Policies for second generation biofuels:
Current status and future challenges

Håkan Eggert*[1], Mads Greaker*, and Emily Potter[2]

Abstract

This report reviews the current status of second generation biofuels. First generation biofuels continue to be substantially subsidized, and this has contributed to the increasing use of such fuel. However, recent studies claim that the future of biofuels lies in second generation biofuels, in particular biochemical ethanol made from cellulose. Thus, in this report we ask the following three questions: How far is second generation biofuels from being a competitive GHG abatement technology? Is it likely that first generation biofuels will bridge the development of second generation biofuels? Should trade policy be used to protect domestic infant second generation biofuels industry from import of low cost first generation biofuels from developing countries?

Keywords: Biofuels, cellulosic ethanol, Second-generation, Subsidies, Trade policies

JEL Classification Numbers: Q20, Q40, Q56

---

[1] *Department of Economics, University of Gothenburg, P.O. Box 640, SE 405 30 Göteborg, Sweden, e-mail: Hakan.Eggert@economics.gu.se

[2] Statistics Norway, POBox8131Dep, NO-0033Oslo, Norway.

Summary

Current state-of-the-art knowledge concludes that green house gas (GHG) emissions must be controlled and reduced within the next 30-40 years. The transport sector contributes almost a fifth of the current global emissions, and its share is likely to increase in the future. Hence, there is a huge demand for low emission solutions for all modes of transport.

This report reviews the current status of second generation biofuels. First generation biofuels continue to be substantially subsidized, and this has contributed to the increasing use of such fuel. However, recent studies claim that the future of biofuels lies in second generation biofuels, in particular biochemical ethanol made from cellulose. Thus, in this report we ask the following three questions: How far is second generation biofuels from being a competitive GHG abatement technology? Is it likely that first generation biofuels will bridge the development of second generation biofuels? And, should trade policy be used to protect domestic infant second generation biofuels industry from import of low cost first generation biofuels from developing countries?

Ethanol made from cellulose using the biochemical conversion process is far from a ripe technology. According to our survey of the literature it seems to have the potential to reduce GHG emissions from the transport sector without leading to devastating changes in land use practice, which recent critique has held against first generation biofuels. Expert reports point to several potential technological breakthroughs which may reduce costs substantially. Hence, given that there are market failures connected to private R&D on cellulosic ethanol, there may be an opportunity for successful public intervention by providing support to R&D. Learning-by-doing also seems crucial for an eventual success of second generation biofuels. Thus, again given that there are market failures connected to the initial diffusion phase of the technology, government support giving the technology a head start could be warranted.

On the other hand, we doubt that the necessary learning gains can be obtained from widespread use of first generation biofuels. Governments should therefore consider scaling down the current support to first generation biofuels, in particular, not increasing the blending mandate targets. It is hard to design blending mandates such that poor performing first generation biofuels are not covered. In order to preserve flexibility when promoting learning-by-doing, governments should instead look for measures directly targeting investments in second generation biofuels facilities. And finally, with targeted support to second generation biofuels, there is no need to pay attention to the infant industry argument. Trade policy should only aim to correct for insufficient internalizing of GHG emission costs from the production of biofuels in countries without a price on carbon.

It is by no means certain that second generation biofuels will play a central role in the decarbonizing of the transport market. Necessary cost reductions may not be achieved. The GHG emissions from land use change connected to large-scale growing of cellulosic feedstock may turn out to offset the gains from changing fuel. Furthermore, other options like hydrogen or electric vehicles may experience major innovations making them preferable to vehicles running on biofuels. It is important to avoid a technological or political lock-in in biofuels. In other words, policies should be flexible, and it should be possible to terminate support programs in short notice.

1 Introduction

Approximately 23% of all carbon dioxide-equivalent (CO_2e) emissions, or anthropogenic GHG emissions, come from the transport sector, which relies on petroleum to supply the majority of the energy used in global transport (International Energy Agency – IEA, 2007). According to the International Panel on Climate Change (IPCC), transport's GHG emissions have increased at a faster rate than any other energy-using sector. Emissions are expected to continue to grow at a rate of about 2% per year if the current energy usage patterns persist, meaning that transport energy use in 2030 will be 80% higher than in 2002. The predicted increase is primarily due to continued economic growth in developing countries. Petroleum accounts for more than 98% of transport fuel in almost all countries except Brazil (IEA, 2004), implying that CO_2e emissions will essentially grow in lockstep with energy consumption. The annual global consumption of gasoline and diesel amounts to a couple of trillion liters (US Energy Information Administration – EIA, 2010), implying that even a modest replacement with biofuels would turnover several hundred thousand million dollars.

Biofuels have been promoted as one possible and promising way of reducing GHG emissions from the transport sector. Moreover, the technology is available today without reducing consumer utility of cars as opposed to hydrogen and battery driven cars. Growth of global biofuel production is mostly a result of ambitious government support programs. Clearly, the support has not only been driven by a concern for GHG emissions, and both the EU and the US have invoked arguments about "energy security" and the need for regional development. However, in this report we evaluate biofuels policies based on the need to reduce GHG emissions.

Biofuels, including ethanol and biodiesel fossil fuel substitutes made from biomass, have been in use since the earliest internal combustion engines. In fact, one of the first prototypes of the diesel engine was designed to run on vegetable oil, and several of Henry Ford's early cars ran on ethanol. The interest in biofuels was renewed as a result of the 1970s oil shocks and is flourishing today with government support motivated by several factors including energy security, climate change concerns, and rural development. Moreover, it is common to distinguish between so-called first and second generation biofuels. While first generation biofuels are made from feedstock also suitable for human food production, second generation biofuels are made from cellulosic material not useable as a food source. According to IPCC (2007), biofuels have the potential to replace a substantial part of petroleum use in the transport sector if technologies using cellulosic biomass succeed. However, according to some scholars, even if cellulosic biofuels become commercially successful, they may still only replace a few percent of fossil fuels on a global scale. Despite great potential in absolute terms, large-scale biomass energy production beyond that level would probably reduce food security and exacerbate forcing of climate change (Field et al., 2008). Carriquiry et al. (2010) concluded that although second generation biofuels may contribute significantly to global energy supply, their economic potential is more limited due to the costs of production relative to those of liquid fossil fuels.

The present report discusses policies for the promotion of second generation biofuels as an alternative to both fossil fuels and first generation biofuels in the transport sector. In particular we ask the following three questions: How far is second generation biofuels from being a competitive GHG abatement technology? Is it likely that first generation biofuels will bridge the development of second generation biofuels? And, should trade policy be used to protect the infant second generation biofuels industry from export of low cost first generation biofuels from developing countries?

We focus on ethanol made from cellulose and disregard second generation biodiesel. While second generation biodiesel according to the literature is a well proven technology with excessively high costs, ethanol made from cellulose is far from a ripe technology. Furthermore, even if current production costs are too high to make it competitive with first generation biofuels, a carefully designed technology policy and a sufficiently stringent climate policy could make it competitive in the future.

Current support for biofuels is to a large extent geared towards first generation biofuels. This need not be a major problem if first generation biofuels is likely to pave the way for second generation biofuels. However, based on our survey we do not find any strong support for the pave the way argument. First, the challenging parts of the cellulosic ethanol production process are not necessary and hence not present in the production of first generation biofuels. Second, the current car fleet can absorb large amounts of cellulosic ethanol without any costly adjustments to either cars or filling stations, ensuring that learning by doing can take place independent of the success of first generation biofuels.

Even though cellulosic ethanol is considered by many to be a promising technology, there is still great uncertainty as to whether production costs will come down and whether the availability of raw materials will be adequate for large-scale use of cellulosic ethanol for transport purposes. Policies for promoting R&D and learning for cellulosic ethanol should only have as their aim to uncover the technology's true potential, and not operate with ambitious goals for the technology's future market penetration.

Some may argue that import of "cheap" first generation biofuels from Non-Annex 1 countries could halt the market introduction of cellulosic ethanol to an undesirable extent. The infant industry argument would hold that second generation biofuels should receive protection in order to be able to develop. However, given that targeted measures to promote R&D and learning-by-doing are put in place, adding another instrument, that as well benefits domestic first generation biofuels, seems superfluous. Trade policy should only aim to correct for insufficient internalizing of GHG emission costs from the production of biofuels in countries without a price on carbon (e.g. Eggert and Greaker, 2009).

It is also well known from the infant industry literature (e.g. Grossman, 1990) that governments, by supporting specific industries, run the risk of creating powerful lobbies that later hamper the withdrawal of support programs when all learning gains are exhausted. Today, we see signs that the support programs for first generation biofuels may have created such a "political lock-in," making it difficult to scale down support even though first generation biofuels have proven less promising than originally thought. Hence, governments should strive to keep flexibility when crafting support programs for cellulosic ethanol.

Brazil is so far the exception in transport fuel consumption. Dating back to the first oil crisis in 1973, the country's sugarcane program PROALCOOL remains in place, and currently 50% of all Brazilian transport fuel comes from first generation biofuels, notably sugarcane ethanol (Weidenmier et al., 2008). However, such dramatic substitution of fossil fuels with first generation biofuels on a global scale would likely have severe effects on food security and habitat conservation. OECD (2006) estimated that replacing 10% of the transport fuel consumption in the US, EU and Canada would require in the range of 30-70% of their respective current crop area. Another estimate suggests that replacing 85% of the global gasoline consumption with first generation biofuel would use up the entire global harvest of sugarcane, maize, wheat, sorghum sugar beet, and cassava (Rajagopal and Zilberman, 2008).

Ligno-cellulosic biomass used for second generation biofuels refers to plant biomass composed of cellulose, hemicelluloses, and lignin. Cellulosic materials are abundant, estimated to make up roughly 60-90% of terrestrial biomass by weight (Pew Center, 2009). Given that land available for the production of feedstock raw materials is ultimately the limiting resource for biofuels production, it is meaningful to mention the differences between first and second generation biofuels in terms of land-use efficiency.

Land-use efficiency (Larson, 2008) refers to the level of transportation service that can be provided from a hectare of land. By taking into consideration the rate of biomass feedstock production per hectare, the efficiency of converting the feedstock into a biofuel and the efficiency of using the biofuel in a vehicle, one can estimate the vehicle-kilometers of travel that can be provided by one hectare of land. Using this measure, second generation biofuels can provide an improvement of approximately 50% in land-use efficiency over sugar-based first generation biofuels and an improvement of up to 2.5 times over starch-based biofuels. This is because they use much more of the above ground biomass than first generation fuels (see also Rajagopal and Zilberman, 2008). In addition, cellulosic feedstock may, to a much larger extent, be produced on marginal land or even be recovered from organic waste and similar residuals, which would reduce the problem of threatening food security and destroying habitats when expanding land use.

Despite significant cost improvements over the past several decades, first generation biofuels are not price competitive with fossil fuels possibly with the exception of Brazil’s sugarcane-based ethanol. Even with recent high petroleum prices and no carbon taxation, most US and EU producers would not be able to operate without government subsidies (Eggert and Greaker, 2009). Furthermore, feedstock commodity price increases and energy costs have both contributed to higher production costs of first generation biofuels from 2004 to 2007 (IEA, 2008). Although there are likely to be incremental improvements in technology, significant technology breakthroughs are unlikely, and feedstock costs, which account for 55-70% of total production costs, are unlikely to fall enough to make first generation biofuels fully competitive (IEA, 2008).

Recent contributions have also directly questioned whether first generation biofuels actually lead to any short-run CO_2 reductions. Obvious sources of emissions include the use of fertilizer when growing the first generation biofuel crops and the use of fossil energy in the harvesting and processing of first generation biofuels (Greaker and Eggert, 2009). Land use change can lead to additional GHG emissions if the area of arable land is increased to accommodate growth of crop inputs for the production of biofuels. When land is cleared and the soil is disturbed, part of the carbon stored in natural soils and forests is released as CO_2. Fargione et al. (2008) introduced the concept of carbon debt and hold that it may take up to several hundred years to reach break-even after such conversion. A recent report found that if the pattern of palm oil production for diesel biofuels continues to develop as estimated, the use of palm oil sourced from peatlands in the production of biofuels would be more than enough to negate the GHG savings from all EU biofuels (EC JRC, 2008). Other recent contributions questioning the GHG reduction benefits of first generation biofuels include Searchinger et al. (2008), Khanna et al., (2009) and Lapola et al. (2009).

Table 1 GHG reduction including indirect effects

Biofuel type	*30 year, 0% discount rate*
Corn ethanol (best case)	-26%
Corn ethanol (worst case)	+34%
Soy-based biodiesel	+4%
Sugarcane ethanol	-26%
Switchgrass ethanol (cellulosic)	-124%

Table 1 summarizes the GHG-reducing effect of different biofuels based on lifecycle analyses. As can be seen, cellulosic ethanol is by far the most promising biofuel (US EPA, 2009). Note also that EU biodiesel made from rapeseed scores badly in terms of GHG reduction potential (Spitzer and Jungmeier, 2006).

Despite the initial optimism and some success of first generation biofuels, the future lies in second generation biofuels (Khanna et al., 2009; Tilman et al., 2009). On the other hand, the promotion of second generation biofuels requires a much more targeted policy approach. The current use of both blending mandates and trade policy encourages the production of first generation biofuels in Annex 1 countries (including the US and the EU Member States). Biofuels produced in the US and EU, are among the worst performing, and hence policies need to be tailored to support cellulosic ethanol. The US is to some extent starting to follow this approach by making funds available for the R&D of second generation biofuels, and in 2010 the US updated the Energy Independence and Security Act, which included the creation of volume requirements for cellulosic biofuels in particular. The EU has not to the same extent tailored its support policies to second generation biofuels.

Current hurdles in the ability of second generation biofuels to compete with first generation biofuels in meeting mandates and other objectives are primarily related to high costs of production due to a combination of unproven conversion technologies and economies of scale. The severity of these hurdles varies depending on which of the two main conversion pathways are employed to produce the second generation biofuels, i.e., biochemical or thermo-chemical biomass-to-liquid. In the next section we survey some of the available technologies and report their future prospects.

2 Status of second generation biofuels

2.1 The thermo-chemical versus the biochemical pathway

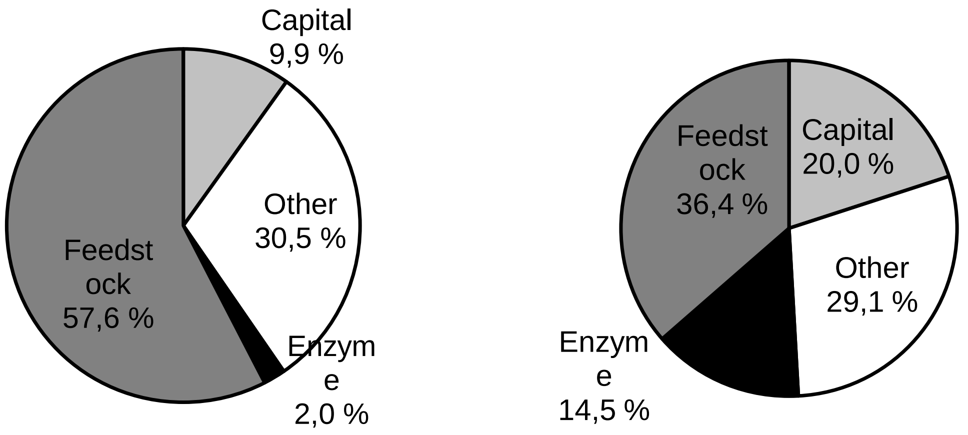
Two dominant conversion processes are used to produce biofuels from biomass feedstock: biochemical and thermo-chemical. A common version of the latter process entails the production of a synthesis gas (syngas) by subjecting the ligno-cellulosic biomass feedstocks to a severe heat treatment in the presence of a controlled amount of air. The syngas is then cleaned before being passed over a catalyst to create a range of liquid fuels – often referred to as Fischer-Tropsch liquid fuels after the name of the synthesis. There already exists an extensive worldwide commercial application of gasification of fossil fuels such as coal, and the experience accumulated from these activities is directly relevant for gasification-based conversion of biomass. Furthermore, most of the equipment components needed in a system for producing thermo-chemical biodiesel through the catalytic synthesis route outlined above are commercially available today. Yet, the production costs for second generation biofuels based on the thermo-chemical pathway are currently not competitive with those for first generation biodiesel or fossil diesel. Since the thermo-chemical route is largely based on existing technologies that have been around for many decades, there are probably quite limited opportunities for significant cost improvements from R&D or learning.

Ligno-cellulosic feedstocks consist of varying levels, depending on the feedstock, of the following three components: cellulose, hemicelluloses, and lignin. The objective of the biochemical pathway is to isolate and convert the first two components, referred to as celluloses, from complex carbohydrates to sugars to ethanol. To date, most of the production of ligno-cellulosic ethanol has taken place in laboratories or pilot-size plant settings. Most companies have only recently begun to construct and operate commercial-sized demonstration plants, with the exception of Iogen, Canada, which has been producing ethanol from wheat straw since 2004. Although the technology has been shown to be effective, the efficiency of conversion processes still has a ways to go to achieve theoretical maximum conversion efficiencies. Thus, compared to the ripe thermo-chemical pathway technology, the biochemical pathway to cellulosic biofuels is an infant technology. According to the economic theory of innovations, it is in the early stages of product and process development, government intervention may be warranted (Grossman, 1990; Olsen et al., 2009). We have therefore chosen to concentrate on the biochemical pathway for second generation biofuels in the present report.

2.2 Current cost picture

Production costs for second generation cellulosic ethanol are currently not competitive with those for first generation biofuels or gasoline. Advances to date have brought down the cost from USD 1.61-2.00/liter gasoline equivalent (lge) in the 1980s to a level where it can compete with ethanol from corn today, and future developments can potentially bring down costs all the way to USD 0.24/lge (Wyman, 2008). Different assumptions about the timing of these factors and feedstock cost predictions explain the variance of future cost estimates ranging from USD 0.24-0.60/lge. Even current costs are hard to confirm due to the proprietary nature of the data and array of feedstock and conversion technologies available. This is evident in the variance in current cost estimates of USD 0.80-1.97/lge in the literature.

Figure 1 Ethanol production cost components by feedstock



Corn Ethanol

Cellulosic Ethanol

(Sources: USDA, 2010)

In Figure 1, we compare the cost split of cellulosic ethanol with that of corn ethanol. Chemical costs per unit of production represent a significantly higher proportion of the total unit cost of production for cellulosic ethanol than for corn-based ethanol due to the difficulty and expense of breaking down the ligno-cellulosic materials to sugars that can be fermented.

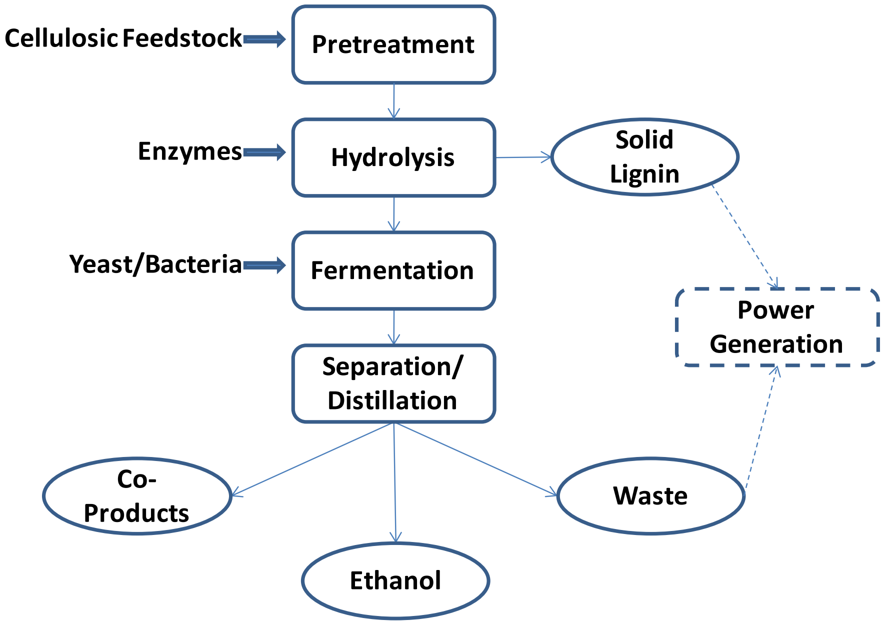
Also, capital recovery costs represent a significantly higher proportion of the total unit cost of cellulosic vs. corn-based ethanol. The US Energy Information Administration estimates the cost of a 13 million liter cellulosic ethanol facility to around USD 375 million, more than five times the cost of a corn ethanol plant of similar size (EIA, 2007).

Biomass feedstock used in the production of second generation biofuels is a smaller component of overall costs than those used in the production of first generation biofuels, yet are still expensive and represent a large portion (~36%) of production costs. Today, the market for cellulosic biomass feedstock is poorly developed. Moreover, most crop residues have low economic value and, in order to minimize disposal costs, cereal crops have been bred and managed to reduce straw and stover yields. These yields can easily be increased if there is a value for these agricultural residues, i.e., if they are used as feedstock in the production of cellulosic ethanol (IEA, 2008b).

2.3 Cost reduction opportunities

Although the steps in the biochemical conversion process are similar to those in the production of first generation biofuels, the nature of the biomass inputs used in the production of ethanol from ligno-cellulosic feedstocks requires different technologies and inputs at various stages of the process. The biochemical conversion pathway is presented in Figure 2.

Figure 2 Biochemical conversion process



We have identified opportunities for cost reductions in all production stages:

(1) Pretreatment – The goal of this stage is to prepare the feedstocks in such a way as to improve the separation of cellulose and hemicellulose from lignin and optimize their subsequent conversion to sugars as well as maximize the value of co-product generation. While the pretreatment stage in the production of first generation biofuels is relatively straightforward, pretreatment of ligno-cellulosic feedstocks is generally extensive and costly due to the strong chemical bonds of the ligno-cellulose structure. Many technologies have been studied, yet none appear to be ideal, although various pretreatments have been shown to be better suited to particular feedstocks. This stage takes place at the ethanol plant.

The different pretreatment methods include:

- water-based (e.g., flow through, partial flow through, steam explosion)
- acidic (e.g., dilute or concentrated acid including H2SO4, controlled pH)
- alkaline (e.g., ammonia freeze explosion and ammonia recycle percolation) and
- organic pulping (e.g., organosolv using acetic acid or ethanol).

Current pretreatment processes do not meet cost and performance goals. Technologies to maximize yields of cellulose and hemicellulose while reducing inhibitors (lignin) to the enzymatic hydrolysis process are still being explored. The current technologies require significant capital investment and have high operating costs. This stage has been identified as requiring learning to improve pretreatment efficiency, which impacts the efficiency of the downstream processing steps (IEA, 2008c).

(2) Hydrolysis/saccharification – There are two major hydrolysis processes: a chemical reaction using acids and an enzymatic reaction. In the traditional methods developed in the 19th and 20th centuries, hydrolysis is performed by attacking the cellulose with an acid. A decrystalized cellulosic mixture of acid and sugars reacts in the presence of water to complete individual sugar molecules (hydrolysis). The product from this hydrolysis is then neutralized and yeast fermentation is used to produce ethanol. The BlueFire Ethanol Fuels uses a proprietary process to convert rice and wheat straws, wood waste, and other agricultural residues to ethanol using acid hydrolysis.

The majority of the proposed commercial-scale biomass-to-ethanol facilities plan to use enzymes rather than acids in order to facilitate fast, efficient, and economic bioconversion of celluloses to sugars. In enzymatic hydrolysis, cellulose and hemicellulose are exposed to cellulase enzymes that convert the carbohydrates into sugars. The enzymatic hydrolysis of starch used in the production of first generation biofuels requires a single family of amylases, while the effective hydrolysis of ligno-cellulosic biomass requires a number of more expensive cellulases to effectively break down the interconnected matrix of cellulose, hemicelluloses, and lignin. The process can be slow, and represent a significant portion of production costs.

Input	Output
Enzymes	
Water	
Cellulose	Glucose (6 carbon sugar molecules = hexoses)
Hemicellulose	Xylose (5 carbon sugar molecules = pentoses)

Within this stage, the identification or development of new enzymes that are able to degrade ligno-cellulosic substrates may lead to the discovery of cheaper enzymes and/or enzymes that hydrolyze ligno-cellulosic materials more efficiently. Enzyme producers have already made significant progress in reducing the cost and effectiveness of these enzymes. Further reductions in costs within this stage of the conversion process will be driven by a combination of new enzymes and by working with industry leaders to integrate and optimize the overall conversion process. Enzyme recycling, i.e., treating multiple batches of feedstock with the same enzymes, may also be used to reduce costs. If the ability to re-circulate enzymes is available, enzyme costs will be dramatically reduced.

(3) Fermentation – In this stage, micro-organisms (bacteria and yeast) are used to convert the sugars produced in the previous stage into ethanol and various by-products. In the production of ethanol from first generation feedstocks, the sucrose or glucose products (6-carbon sugars) are metabolized by saccharomoyces or "baker's yeast," i.e., well-known natural yeast cells. Following the fermentation of the hexoses, the ethanol is recovered by distillation. The second generation process produces hexose and pentose sugars as a result of the hydrolysis process. Whereas the fermentation of hexoses using the natural yeasts already employed in large-scale corn-to-ethanol industries is not difficult provided an absence of inhibitors, fermentation of pentose sugars is more difficult and new genetically modified yeast strains are being developed to effectively use these sugars. Furthermore, there are no known natural organisms that can convert both hexose and pentose sugars at high yields.

Cost-effective fermentation relies on the ability of organisms to co-ferment pentose and hexose sugars if the feedstock contains a large amount of pentoses. Significant progress has been made in engineering micro-organisms for co-fermentation, yet their sensitivity to inhibitors and the production of unwanted by-products remain serious problems that have to be overcome for the systems to become commercially viable (IEA, 2008a). New micro-organisms dictate yield and rate at which products of the saccharification stage can be turned into alcohol. Theoretically, a fast pentose-fermenting micro-organism could increase biomass to ethanol yield by 30-40% (Terranol, 2010).

(4) Product separation – In this stage, ethanol is separated from the fermentation broth by distillation and dehydration. The residual lignin, unreacted cellulose and hemicellulose, ash, enzyme, organisms, and other components end up at the bottom of the distillation column. These materials may be concentrated and burned as fuel to power the process, or may be converted to various revenue-generating co-products. There are no significant differences or difficulties in this final product separation phase between first and second generation biofuels.

Consolidation of processes such as simultaneous saccharification and fermentation can provide additional processing cost savings. In addition to the production process itself, reducing the cost or increasing the yield of the ligno-cellulose feedstock and optimizing the collection, development, and commercialization of valuable co-products provide further opportunities for cost savings.

We conclude that significant cost reductions for cellulosic ethanol seem to depend on a series of small and large innovations in all stages of the production process. Moreover, that these innovations are not likely to be induced from increased production of first generation biofuels. A combined effort in R&D and technology learning from commercial-scale cellulosic ethanol production facilities is therefore likely needed. For instance, in the pretreatment stage, we predict that much progress will come from learning since the basics of the pretreatment processes have been identified, while within the enzymatic hydrolysis stage, R&D is essential to discover new, more effective enzymes. In the next section we turn to the question of how policy can promote R&D and learning.

3 Policies to promote learning in second generation biofuels

3.1 Theories of learning and R&D

Producing cellulosic ethanol requires significant research, demonstration efforts, and experience with production in large scale facilities if it is to become a cost-effective gasoline substitute and competitive with first generation biofuels. According to IEA (2008b), "strong policy signals on the sustainable production and use of biofuels, and efforts to spur the competitiveness of second generation technologies, will need to accompany their large-scale market penetration…"

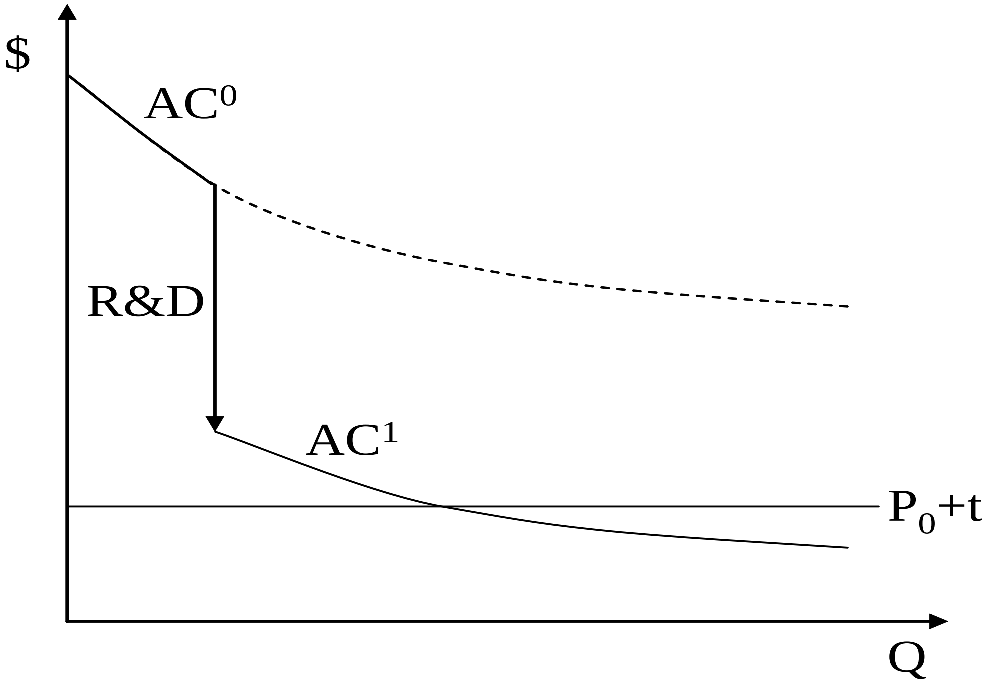
Learning curves may be powerful tools when it comes to explaining past and indicating future cost gains for relatively new technologies. In its basic form, a learning curve explores the relationship between accumulated production at time t and average cost of production at time t. It has been shown in numerous studies that a significant, negative trend can be found between the cost of a new technology and the accumulated supply of it; take for example the gas power electricity generation technology (IEA, 2000).

There are at least two fundamental mechanisms at work behind a learning curve; see IEA (2000). First, as personnel engaged in the planning and production of the new product gain experience with the new technology, say a second generation biofuels plant, they are likely to become more efficient and better organized, both with respect to how to build and how to run the plant. Moreover, experience with the product in question makes it possible to explore scale advantages in production. This will also show up as a reduction in unit costs.

Second, experience may also induce R&D, which may lead to further improvements in technology, i.e., so-called process innovations. Better enzymes would be an example of a process innovation that would reduce unit costs. Further, technological progress may also be independent of experience with the product under study. For instance, food-related research on crop yields could be utilized by the biofuels industry to reduce feedstock costs in biofuels production.

From our discussion on the prospects for second generation biofuels, we conclude that both R&D and learning seem to be necessary. This can be illustrated by the following learning curves.

Figure 3 The effect of learning and R&D for second generation biofuels



In Figure 3 the letter Q denotes accumulated production of cellulosic ethanol, AC denotes average cost of cellulosic ethanol, P_0 + t denotes the price on fossil fuel including a carbon tax and the Y-axis measures costs and prices in $. The upper curve denoted AC^0 illustrates the process of learning without R&D. Given the assumed curvature in the figure, learning will never be sufficient to make cellulosic ethanol competitive with fossil fuels. However, if successful R&D can be carried out, a shift to the lower curve AC^1 is possible. Still, R&D alone is not enough to achieve competiveness as long as the accumulated output is low. The question is then whether the government should intervene not only to support R&D, but also to spur second generation biofuels production in order to realize the necessary cost reductions.

It is not obvious that the potential for learning requires government intervention. This is analyzed in three theoretical contributions by Spence (1981), Fudenberg, and Tirole (1983) and Dasgupta and Stiglitz (1988). All contributions point out that with low discounting of future profits and low spillover in learning, that is, firms do not learn easily from each other, firms will likely internalize the learning effect. The degree to which learning is shared between firms is clearly important for this to happen. High knowledge spillover between firms decreases the proprietary value of additional output in any period and consequently reduces the incentive to internalize the learning effect. There are many, small players in the second generation biofuels industry, which could indicate that future learning gains are not internalized when firms make their investment and output decisions. Hence, there could be a role for the government to ensure a minimum level of investments in large scale second generation biofuels facilities in order to promote learning.

3.2 Policy instruments and effect on learning

In many biofuels-producing and -consuming nations, most policies do not distinguish between first and second generation biofuels, meaning that the bulk of the support goes to first generation biofuels. One example is the so-called blending mandate, i.e., a regulation that requires a certain share of total transport fuel sales to be biofuels. As shown by Eggert and Greaker (2009), a blending mandate is nothing more than an implicit subsidy to all biofuels, regardless of feedstock and process, and an implicit tax on fossil fuels. As important, blending mandates radically change the way different instruments work.

Clearly, all instruments that increase production also increase learning. Moreover, to the extent that economic actors believe that the current subsidies to production will be around tomorrow, R&D today becomes more profitable. However, the instruments differ if we compare i) the amount of extra learning obtained per $ of public spending and ii) the amount of additional R&D per $ of public spending. With respect to R&D, governments can probably maximize the amount of additional R&D per $ of public spending by subsidizing R&D directly. This can be done in a number of ways such as by setting up public R&D laboratories, by co-financing private R&D, etc. We will not venture further into the design of R&D policy here, yet note that instruments that mainly increase current production volumes are probably not efficient instruments for increasing current R&D.

With respect to learning, subsidies should target to the technologies where governments expect learning to occur. Eggert and Greaker (2009) provide the following taxonomy of instruments:

Table 2 The effect of instruments on learning

	Without blending mandate effect on production			*With blending mandate effect on production*		
	Domestic first gen.	Domestic second gen.	Foreign first gen.	Domestic first gen.	Domestic second gen.	Foreign first gen.
Tax on GHG emissions from conventional fuels	+	+	+	+	+	+
Blending mandate	0	0	0	++	+	++
Tariff on imports	0	0	-	++	+	-
Insufficient internalizing of costs of GHG emissions, production abroad	0	0	+	-	-	+
Insufficient internalizing of costs of GHG emissions, domestic production	++	+	0	++	+	-
Strict GHG emission product standards	0	0	0	-	+	++
Investment subsidy to second generation biofuels	0	+	0	0	+	0

A GHG tax on conventional fuels will increase the price of conventional fuels and make biofuels in general more profitable. Since a GHG tax on conventional fuels is warranted regardless of the existence of biofuels, it should be pursued without considering possible learning effects.

As mentioned a blending mandate supports all biofuels, implying that the currently least expensive ones will benefit most. Hence, a blending mandate is an inefficient way to support learning with respect to second generation biofuels.

As long as there is no blending mandate, trade policy will not affect learning in second generation biofuels. The reason is that the price of transportation fuels is given as the price of conventional fuels. Thus, a tariff only reduces imports of foreign first generation biofuels. A blending mandate changes this logic. With a blending mandate, transportation fuel suppliers are required to blend in biofuels. If foreign biofuels become more expensive due to the tariff, fuel suppliers substitute foreign biofuels with domestic biofuels. However, they will choose the cheapest option, which currently is domestic first generation biofuels. Thus, trade policy is also an inefficient way to support learning with respect to second generation biofuels.

Non-Annex 1 countries have likely not internalized the cost of GHG emissions from their biofuels production. This constitutes a subsidy to the export of biofuels to Annex 1 countries. Without a blending mandate in place, there is no effect on the learning in second generation biofuels in Annex 1 countries. This changes with a blending mandate for the same reasons as explained above.

Finally, Annex 1 countries may also have failed to internalize the cost of GHG emissions from their biofuels production fully. For instance, run-off of fertilizer from fields produces nitrous oxide (N_2O), which is a very strong GHG. Many Annex 1 countries do not regulate run-off properly. From Table 2 we note that insufficient internalizing of costs of GHG emissions caused by domestic biofuels production could spur learning. However, this is a costly way of promoting learning as it likely promotes first generation more than second generation biofuels, and since first generation biofuels are more GHG intensive it may lead to increased GHG emissions thus making it necessary to pay for more expensive GHG abatement in other sectors of the economy (given a ceiling on emissions).

A strict GHG emission standard only has an effect if combined with a blending mandate. The standard then determines which biofuels are eligible for the blending mandate. Since first generation biofuels from the US and EU score badly in terms of GHG-reducing potential, they may be shut off from being used to fulfill the blending mandate. This will benefit second generation biofuels as long as they score satisfactorily in terms of GHG-reducing potential. However, imported biofuels may also score well in terms of GHG-reducing potential, and thus the effect on second generation biofuels could be limited. That is, the standard will mainly favor foreign first generation biofuels with respect to the blending mandate since second generation biofuels are not cost competitive with foreign first generation biofuels. However, foreign first generation biofuels should receive no subsidy, which in fact is the effect of a blending mandate. One should also take into consideration that it is difficult to calculate GHG emissions for biofuels due to the indirect effects through food markets and the emissions from land use change.

If Annex 1 countries decide to stick with the blending mandates, the infant industry argument would hold that the competition from foreign first generation biofuels should be limited by trade policy. On the other hand, countries then end up with a very complicated policy mix. First, they must introduce and administer a GHG emission standard in order to shut out poorly performing first generation biofuels from the implicit subsidy provided by the blending mandate. Second, they should put a tariff on foreign biofuels in order to deny well-performing foreign first generation biofuels the implicit subsidy created by the blending mandate. Therefore, it is likely better to support learning in the second generation biofuels industry directly by requiring that some share of the blending mandate must be fulfilled by cellulosic ethanol. As we can see from the Table 2, investments subsidies could target second generation biofuels solely. Then, if used at all, trade policy should only aim to correct for insufficient internalizing of the costs of GHG emissions from the production of the imported biofuels (Eggert and Greaker, 2009).

Some argue that we need first generation biofuels to "pave the way" for second generation biofuels. We have already argued at the end of Chapter 2 that there seems to be no such link on the producer side. The technologies and the development challenges are simply too different. On the distribution side, gasoline stations need to invest in separate storage facilities and pumps in case they are selling high biofuels blends like E85, which consists of 85% ethanol and 15% gasoline. On the consumer side, all cars can run on blends of up to 5% biofuels without any adjustment, while consumers need special "multifuel cars" to be able to run on high blends like E85. We question the "pave the way" logic, i.e., that a developed market for biofuels will make it easier for second generation biofuels to enter and for learning to take place. The user side of the market is able to accommodate up to 5% of the total transport fuel volume without any changes in its capital stock.

4 *Current support to ligno-cellulosic ethanol*

4.1 The US

In 2009, the US produced 10.8 billion gallons, or 40.7 billion liters, of ethanol, a 5.6-fold increase over the 2000 level. US support for ethanol production and consumption based on both traditional and ligno-cellulosic feedstocks comes in many forms, including tax credits, tariffs, standards, and direct funding.

Tax Credits[3]:

- Excise tax credit for ethanol fuel blenders: USD 0.45 per gallon of ethanol (including imported ethanol; down from USD 0.51 per gallon once annual production or importation of 7.5 billion gallons is reached)
- Small ethanol producer credit: USD 0.10 per gallon (applies to plants producing no more than 60 million gallons per year; credit applies to the entire amount of cellulosic, but is limited to 15 million gallons of production for conventional ethanol)
- Cellulosic biofuel producer credit: USD 1.01 (must be produced and used as a fuel in the US, net of other ethanol excise tax credits)

Tariffs:

- There are no tariffs on fibrous cellulosic materials[4]

---

[3] http://www.law.cornell.edu/uscode/html/uscode26/usc_sec_26_00000040----000-.html

[4] http://www.usitc.gov/publications/docs/tata/hts/bychapter/1000C47.pdf

- Ethyl alcohol to be used as a fuel: USD 0.1427 / liter[5] (= USD0.54 per gallon) plus a 2.5% ad valorem charge, which amounts to approximately a 30% combined tariff (note that fossil fuels have close to a zero import duty)

Some countries are exempt from these tariffs through the Caribbean Basin Initiative and the North American Free Trade Agreement (NAFTA). The Renewable Fuel Standard 2005 required 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012, later increased to 9 billion gallons in 2008, and then set to increase each year to reach 36 billion gallons in 2022, i.e., 7% of the expected annual gas and diesel consumption in 2022 (US Environmental Protection Agency – EPA, 2010).

In 2010, the Energy Independence and Security Act created volume requirements by renewable fuel type and lifecycle GHG performance threshold standards. While production of corn ethanol is set to stabilize at 15 billion gallons per year, cellulosic ethanol has a targeted increase from zero in 2010 to more than 15 billion gallons in 2022. Although the mandates guarantee a market for second generation biofuels, it is possible for the EPA to delay or waive the mandate in a particular year if it is found to cause adverse economic or environmental impacts, or if capacity simply cannot be met (USDA, 2010). Furthermore, the EPA is required to evaluate and make appropriate market determinations for setting the cellulosic biofuels standard each year for the ensuing year. Koplow (2009) estimates the level of incremental subsidies provided by the Renewable Fuel Standard above existing tax credits and tariffs for ethanol made from corn and cellulosic biofuels to be USD 0.14 and USD 1.25 per gallon, respectively. This brings the total estimated corn and cellulosic biofuel subsidies to USD 0.60 and USD 2.26, respectively, and does not include feedstock input price effects of heavily subsidized corn.

The US is providing incentives for producers to produce cellulosic ethanol on a commercial scale and, by limiting use of first generation ethanol to 15 billion gallons, is signaling confidence in the ability of cellulosic biofuels to contribute significantly as a renewable transport fuel despite the lag in build-up of production capacity. In addition, the US has made billions of dollars available for technological development and construction of pilot and commercial demonstration production facilities. The funding is primarily available through the Department of Energy (DOE) and US Department of Agriculture (USDA), yet numerous states also offer incentives through the use of grants, tax breaks, and loan guarantees. In 2006, total cumulative funding through national and state programs applicable to ethanol exceeded USD 2.5 billion (OECD/IEA, 2008). From 2007 to 2009 alone, the federal government committed a total of more than USD 2 billion to next generation biofuels in direct private sector support and to university research and development, including biomass projects. In December 2009, the DOE’s Office of Biomass Program awarded USD 564 million (included in the USD 2.5 billion above) for the construction and operation of pilot, demonstration and commercial-scale biorefineries. The USDA also extended two major loan guarantees totaling USD 134.5 million in 2009 through the Biorefinery Assistance Program, which is authorized to support the construction of up to four demonstration cellulosic ethanol facilities and to provide over USD 750 million in grants over a three-year period for the commercial production of ethanol from cellulose (USDA Rural Development, 2009).

US policy has generally favored production incentives and mandates and accordingly, distribution and refueling infrastructure as well as availability of fuel-compatible vehicles

---

[5] http://www.usitc.gov/publications/docs/tata/hts/bychapter/1000C99.pdf (Heading/Subheading 9901.00.50)

continue to be of concern as potential hindrances to the growth in consumption of biofuels. Meeting blending mandates will require additional policies such as those targeted to infrastructure development and vehicle efficiency. Coyle (2010) concluded that "blending and shipping constraints may encourage investors to turn away from cellulosic ethanol in favor of processes that yield green fuels (e.g., green diesel, biobutanol) more closely substitutable for fossil fuels."

The US had 2,052 gas stations providing E85 in 2010, mostly in the Midwest due to difficulties transporting ethanol. More exactly, ethanol cannot be shipped in existing crude oil or petroleum fuel pipelines since it absorbs water and other impurities, affecting fuel quality and shortening the lifetime of pipelines. Support is granted for more E85 refueling infrastructure and fueling stations receive a tax credit of 50% (up to USD 50,000 per station) of the cost of installing pumps prior to 2011 that dispense ethanol blends of at least 85%. Only about 8 million flexible-fuel vehicles that can use blends of up to 85% ethanol exist and 10% blends is the current legal limit for conventional vehicles. Allowing manufacturers to receive credit for flexible-fuel vehicles against their Corporate Average Fuel Economy (CAFE) obligations was a powerful driver in the production of biofuel-compatible vehicles (Galik et al., 2009). However, this policy has been claimed to enable a number of US auto manufacturers to avoid penalties that they otherwise would have had to pay on inefficient fleets, allowing them to avoid investments in fuel efficiency (IEA, 2010).

4.2 The EU

EU ethanol production in 2009 was 4.9 billion liters, up from 2.8 billion liters in 2008 and representing an increase of 170% from 2004, with production from wood pulp, whey and waste feedstocks, i.e., second generation, increasing, yet only accounting for 1% of the total production (ePure, 2010). Imports for fuel use, predominantly from Brazil, totaled approximately 0.95 billion liters. The Climate and Energy Package, adopted in December 2008, contains important legislation for biofuels including a 10% binding target for use of renewables in the transport sector by 2020 and the introduction of a comprehensive and unparalleled set of sustainability criteria that biofuels need to fulfill in order to be counted toward the target. The Renewable Energy Directive highlights the necessity to "ensure the commercial availability of second generation biofuels." Furthermore, when demonstrating compliance with targets for the use of energy from renewable sources within the transport sector, the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material will be considered to be twice that made by other biofuels; however, the Directive does not set a specific quota for second generation biofuels. Among other sustainability criteria, a minimum GHG savings of at least 35% compared to fossil fuels from 2013 onwards, rising to 50% and 60% in 2017 and 2018, respectively, is required. These standards could work in favor of cellulosic ethanol and other second generation biofuels since they have a higher GHG reduction potential than the biofuels currently produced, with the exception of sugarcane-based ethanol already imported from Brazil by several EU Member States since this fuel already meets these criteria according to some lifecycle studies and is much less expensive.

The double counting of non-food cellulosic biofuels in the renewable target and GHG criteria are the only policies that indirectly promote the use of lingo-cellulosic ethanol at the EU level. In order to implement the current 10% binding target for the biofuel share of transport fuel consumption, the European Commission created beneficial conditions for second generation biofuels. Hence, the Commission requires that Member States give double weighting in their national biofuel obligations to biofuels originating from different feedstock sources, i.e., biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material (for a critical discussion, see Eickhout et al., 2008).

While the biofuels market in the EU is predominantly a biodiesel market, Sweden has been active in the ethanol field for several years with policy measures including promotion of high-blend or pure biofuels and low blends compatible with existing distribution infrastructure and engines; tax benefits with no limits on quantities (all ethanol used for fuel is tax exempt); and investment in research, technology, and development. Sweden's supply of ethanol is a combination of domestic production and imports from Brazil. The country is treating first generation as a bridge to second generation ethanol. Tax exemptions and biofuel obligations that require fuel suppliers to include a certain level of biofuels in the fuel have been adopted by several EU Member States, and the European Commission encourages and believes that the use of obligations, by ensuring large-scale deployment, can bring down the cost of promoting biofuels. Excise tax exemptions for biofuels produced or blended in European countries have been introduced at various levels up to 100% by most Member States. Germany is one of few countries with excise tax privileges provided to second generation biofuels. The German Biofuels Quota Act states that "alcohols obtained by biotechnological methods for cellulose hydrolysis…are particularly eligible for favorable tax treatment" (IEA, 2007). Additionally, Sweden requires all gas stations to sell at least one renewable motor fuel and also provides subsidies equal to USD 1,400/vehicle[6] for the purchase of energy efficient vehicles and vehicles that can use renewable fuels. In 2008, the EU had around 170,000 flexible-fuel vehicles in operation, of which 70% were in Sweden, and 2,200 E85 pumps. Sweden's research as it relates to the usage of renewable fuels in the transport sector focuses on working closely with the vehicle industry to develop vehicles able to use renewable fuels. It is not clear what, if any, portion of this is devoted solely to cellulosic ethanol.

Other large ethanol producers in Europe include Spain and France. Spain's national and regional governments provide subsidies for plant construction, and have exempted alcohol used for biofuel from taxation through 2012, amounting to USD 0.57/liter (IEA, 2010). Most ethanol is produced from cereals, predominantly wheat and barley. France has utilized favorable tax treatment and blending quotas to spur the growth of biofuel production and consumption, and this helped the country meet its 2007 goal of having biofuels comprise 3.5% of the total amount of transport fuels consumed. The French tax preference rate has been revised downwards annually. In 2008, the rate was EUR 0.27/liter[7] of ethanol and it was only available to plants officially approved by the French government through a bidding process (USDA, 2008). Following an energy and ecological balance review of biofuels, the French Minister of Environment retreated from the 2015 target of 10% biofuels. Since then, the government has proposed legislation that supports a biofuels certification system that will have economic, social, and environmental impacts, and also encourages research on second generation biofuels. One of the main research programs on second generation biofuels, Futurol, is exploring the enzymatic hydrolysis conversion process using mainly straw and wood biomass.

The EU has import protection in place in the form of a tariff on denatured ethanol that adds around 45-50% to the cost of imported ethanol (FAO, 2008). Other measures that have been implemented by some countries to promote biofuels include allocation of resources for

---

[6] USD 1 = 6.60 SEK in Jan, 2011.

[7] USD 1 = EUR 0.73 in January, 2011.

expansion of energy crops (Estonia, Slovenia), tax exemptions for corporate fleets and flexible-fuel vehicles sales (Ireland), government fleet mandates (UK, Sweden), and exemption from congestion charges and access to free parking (Sweden). Direct funding for research, infrastructure, and development of biofuels is available in a number of countries, although mainly for first generation technologies.

4.3 Brazil and China

Brazil is the world's second largest producer of ethanol fuel behind the US, with 28 billion liters produced in 2008. There is currently no commercial production of second generation biofuels in Brazil, nor is there an investment policy for first or second generation biofuels (some Brazilian states offer tax incentives for first generation mills or special loan conditions to support more efficient technologies). However, several companies and organizations have initiated second generation R&D efforts and set up dedicated laboratories and pilot plants. The IEA notes that the existing refinery infrastructure, in combination with vast amounts of bagasse, creates a supportive environment for the development of second generation biofuel production. In April of 2010, Brazil temporarily suspended its 20% tariff on imported ethanol until December 31, 2011.

Today, Brazil's biofuel industry is competitive with fossil fuels without government subsidies. In response to the 1970s oil crisis, the country invested heavily in the development of the ethanol industry, beginning with policies to provide direct funding to create biofuel capacity and followed by a group of policies to promote ethanol use, including the setting of an ethanol (E100) price 25% less than the gasoline price; a 3% reduction in taxes for vehicles powered by ethanol; an ethanol blending quota of 20-25%; import tariffs on foreign ethanol; a ban on diesel powered vehicles; mandatory use of alcohol-powered vehicles for all governmental institutions; guaranteed remuneration for producers; public loans designated for production capacity increase; subsidized loans for farmers; obligations for gas stations to sell ethanol; and maintenance of ethanol strategic stocks. The combined policies resulted in the adaptation of vehicle engines to E100 fuel. High global sugar prices in the early 1980s led to a shift away from E100 vehicles; nevertheless, today all vehicles run on E20 or E25 and the sales of flexible-fuel vehicles capable of running on E100 are strong, accounting for 90% of vehicles sold. Furthermore, Brazil has a distribution network of more than 37,000 gas stations with E25 pumps, of which 35,000 have at least one E100 pump. In 1996, the Brazilian government initiated a program to reduce subsidies and by 1999, it stopped controlling ethanol prices and eliminated direct industry subsidies. Simultaneously, a new law required all gasoline sold in Brazil to contain a 20-25% blend of ethanol.

China's production of ethanol reached 1.5 billion liters in 2008, supported by funds for construction of ethanol plants, preferential tax policies exempting some producers from a 5% fuel ethanol consumption tax, and allocation of funds to subsidize losses (IEA/OECD, 2008). The target for 2020 is for biofuels to reach 15% of the total amount of fuel sold. In 2006, due to concerns about how ethanol production from food crops could affect food supply, the government began to restrict production of corn ethanol and announced further subsidies and tax breaks for both biofuel producers and farmers who raise feedstocks other than grains. Through the Interim Measures of Special Fund Management for Developing Renewable Energies, special funds have become allotted to the multi-sectoral development of renewable energy, with the transport sector focused on ethanol made from sugarcane and cassava (IEA/OECD, 2008). The National Development and Reform Commission acknowledged the need to develop biofuel technology using cellulosic biomass, but clear support policies have yet to be introduced. In December 2007, the US and China entered into an agreement that covers exchange of scientific, technical, and policy information on biomass production and its conversion into biofuels and other products with a particular focus on long-term R&D in order to promote further research into and greater use of biomass. Biofuel production in China is subject to restrictions on foreign investment, i.e., Chinese investors must hold an investment ratio of 51% or more (IEA/OECD, 2008). The country has no specific policies targeting second generation biofuels.

Although no policies specific to biofuels exist at the international level, international trade of biomass feedstocks and biofuels does exist and has the potential to increase substantially. Ambitious blending requirements may necessitate the need for imports. IEA (2010) sees a shortage in the US's domestic supply of first generation and cellulosic biofuels compared to Renewable Fuel Standard's blending requirements for 2012. Furthermore, the US DOE projects that 37.9 billion liters of biofuels will be traded globally in the long term. Gurgel et al. (2007) hold that low land prices and high biomass productivity per hectare in tropical areas in Central and South America and Africa could supply 45-60% of agriculture and forestry residue biomass for second generation biofuel production under CO_2 stabilization scenarios with unrestricted trade of biofuels. Table 3 summarizes the policies in place by the countries discussed for both first generation and second generation ethanol fuels.

Table 3 Summary of policy measures in place for first and second generation ethanol biofuels

	RFS	Blend. requir.	Tax credits	Tariffs	R&D support	Plant constr.	GHG standards	CO_2 permits/ tax
US[1]	Levels inc. annually		USD 0.45/g; 1.01/g	USD 0.54/g+2.5%: 30% total	Yes	Yes	Planned	
EU[2]		10% (2020)	Yes	Yes	Yes		Planned	In some countries
Brazil[3]		20-25%		20%				
China	15% (2020)		5%		Yes	Yes		

1. The US is the only country with separate mandates and tax credits for cellulosic biofuels. The Renewable Fuel Standard mandates production of biofuels equal to approximately 7% of the estimated 2020 consumption of gasoline and diesel.
2. Level of tax credits/exemptions vary by country.
3. Tariff has been temporarily suspended.

The US and EU have employed different strategies to support the research and development of a second generation biofuels industry. The US provides a wide array of producer incentives through more substantial tax credits and explicit consumption mandates, although the latter is most likely not as effective as it may appear since the criteria can be modified annually. Furthermore, the magnitude of funds available for R&D, including for construction of facilities, dwarfs that available from the EU and its Member States. The EU only indirectly promotes second generation biofuels through the adoption of standards and double-counting of non-food cellulosic biofuels. In the US, the majority of funds and policies aim to support technological innovation and production, while in the EU, countries like Sweden tend to focus on the infrastructure for widespread use of all biofuels.

A vast majority of all resources devoted to the development of various energy sources and systems have so far focused on nuclear energy and fossil fuels (Rajagopal et al., 2009). Still, the small percentage used for renewable energy, of which only a share has been used for biofuels, amounts to many USD billions. While the motives for developing biofuels have always been multipurpose, with the largest emphasis historically on energy security, the most commonly cited reason today is the concern of global warming. Since biofuels still comprise an almost negligible part of the total consumption of transport fuels, its contribution to mitigating the increase in GHG is limited. In fact, many recent influential studies indicate that the net contribution from biofuels to GHG emissions may even have been negative so far. The most influential critique concerns the indirect land use changes and the fact that subsidized biofuels may have spurred deforestation when the search for new land to grow biofuels feedstock has led to even tropical rainforest being cut down (Searchinger et al., 2008; Fargione et al., 2008; see also Holtsmark, 2010).

5 Future biofuels policies

The growth of global biofuels production is mostly a result of ambitious government support programs. Clearly, the support has not only been driven by a concern for GHG emissions, and both the EU and the US have invoked arguments about “energy security” and the need for regional development. However, in this report we evaluate biofuels policies based on the need to reduce GHG emissions. We then discuss three major policy areas with a view to help develop the global biofuels supply in a more sustainable way:

i. Given market failures connected to private R&D on cellulosic ethanol, increase the available amount of public and private funds for R&D.
ii. Given learning-by-doing spill-overs among firms making it less probable that private actors will invest in learning, provide an exclusive subsidy to cellulosic ethanol equal to the learning investment during a limited period of time.
iii. Ensure correct pricing of fossil fuels.

Increase funds for R&D of alternative transport fuels.

The profits from investing in R&D are highly uncertain; no one can say for sure whether the outcome will turn out successful. There are several reasons why private investments in R&D will be below the social optimum; often there are innovation spillovers and a lack of patent regimes that would guarantee all benefits from a successful program to the funder. Hence, there is an incentive to try to free ride on others’ progress and, in addition, there are credit constraints (Arrow, 1962; Alston and Pardey, 1996; Jaffe et al., 2005). Fluctuations in energy prices also create uncertainty for potential investments in production capacity and infrastructure necessary for consumption. Such conditions lead to poor incentives for irreversible capital investments, ultimately resulting in a loss of production capacity as firms go bankrupt. Several contributions (e.g., Hochman et al., 2008; and Rajagopal et al., 2009) hold that government interventions with subsidies for production, consumption, and R&D have been instrumental in the development of demand and supply of alternative energy. These supporting activities have spurred investments, and, together with mandates for renewable fuels that guarantee a market for renewable fuels, have therefore promoted a successful development (Fischer and Newell, 2008; Rajagopal and Zilberman, 2008). The presence of spillover effects leads to an underinvestment in R&D compared to what is socially optimal, and the existence of network externalities may inhibit widespread adoption of the renewable fuels. For instance, empirical studies, according to Popp (2006), suggest that imperfections in the markets for innovations imply that the social returns to R&D are about four times higher than the private returns (Hoel, 2010).

Mabee (2007) found that the success in the largest biofuel-producing states in the US (over half of the domestic production capacity is found in Illinois, Iowa, and South Dakota) is closely related to the availability of direct state funding incentives designed to support the industry in its start-up phase, while tax exemptions do not seem to influence production capacity. Obviously, access to feedstock also played a significant role given that all of these states and other major ethanol-producing states lie within or in close proximity to the so-called Corn Belt. Furthermore, the largest ethanol fuel markets in the US and Europe have emerged close to feedstock areas and production facilities since the cost of producing and transporting ethanol is the primary limitation to widespread use (IEA, 2004).

Several nations have allocated and begun to distribute funds for the purposes mentioned above. Regardless of the reason for a country's interest in developing a cellulosic ethanol industry, R&D funds are necessary to overcome the private sector's underinvestment due to spillover effects. The most difficult issue with respect to this policy is deciding what level of funds to make available. The public support for energy research in IEA countries of USD 10 billion accounted for about 7% of the total R&D investments in 2006, including funds allocated to renewable energy sources. These figures are extremely low compared to the subsidies for fossil fuels of USD 250 billion in the same year (CICERO, 2010).

Rajagopal et al. (2009) use the term innovation policies for measures to address the issue of low investment levels in energy R&D. They focus on both the problem of knowledge externalities and the financial market reasons for underinvestment in innovation. Although venture-capital firms exist, small and innovative firms may still suffer from a higher cost of capital, leading to under-provision of investment in innovations from these firms (Hall, 2002)

Investment subsidies for a limited time period to realize learning potential

One of the criticisms of tax credits and implicit subsidies like blending mandates, in place is that, they do not distinguish between technologies at different development stages. Further, they are not linked to the development in costs or other market conditions, and they do not have sunset clauses. This can result in expensive or inefficient technologies or pathways being perpetually favored, creating a situation of "technology lock-in" (Rajagopal and Zilberman, 2007). The schemes created to promote learning must be transitional and support must be decreasing over time in order to move towards market competitiveness, and to avoid adverse lock-in effects and large subsidy burdens (IEA, 2010).

Ideally, in order to promote learning in second generation biofuels production; public policy should include a subsidy equal to the learning investment for cellulosic ethanol, defined as the difference between the price of conventional fuel and cellulosic ethanol. We are then assuming that cellulosic ethanol can in fact become price competitive with fossil fuel-based transport fuels as estimates suggest if the right policies are adopted and R&D investments are undertaken. This would imply a steadily declining subsidy payment to producers as unit costs decline and sales of the cellulosic ethanol increase. If costs fail to decline with increased production as estimated, governments should re-evaluate the subsidy and other fossil-fuel based substitutes to determine whether or not to continue their support of the sector. Periodic evaluations are necessary in order to mitigate the chance of developing and adopting expensive, inefficient technologies. Governments must be able to terminate the subsidy scheme if the expected learning effects are not realized. Hence, it is likely better to subsidize capital investments upfront than to rely on various forms of price support, including blending mandates, that has to be kept in place for several years, maybe decades, in order to spur large capital investments.

The US is the only country at this time that has adopted blending mandates for "advanced" biofuels, including cellulosic biofuels. Blending mandates for advanced biofuels essentially guarantee a market for the cellulosic biofuels regardless of price, which removes the distribution network demand risks from producers, encourages production, and most likely improves their ability to attain financial backers. By expanding the market for these new products, mandates can alter the profitability of R&D activities within the cellulosic biofuels field as well. The persistent demand created by the mandate without consideration for costs may also reduce the incentive to develop cost-cutting innovations. The ability of the US EPA to review and revise targets annually is important in order to prevent widespread adoption of cellulosic ethanol in transport fuels in case the technological advancements required to meet necessary production cost reductions are not attained and to avoid technology lock-in. Blending mandates require additional policies targeted at infrastructure development and vehicle efficiency requirements in order to be effective. Furthermore, mandates do not discriminate between clean, in terms of GHG emissions, and dirty biofuels and will base adoption purely on cost considerations in the absence of fuel standards. Galik et al. (2009) noted that the removal of the Renewable Fuel Standard may have a limited impact on ethanol production if production tax credits are available.

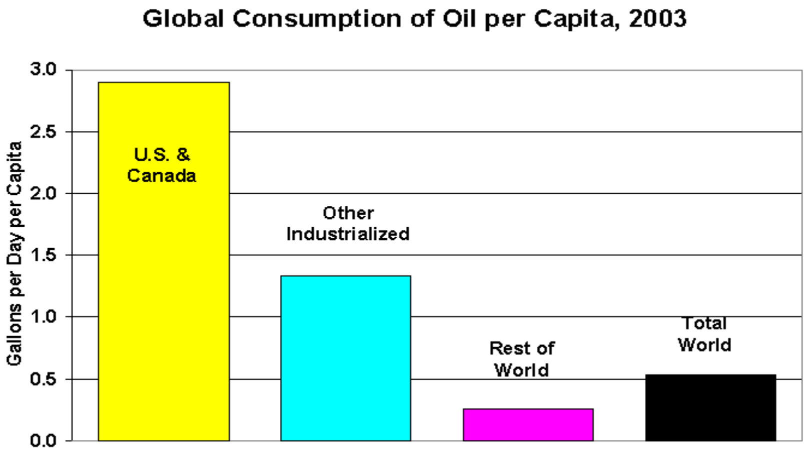
Tax credits have been introduced by several of the countries with renewable energy goals for the transport sector. General tax exemptions for biofuels make these fuels more price-competitive with petroleum fuels and can be a particularly effective tool in countries where the fuel excise tax represents a significant percentage of the price consumers pay for fuels. On the other hand, they may adversely affect the fiscal situation in countries that rely on the revenue for a large portion of their budget. A tax credit is the equivalent of a subsidy to the producer and can lead to the realization of cost reductions from learning effects if the reduced marginal costs induce producers to increase production. However, the learning effects will be realized more efficiently through the learning subsidy, rendering the tax credits/exemptions unnecessary over time.

Although subsidies for a limited period to realize learning effects may be feasible, we again stress the need to actually limit the time period. If an industry is provided support, even limited success will create an active lobby group. The parties that stand to benefit from government support have strong incentives to convince the politicians and desk officers how beneficial the existing support is and how necessary it is to postpone any planned phase-out of the public subsidies. There is always a risk that the potential gains for society from a promoting policy may be partly or even fully offset by wasteful rent seeking if such opportunities are available due to, e.g., limitations in the design of the support (Grossman, 1990). Hence, the use of public support to learning investment may create a situation of "political lock-in."

Getting the fossil fuel prices right

Two-thirds of the global oil consumption is used for transportation and a major share of the transport fuel is consumed in the US and Canada. More than 40% of the global gasoline consumption and about 20% of the diesel consumption takes place in North America. In 2003, the per capita consumption of oil in the US and Canada was 2.9 gallons per day, while the corresponding figure in other industrialized countries was 1.3 gallons per day and the global per capita consumption was 0.5 gallons per day as shown in Figure 4 (EIA DOE, 2010). In the EU, the price for a gallon of gasoline amounts to USD 6-8, while the corresponding figure for the US and Canada is USD 2.6 and 3.7, respectively. The high per capita consumption in the US is clearly to a large extent a result of a very low gasoline price. It is of course possible that the gasoline prices in the EU are too high in relation to the external effects caused by fuel consumption, yet if we assume that the current prices in EU do approximately reflect the external costs, the global efforts to control GHG emissions would benefit tremendously from an adjustment of US prices to the same level as in the EU. Such development would also facilitate gasoline price increases in countries like China and Russia, which are currently about USD 3 per gallon (HybridSUV, 2010). A similar argument could be made concerning subsidies for fossil fuels.

Figure 4 Global Consumption of Oil per Capita (EIA, DOE, 2010)



Transport accounts for roughly 21% of GHG emissions in the EU and accounted for 33% of CO_2 emissions in the US in 2008, an increase of 21.6% over 1990 levels, making it the largest end-use CO_2 emitting sector with motor gasoline being the primary source.[8] Raising fuel taxes in the US by the amount suggested may be far from feasible, and an alternative would then be to aim for a cap-and-trade system for fuel suppliers. If emission rights are not auctioned, but given away for free – the most common procedure is grandfathering, i.e., rights are allocated on the basis of historical emissions – the government misses the opportunity of getting funding in a less distortive manner than, e.g., through income and consumption taxes. However, implementing a cap-and-trade system for a market where there

---

[8] http://www.eia.doe.gov/oiaf/1605/ggrpt/carbon.html

are so many actors, as in the market for end-use of transport fuel, is complicated, and may be late in coming. Under conditions of suboptimal fossil fuel taxes and missing cap-and-trade systems, a government mandate may be a preferable second-best approach. However, a general mandate for biofuels will also drive up the consumption of first generation biofuels, implying potential negative side effects, and have a limited effect on GHG emissions as described earlier. Revising to an alternative scheme where the mandate only accepts second generation biofuels could then be preferred, yet subsidies with mandates lead to adverse interaction effects where oil consumption is subsidized instead (de Gorter and Just, 2010).

6 Conclusion - when to call it quits

Current state-of-the-art knowledge concludes that GHG emissions must be controlled and reduced within the next 30-40 years (IPCC, 2007). The transport sector is almost completely dependent on fossil fuels and contributes almost a fifth of the current global emissions, and its share is likely to increase in the future. Hence, there is a huge demand for low CO2 solutions for all kind of vehicles.

This report reviews the current status of second generation biofuels; particularly biochemical ethanol made from cellulose, and discusses policies that could facilitate competitiveness of such fuels. First generation biofuels have been and are still substantially subsidized, and this has contributed to the increasing production and use of such fuels. However, recent studies claim that the future of biofuels lies in second generation biofuels, and we find little support for the previously made argument that first generation will bridge the second generation biofuels. Hence, governments should reconsider increasing the existing support to first generation biofuels. The support to second generation biofuels should aim at distinguishing between first and second generation, and should avoid creating a new “lock-in” of second generation biofuels in case they do not fulfill current expectations.

Ethanol made from cellulose using the biochemical conversion process is far from a ripe technology, and it has the potential to reduce GHG emissions from the transport sector without leading to devastating changes in land use practice, something that recent critique has held against first generation biofuels. Hence, there may be a scope for successful public intervention by providing substantial support to R&D and to technology learning in order to achieve the necessary cost reductions both from innovations and from economies of scale.

This report questions the use of blending mandates to promote second generation biofuels. Firstly, the current and planned levels in the US and EU seem to be too ambitious given the large uncertainty about the technology’s potential. Secondly, it is hard to design blending mandates such that poor performing first generation biofuels are not covered. Thirdly, in order to spur investments in second generation biofuels facilities, blending mandates must be continued for at least a decade. In order to preserve flexibility, governments should also for measures directly targeting investments in second generation biofuels facilities.

With targeted support to second generation biofuels, there is no need to pay attention to the infant industry argument, i.e. that competition from well performing foreign first generation biofuels should be limited by trade policy. Trade policy should only aim to correct for insufficient internalizing of GHG emission costs from the production of these biofuels (see Eggert and Greaker, 2009).

One important support to biofuels development could be accurate pricing of fossil fuels on a global scale, i.e., an unsubsidized price plus an additional cost from an optimal carbon tax or a well-functioning tradable emission permit scheme. Today, petroleum products are cheap in many countries due to annual subsidies in the range of USD 200-600 billion.

It is by no means certain that second generation biofuels will play a central role in the decarbonising of the transport market. Even if a favorable environment for innovations and scale economies is created, necessary cost reductions may not achieved. The GHG emissions from land use change connected to large-scale growing of cellulosic feedstock may turn out to off-set the gains from changing fuel. Finally, other options like hydrogen or electric vehicles may experience major innovations making them preferable to vehicles running on biofuels. Hence, it is important to avoid a technological lock-in in biofuels and, although the fossil fuel lobby is a lot more powerful, we also note that lobby groups for biofuels are growing in influence and are likely to advocate continued support to biofuels, creating a potential risk of political lock-in.

Interviews

Erik Trømberg, Research Scientist, Dr. Science, Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management, July 7, 2010.

Svein Jarle Horn, Research Scientist, Dr. Science, Norwegian University of Life Sciences, Department of Chemistry, Biotechnology and Food, July 23, 2010.

References

Alston, J. and P. Pardey. 1996. *Making Science Pay: The Economics of Agricultural R&D Policy*. Washington, DC: Am. Enterp. Inst.

Arrow, K. 1962. Economics Welfare and the Allocation of Resources for Invention. Princeton, NJ: Princeton University Press.

Bioenergy Policy, Markets and Trade and Food Security, Food and Agriculture Organization of the United Nations, June 2008, p4. Link

Ethanol For Sustainable Transport: Results and recommendations from the European BEST project, Environmental and Health Administration, City of Stockholm, [date], p8

Biofuels for Transport: An International Perspective, IEA, 2004.

Biofuels in the European Context: Facts and Uncertainties, Joint Research Centre, European Commission, 2008. http://ec.europa.eu/dgs/jrc/downloads/jrc_biofuels_report.pdf

Biofuels in the US Transportation Sector, US Energy Information Administration, Independent Statistics and Analysis, Feb 2007. Link

Biofuels Progress Report: Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union, Commission of the European Communities, p7, 8. Link

Bushnell, J.E., C. Peterman, and C.D. Wolfram. 2008. Local Solutions to Global Problems: Climate Change Policies and Regulatory Jurisdiction. *Rev. of Env. Economics and Policy* 2(2): 175-193.

Carriquiry, M.A., D. Xiaodong, and G.R. Timilsina. 2010. *Second-Generation Biofuels Economics and Policies*. Policy Research Working Paper 5406. The World Bank.

CICERO, cited in a presentation given by Knut H. Afsen 'The Greenhouse Effect – Scenarios', presented March 10, 2010, p37.

Coyle, W.T. 2010. Next-Generation Biofuels: Near-Term Challenges and Implications for Agriculture. Outlook Report No. (BIO-01-01) 26 pp, May 2010. http://www.ers.usda.gov/publications/bio0101/

Dasgupta P. and J. Stiglitz (1988), Learning-by-Doing, Market Structure and Industrial and Trade Policies, Oxford Economic Papers, 40/2, p.246-268.

De Gorter, H. and D.R. Just. 2010. The Social Cost and Benefits of Biofuels: The Intersection of Environmental, Energy and Agricultural Policy. *Appl. Economic Perspectives and Policy* 32(1): 4-32.

Deploying Renewables: Principles for effective policies, OECD/IEA, 2008.

DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, p2, 26 Link

Eggert H. and M. Greaker (2009), On biofuels and trade: Tariffs, standards or import subsidies? Mistra Entwined Project, Scandinavian Working Papers in Economics.

EIA. 2010. US Energy Information Administration, 2010 10 14, http://www.eia.doe.gov/steo/gifs/Fig6.gif

EIA. 2010. US Energy Information Administration, 2010 10 22 http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/oil_market_basics/dem_image_cons_per_cap.htm#Consumption%20of%20Oil%20Per%20Capita

EIA. 2010. US Energy Information Administration, 2010 10 22, http://www.eia.doe.gov/steo/contents.html

Eickhout, B., GJ van den Born, and J. Notenboom. 2008. Local and global consequences of the EU renewable directive for biofuels: Testing the sustainability criteria. Netherlands Environmental Assessment Agency, MNP Report.

Endresen, Ø., E. Sørgaard, J. K. Sundet, S. B. Dalsøren, I. S. A. Isaksen, T. F. Berglen, and G. Gravir. 2003. Emission from international sea transportation and environmental impact. J. Geophys. Res. 108(D17) 45-60.

English translation of Germany’s Biofuels Quota Act, p4. Link

EPA Finalizes Regulations for the National Renewable Fuel Standard Program for 2010 and Beyond, US EPA, Feb 2010. http://www.epa.gov/oms/renewablefuels/420f10007.htm

EPA. 2009. EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels. Technical Hihlight.

ePURE: the voice of the European renewable ethanol industry. 2010. http://www.epure.org/

Fargione, J., J. Hill, D. Tilman, S. Polasky, P. Hawthorne. 2008. Land clearing and the biofuel carbon dept. *Science* 319: 1235-1238.

Field, C.B., Campbell, J.E., Lobell, D.B., 2008. Biomass energy: the scale of the potential resource. Trends in Ecology and Evolution 23, 65–72.

First Generation Biofuels Gain Credibility – Next Generation Projects, USDA Foreign Agricultural Service, Global Agricultural Information Network, May 2010, p3, 4. Link

Fischer, C. and R. Newell. 2008. Environmental and technology policies for climate mitigation. J. of Environ. Econ. Manag. 55(2): 142-62.

France Biofuels Update, USDA Foreign Agriculture Service, July 2008, p4. Link

Fudenberg D. and J. Tirole (1983), Learning-by-Doing and Market Performance, Bell Journal of Economics, 14/2, p. 522-530.

Further Advances in Lignocellulosic Ethanol, NILE Project, 2010. Link

Galik, C., Hodgson, W., Raborn, C. and P. Bean. 2009. *Integrating Biofuels into Comprehensive Climate Policy: An overview of biofuels policy options*, Nov 2009.

Gaps in the Research of second Generation Transportation Biofuels, IEA Bioenergy, 2008.

Greaker M. and T. R. Heggedal (2010), Lock-in and the transition to hydrogen cars: Should governments intervene?, *The B.E. Journal of Economic Analysis and Policy* 10-1 (Contributions), Article 40.

Grossman, G. 1990. “Promoting new industrial activities: A survey of recent arguments and evidence,” OECD Economic Studies, Vol. 14 (Spring) pp. 87-125.

Gurgel, A., Reilly, J.M., and Paltsev, S.(2007) "Potential Land Use Implications of a Global Biofuels Industry," *Journal of Agricultural & Food Industrial Organization*: Vol. 5: Iss. 2, Article 9.

Hall, B. 2002. The financing of research and development. *Oxf. Rev. Econ. Policy* 18(1): 35-51.

Hochman, G., S. Sexton, and D. Sexton. 2008. The economics of biofuel policy and biotechnology. J. Agic. Food Ind. Organ. 6(2): aritc. 8.

Hoel, Michael (2010) *Environmental R&D*, Department of Economics, University of Oslo Link

Holtsmark, B. 2010. Virkningene på klimagasutslipp ved økt bruk av biodrivstoff – en litteraturgjennomgang. (In Norwegian) Statistics Norway: Oslo.

HybridSUV. 2010. October, 2010. http://www.hybridsuv.com/news/world-gas-prices

International Energy Agency (2000), Experience Curves for Energy Technology Policy, OECD/IEA 2000.

International Energy Agency (IEA). 2007. World Energy Outlook 2007. www.iea.org/textbase/nppdf/free/2007/weo_2007.pdf

International Energy Agency (IEA). 2010. World Energy Outlook 2010.

International Energy Agency 2007. Renewables in Global Supply: An IEA Factsheet. Paris: OECD/Int. Energy Agency.

International Energy Agency *Technology Essentials*, OECD/IEA, Jan 2007, p1.

International Energy Agency. 2004. *Biofuels for Transport: An International Perspective*. Paris: OECD/IEA.

International Energy Agency. 2008a. *first- to second-Generation Biofuel Technologies: An overview of current industry and RD&D activities*. Paris: OECD/IEA.

International Energy Agency. 2008b. *Deploying Renewables: Principles for effective policies*. Paris: OECD/IEA.

International Energy Agency. 2008c. *Gaps in the Research of second Generation Transportation Biofuels*. Paris: IEA.

IPCC Fourth Assessment Report: Climate Change 2007, Working Group III: Mitigation of Climate Change, Executive Summary. Link

Issue Brief: Converting Cellulose Into Ethanol and Other Biofuels, Ethanol Across America, Apr 2010. Link

Jaffe, A., R. Newell, and R. Stavins. 2005. A tale of two market failures: technology and environmental policy. Ecol. Econ. 54(2); 164-74.

Joint Research Centre, European Commission. Biofuels in the European Context: Facts and Uncertainties, 2008, p10. Link

Katsoulacos, Y. and D. Ulph. 1998. Endogenous Spillovers and the Performance of Research Joint Ventures, *The Journal of Industrial Economics* 46(3): 333-357.

Khanna, M., G. Hochman, D. Rajagopal, S. Sexton, and D. Zilberman. 2009. Sustainability of food , energy and environment with biofuels. Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2009 4, No. 028: 1-8.

Koplow, D., 2009. *A Boon to Bad Biofuels: Federal tax credits and mandates underwrite environmental damage at taxpayer expense*. Friends of the Earth. http://www.foe.org/energy/biofuels-subsidies

Kusar, H., Energy Technology Department – Fuel-based Energy Systems & Transport Unit, Swedish Energy Agency, *Swedish National Biofuel Policy*, [date]. Link

Larson, E. D. *Biofuel Production Technologies: Status, prospects and implications for trade and development.* UNCTAD Biofuels Initiative, 2008. Link

Mabee, W.E., April 2007. *Policy Options to Support Biofuel Production*, p341&342.

Motaal, D.A. *The Biofuels Landscape: Is there a role for the WTO?*, Journal of World Trade, Feb 2008.

Natural Resources Canada, nrcan.gc.ca, Office of Energy Efficiency, Directory of Energy Efficiency and Alternative Energy Programs in Canada.

OECD/IEA Bioenergy. 2008. *first- to second-Generation Biofuel Technologies: An overview of current industry and RD&D activities*, Nov 2008.

OECD. 2006. *Agricultural Market Impacts of Future Growth in the Production of Biofuels*, p11 – 14.

Pray, C. E. and D. Zilberman, *The Emerging Global Biofuel Industry: The Biofuel Situation and Policies in Developing Countries*, Giannini Foundation of Agricultural Economics, University of California, May 2009, p9. Link

Rajagopal, D., and D. Zilberman. 2008.Environmental, economic and policy aspects of biofuels. *Found. Trends Microecon*. 4(5): 353-468.

Rajagopal, D., S.E. Sexton, D.W. Roland-Holst, and D. Zilberman. 2009. Recent Developments in Renewable Technologies: R&D Investment in Advanced Biofuels. *Annual Review of Resource Economics* 1: 309-332.

Searchinger T. D., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T. Yu. 2008. Use of US Croplands for Biofuels Increases Greenhouse Gas Through Emissions from Land-Use Change, *Science* 319: 1238-1240.

Spence M.A. (1981), The learning curve and competition, Bell Journal of Economics, 12, p. 49-70.

Spitzer, J. and G. Jungmeier, *Greenhouse Gas Emissions of Bioenergy Systems*, 2006. Link

Sustainable Production of Second Generation Biofuels: Potential and perspectives in major economies and developing countries, IEA, Feb 2010.

Tilman, D., R. Socolow, J.A. Foley, J. Hill, E. Larson, L. Lynd, S. Pacala, J. Reilly, T. Searchinger, C. Somerville, and R. Williams. 2009. Beneficial Biofuels—The Food, Energy, and Environment Trilemma. *Science* 17 July 325: 270-271

Ulph, D. 1994. *Strategic Innovation and Strategic Environmental Policy,* Trade Innovation, Environment, Kluwer Academic Publishers, The Netherlands, p214.

USDA Rural Development, 2009 http://www.rurdev.usda.gov/ia/rbcs_9003_Fact_Sheet.pdf

USDA. 2010. *Next-Generation Biofuels: Near-Term Challenges and Implications for Agriculture*, Economic Research Service – USDA, May 2010.

World Bank. 2010. World Development Report. http://econ.worldbank.org

Wyman, C.E. 2008. Cellulosic Ethanol: A Unique Sustainable Liquid Transportation Fuel. *Mater. Res. Soc. Bull. Harnessing Mater. Energy* 33: 381-383.