is by using beer broth that has been introduced by researchers at Cornell University. In terms of its chemical characteristics, the fermentation broth of beer is identical to that of ethanol. By using microbes, ethanol from beer broth can be upgraded into caproic acid (a carboxylic acid) that is called a versatile fuel precursor and is

considered to be an even better product than ethanol. While the production of traditional ethanol is energy-intensive and expensive, the caproic acid can be produced by means of the current ethanol production lines and applied for a wide range of purposes, e.g., animal feed or anti-microbial agents [21,22]. The only limitation nowadays is the production scale and the associated production costs.

#### 4. Feedstocks for second generation biodiesel

In recent years, oil palm, algae and jatropha have been studied as potential biodiesel feedstocks. They have been found to produce much higher oil yields, compared to traditional feedstocks, such as soybean or rapeseed (Table 1). However, several other highly efficient feedstocks bear a high potential of becoming biofuels feedstocks of the future, although they have not been investigated sufficiently yet.

One of those potential feedstocks is camelina (*Camelina sativa*) which, like rapeseed and canola, belongs to the mustard family (*Brassicaceae*). Camelina is a short-seasoned (planted in early spring, harvested in late July) fast-growing crop which has very low water and fertilizer requirements. It can grow on marginal lands and be used as a rotational crop boosting yields of wheat and other rotated crops. The plant produces seeds with 35–38% oil content that can be seeded and harvested with conventional farm equipment and used for biodiesel production. The remaining camelina meal, containing high levels of omega-3 fatty acid, can be used as a protein-rich feed source for livestock [23]. Also, environmental footprint of camelina is very positive. Camelina-based fuel jets proved to produce 84% less CO<sub>2</sub> emissions than when run on petroleum fuel [24]. Camelina-based fuel has been in use among commercial and military aircraft, e.g., Blue Angels and Thunderbirds high precision jet fighter demonstration teams. It provides a more viable solution than ethanol that ignites too easily and, thus, does not meet safety standards on board ships while its energy content is too low for long range missions. It is also a more efficient solution than commercial biodiesel that absorbs water too easily [23].

Another prospective feedstock for biodiesel production, just emerging on the biofuels market, is pongamia (*Pongamia pinnata*, also called: pongam tree, karum tree and poonga-oil tree). The tree is native to India and Australia and has a high growth rate, high drought resistance and produces oily seeds. It has low requirements in terms of irrigation and pest control, while it can also be grown on marginal lands in hot and dry climates. Therefore, the most recent plantations in the US have been established in Texas by the biofuel company TerViva. As pongam trees are leguminous (they fix atmospheric nitrogen), they do not require fertilizers. A single tree is said to yield 9–90 kg seed per tree, with the yield potential of 900–9000 kg seed/ha. The average oil content is 18–27.5% depending on the extraction technology [25]. The seeds can be harvested and prepared with conventional equipment used for processing tree nuts, peanuts and other crops. The oil can be transferred to refineries without any modifications. It has been

**Table 1**  
Oil yields from various biomass sources and biofuels productivity.  
Source: Chisti [40]; Mata et al. [41].

Crop	Oil yield (l/ha/yr)	Biofuel productivity (kg/ha/yr)
Soybean	446	562
Sunflower	952	946
Rapeseed	1,190	862
Jatropha	1,892	656
Oil palm	5,950	4747
Microalgae (30% oil by wt.)	58,700	51,927
Microalgae (70% oil by wt.)	136,900	121,104

Note: 1 L (Liter) = 0.2643 gallons, 1 kg = 2.2 pounds, 1 ha = 2.47 acres, wt. = weight.

estimated that pongamia trees can generate up to thousands of gallons of biofuels from one acre, at the cost of \$1/gal (\$0.26/l) of biofuel [26]. After the oil is removed, the leftover seed cake can be used as a fertilizer or blended with soybean for animal feed. Moreover, the trees can create favorable conditions for wildlife habitats and the seeds can be used to produce other products for medicine and cosmetics branches [27]. With the positive economic and environmental traits, pongamia can be viewed as a promising feedstock for future biodiesel production, especially in dry and hot regions.

Pennycress (*Thlaspi arvense L.*) constitutes another efficient option and it has been proven by the USDA [28] to be present in 49 US states as a weed plant. The oil content of pennycress (36% with the major fatty acid – erucic acid) is approximately twice as high as that of soybean and it also outperforms corn in terms of its net energy output. Thus, it provides a more sustainable solution from the environmental footprint perspective. A minimum amount of 907 kg (40 bushels) of pennycress can be harvested per acre, which would allow for producing about 115 gallons (435 L) of biodiesel [29,30]. If grown on marginal land, pennycress does not compete with food/feed production and can be used in winter as a ground cover crop protecting soil from erosion. It can also be harvested in spring to prepare the soil for growing other crops in summer, e.g., soybeans, and it can be intercropped with corn and wheat. Pennycress can be easily harvested with the conventional equipment used for other crops [31]. Water, nutrient and herbicide requirements of pennycress, as well as insect and disease pressures, and environmental stresses need to be evaluated before using the crop for commercial biodiesel production. With its excellent biodiesel properties and a very short growing season, pennycress is said to have a tremendous opportunity to be commercialized as a biofuel feedstock in the future [28,32]. More studies on economic feasibility of the feedstock would be required to closer investigate the efficiency potential of the feedstock in the long-term perspective.

Another prospective plant for biodiesel production is crambe – a Mediterranean plant that has been introduced to the US in the 1940's. Crambe is drought-tolerant and can be compared with soybeans in terms of its economic efficiency. It also has up to 9% more erucic acid than rapeseed, which is a beneficial characteristic when the oil is used for biofuels production, although it has been associated with cardiac disease in humans. As recently investigated by the University of North Dakota Energy and Environmental Research Center (EERC), crambe seed oil can be converted into biofuels identical with petroleum fuels. In addition to its potential as a biofuel feedstock, crambe oil can be used for producing synthetic rubber, erucic acid-based materials, e.g., plastic film and nylon (currently produced from the imported rapeseed), as well as a lubricant for corrosion control [33].

Although the main focus of the paper is to present prospective and little-explored feedstocks and technologies for ethanol and biodiesel production, algae feedstock (for production of third generation biofuels) is worth mentioning in this context.

Algae constitute a unique feedstock. They contain high levels of both lipids and sugars and, thus, can be used for both biodiesel and ethanol production successively, in a two-stage process. In addition, algae is highly efficient and can produce between 10 and 100 times more oil per acre as compared with traditional oil crops (e.g., oil palm), while it can grow 20–30 times faster than food crops [34]. As elaborated by Ziolkowska and Simon [35], the prospects for algae feedstock are promising, especially in the face of new market technologies such as 'milking algae' (that allows for continuous deriving of algal oil instead of their one-time harvesting and processing), genetic engineering (for increasing algae growth and lipid production by algal cells), 'direct-to-ethanol' process (which produces ethanol from cyanobacteria

without the harvesting and dewatering stage) and combined off-shore systems, e.g., Offshore Membrane Enclosures for Growing Algae. Further research and developments are necessary as well as a direct support from the US Government and the industry sector for algae feedstock and algae biofuels to be commercialized on a large scale.

## 5. Perspectives for second generation biofuels

Among the commonly known and the newly emerging feedstocks for biofuels production, different feedstocks have different advantages in terms of oil/sugar yields, technological requirements, environmental footprint and additional benefits and impacts on ecosystems and biodiversity. This creates several challenges for the industry and the R&D sector to invest in the most efficient and sustainable feedstocks, which will require many years of intensive investigations. Also, interdisciplinary collaborations will need to be intensified to be able to assess the potentials of the enumerated and other emerging feedstocks at several different levels.

The changes and progress in the biofuels industry in recent years have shown potentials for an investment-friendly environment for new biofuels technologies. This could create a stable background for innovative biofuels technologies of the future in the long-term, where the total biofuels market would be supplied with biofuels from a balanced mix of different sustainable feedstocks. In this way, extreme natural resource overuse could be avoided, while the tradeoff conditions of food vs. fuel production could be (at least partially) solved. However, more likely only a handful of technologies and feedstocks will prove economically viable and competitive with current traditional feedstocks, and approved to be produced on a commercial scale. As none of the second generation biofuels feedstocks has reached such a technological maturity yet, starch from corn and sugar are still dominating the ethanol production nowadays. Given the current technological development, no other second generation feedstocks are cost competitive enough to gain momentum on the biofuels market at this point of time.

The problem with technological maturity relates mainly to high total costs (including experiment costs, technological costs and availability of the feedstock) that are among the most relevant factors determining the process of large-scale production. Thus, economic obstacles hinder the development of more environment-friendly technologies, as it was proved that second generation biofuels feedstocks have low direct or indirect GHG emission impacts and thus outperform conventional biofuels feedstocks [36,37].

On the other hand, it needs to be underlined that another factor determining economic and environmental sustainability of the second generation biofuels is the location where the feedstock is cultivated. Biofuels feedstocks (even if second generation) grown on arable land can create indirect competition for food and feed production, as the land used for biofuels feedstock plantations could theoretically be used to produce other crops or as pastureland for cattle grazing. A strongly recommended approach would consider cultivating biofuel feedstock on marginal lands that are unsuited for crop production due to biophysical factors (e.g., water scarcity, low soil fertility, topography), poor or missing crop management practices and/or unfavorable distance from/to the market. Thus, second generation biofuels not competing with food/feed in either direct or indirect way would be most sustainable and could be seen as a prospective solution in the years to come.

It also needs to be mentioned that more experiments and investments as well as economic and environmental analyses are necessary to establish a commercial biofuels production from the above mentioned feedstocks. With the current and anticipated



technological developments it could be possible in the future to provide a ranking of the presented feedstocks and an assessment on real potentials of those feedstocks to be economically feasible and competitive with traditional biofuels feedstocks. According to Kenney and Park Ovard [38], a balance between the biofuels costs and quality is also indispensable to boost the process of scaling up biofuels production.

In the mid- and long-term, biofuels production and feedstock selection for commercial biofuels will be determined by several interacting factors and related uncertainties, e.g., on the biofuel/fuel markets, in the field of technological development and on the political level (i.e., governmental subsidies). As explained by Tyner [39], the current government policies in place do not provide the degree of reduction in uncertainty that would be necessary to induce commercial investments in cellulosic biofuels.

## 6. Conclusions

The paper identified and discussed several feedstocks with the potential to be used in the future for second generation biofuels production. The discussion on prospective solutions for the future is relevant due to the decreasing enthusiasm about conventional biofuels and due to their competing with food and feed production, which might subsequently contribute to high and volatile food prices. Also, direct and indirect impacts on land use and other natural resources as well as the consequently changing regulations, make scientists, policy makers and industry representatives seek more feasible and promising solutions.

Among the discussed feedstocks, corn stover is currently a number one feedstock that has been used for ethanol production since 2008 and its implementation is expected to grow in each following year. Other plants for ethanol production (e.g., switchgrass, miscanthus, elephant grass, poplar), or plants for biodiesel production (e.g., camelina, pongamia, pennycress, crambe) have many advantages outperforming the current traditional feedstocks. More R&D studies and experiments are necessary to assess the market viability of those feedstocks and possibilities of their commercialization in the future. Use of bacteria and fungi strains as well as genetic modifications can help to enhance biological abilities of the plants to produce more sugar and oil for ethanol and biodiesel production, respectively.

In the mid- and long term, production of cellulosic ethanol and other second generation biofuels (both ethanol and biodiesel) on a large commercial scale will be determined by several factors, mainly production costs, storage and transportation costs of the feedstock and land use changes.

## References

- [1] T. Richard, Y. Chisti, C. Somerville, H. Blanch, B. Babcock, S. Gheewala, D. Zilberman, Ask the experts: the food versus fuel debate, *Biofuels* 3 (6) (2012) 635–648.
- [2] US Environmental Protection Agency (EPA), National renewable fuel standard program—Overview, Washington, DC: Office of Transportation and Air Quality, US EPA, 2010 (April 14).
- [3] R.M. Berka, I.V. Grigoriev, R. Otilar, et al., Comparative genomic analysis of the thermophilic biomass-degrading fungi *Myceliophthora thermophila* and *Thielavia terrestris*, *Nat. Biotechnol.* 29 (2011) 922–927.
- [4] P. Vinuselvi, J.M. Park, J.M. Lee, K. Oh, J.M. Ghim, S.K. Lee, Engineering microorganisms for biofuel production, *Biofuels* 2 (2) (2011) 153–166.
- [5] G. Stephanopoulos, Challenges in engineering microbes for biofuels production, *Science* 315 (5819) (2007) 801–804 (9 February 2007).
- [6] T. Casey, U.S. Department of energy announces new biofuel to replace gasoline, *Cleantechnica* (2012) <http://cleantechnica.com/2011/03/08/u-s-department-of-energy-announces-new-biofuel-to-replace-gasoline/> (accessed 08.03.11).
- [7] Energy Department announces new advance in biofuel technology, DOE. [http://apps1.eere.energy.gov/news/progress\\_alerts.cfm/pa\\_id=497](http://apps1.eere.energy.gov/news/progress_alerts.cfm/pa_id=497) (accessed 07.03.11).
- [8] T. Casey, *E. Coli* Bacteria: What Doesn't Kill Us, Makes Us Biofuel *Cleantechnica*. <http://cleantechnica.com/2011/11/29/e-coli-bacteria-what-doesnt-kill-us-makes-us-biofuel/>, 2011 (accessed 29.11.11).
- [9] T. Casey, Cargill, Shell and Honda team up to make gasoline from pine and corn waste, *Cleantechnica*, 2011 <http://cleantechnica.com/2011/06/06/cargill-shell-and-honda-team-up-to-make-gasoline-from-pine-and-corn-waste/> (accessed 06.06.11).
- [10] W. Tyner, Why the push for drop-in biofuels? *Biofuels* 1 (6) (2010) 813–814.
- [11] FAPRI-ISU, World Agricultural Outlook Database Corn Stover, FAPRI: Ames, IA, 2011.
- [12] T. Casey, New Frankenstein switchgrass is good news for the Navy, too, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/09/11/new-switchgrass-leads-to-cheaper-biofuels-for-navy/>.
- [13] A. Perry, Immature Switchgrass Could Help Cellulosic Ethanol Industry, USDA, Washington DC, 2012. <http://www.ars.usda.gov/is/pr/2012/120906.htm>.
- [14] D. O'Brien, A. Napiergrass, Potential biofuel crop for the sunny Southeast, USDA, Washington DC, 2012 <http://www.ars.usda.gov/is/pr/2012/120927.htm> (accessed 21.10. 2012).
- [15] T. Casey, Elephant Grass Could Be Secret Weapon in Biofuel Wars, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/10/01/usda-say-elephant-grass-biofuel-could-work/> (accessed 1.10.2012).
- [16] T. Casey, Oxymoron of the Day: Nocturnal Photosynthesis, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/10/02/doe-grants-14-million-for-nocturnal-photosynthesis-and-poplar-tree/> (2.10.2012).
- [17] T. Casey, Money Doesn't Grow on Trees, but Biofuel Does, *Cleantechnica*, 2010 <http://cleantechnica.com/2010/03/02/money-doesnt-grow-on-trees-but-biofuel-does/> (accessed 2. 3.2010).
- [18] T. Casey, Orange You Glad I Said Biofuel? *Cleantechnica*, 2012 <http://cleantechnica.com/2012/07/07/opecc-uses-orange-peel-for-biofuel-and-other-biobased-products/> (accessed 7.7.2012).
- [19] T. Casey, A Sustainable Recipe for Biofuel: Ethanol from Orange Peels and Tobacco, *Cleantechnica*, 2012 <http://cleantechnica.com/2010/02/25/a-sustainable-recipe-for-biofuel-ethanol-from-orange-peels-and-tobacco/> (accessed 25.2.2010).
- [20] T. Casey, Tobacco Goes from Dark Side Villain to Biofuel Hero, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/02/25/berkeley-lab-researchers-convert-tobacco-to-biofuel/> (accessed 25.2.2012).
- [21] Cornell University Researchers convert 'beer' into a better-than-ethanol biofuel. <http://www.news.cornell.edu/stories/June12/ethanolUpgrade.html> (accessed 26.6.2012).
- [22] T. Casey, Making Better Biofuels, from Beer Broth, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/06/28/making-better-biofuels-beer-broth/> (accessed 28.6.2012).
- [23] *Cleantechnica*. U.S., Navy Super Hornet Has Camelina Biofuel in its Sights. <http://cleantechnica.com/2009/09/13/us-navy-super-hornet-has-camelina-biofuel-in-its-sights/>, 2003 (accessed 23.10.2012).
- [24] Sustainable Oils, Camelina Information. <http://www.susoiils.com/camelina/>, 2009 (accessed 23.10.2012).
- [25] Purdue University, *Pongamia pinnata* (L.), [http://www.hort.purdue.edu/newcrop/duke\\_energy/Pongamia\\_pinnata.html](http://www.hort.purdue.edu/newcrop/duke_energy/Pongamia_pinnata.html), 1998.
- [26] Sika N. Startup Nuts to biofuel CNN Business News <http://money.cnn.com/video/news/2012/11/26/n-in-pongamia-biofuel.cnnmoney/index.html> (accessed 26.11.2012).
- [27] T. Casey, Poisonous Purple Pongam Tree Could Be Next Biofuel Superstar, *Cleantechnica*, 2012 <http://cleantechnica.com/2012/01/31/poisonous-purple-pongam-tree-could-be-next-biofuel-superstar/> (accessed 31.1.2012).
- [28] USDA, Plants profile. <http://plants.usda.gov/java/profile?symbol=THAR5>, 2012.
- [29] T.A. Isbell, M.M. Gass, R.L. Evangelista, S.F. Vaughn, Pennycress (*Thlaspi arvense*) as a biodiesel in a one year-two crop rotation with soybean, Book of Abstracts, 20th Annual Meeting of the Association for the Advancement of Industrial Crops, College Station, Texas, 2008 September 7–11, p. 6.
- [30] R.L. Evangelista, T.A. Isbell, S.C. Cermak, Extraction of pennycress (*Thlaspi arvense* L.) seed oil by full pressing, *Industrial Crops Products* 37 (2012) 76–81.
- [31] *Cleantechnica*. Pennycress? Yep It's the Next Big Biofuel, <http://cleantechnica.com/2012/04/19/pennycress-yep-its-the-next-big-biofuel/>, 2012.
- [32] B.R. Moser, Biodiesel from alternative oilseed feedstocks: camelina and field pennycress, *Biofuels* 3 (2) (2012) 193–209.
- [33] T. Casey, Corn Biofuel is Toast: Here Comes *Crambe*, *Cleantechnica*, 2009 <http://cleantechnica.com/2009/02/19/corn-biofuel-is-toast-here-comes-crambe/> (accessed 19.,2.2009).
- [34] A.L. Ahmad, N.H.M. Yasin, C.J.C. Derek, J.K. Lim, Microalgae as a sustainable energy source for biodiesel production: a review, *Renew. Sust. Energy Rev.* 15 (2011) 584–593.
- [35] J.R. Ziolkowska, L. Simon, Recent developments and prospects for algae-based fuels in the us, *Renew. Sust. Energy Rev.* 29 (2014) 847–853.
- [36] J.M. Melillo, J.M. Reilly, D.W. Kicklighter, et al., Indirect Emissions from Biofuels: How Important? *Science* 326 (5958) (2009) 1397–1399.
- [37] D. Rajagopal, G. Hochman, D. Zilberman, Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies, *Energy Policy* 39 (1) (2011) 228–233.
- [38] K.L. Kenney, L. Park Ovard, Advanced feedstocks for advanced biofuels: transforming biomass to feedstocks foreword, *Biofuels* 4 (1) (2013) 1–3.
- [39] W. Tyner, Cellulosic biofuels market uncertainties and government policy, *Biofuels* 1 (3) (2010) 389–391.
- [40] Y. Chisti, Biodiesel from microalgae, *Biotechnol. Adv.* 25 (3) (2007) 294–306.
- [41] T. Mata, A. Martins, N. Caetano, Microalgae for biodiesel production and other applications: A review, *Renew. Sust. Energy Rev.* 14 (2010) 217–232.