

# Biofuels in Brazil

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## **Abstract**

Many Americans are worried about the recent fluctuations in oil prices and the fact that the United States imports much of its energy from foreign oil. The United States is looking for a way to limit the dependence on foreign oil and use sustainable substitutes made in the United States. Brazil serves as a perfect case study because it meets 85% of its gasoline needs from ethanol made from sugarcane. The goal of this study is to outline the steps Brazil took to make the switch from an oil economy to an energy independent society using ethanol. This report also addresses ways that the United States can try to emulate Brazil.

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## Introduction

The modern world runs on crude oil, the lifeblood of developing and developed nations alike. The possession, transportation, and end use of oil impacts global politics, international relations, and even down to the most basic and local of jobs and services. With its high energy density and easy storage, it is hard to escape the influence of oil, especially when gigantic economies like Japan, China, and Germany imported an average of 5,031, 3,356, and 2,514 barrels of oil per day (respectively) in 2006 (Energy Information Administration). But even the combined thirsts of these countries could not compete with the United States, which although produced 8,330 barrels a day, had to import an additional 12,357 barrels a day in 2006 in order to sate its energy lust (EIA).

Even with likely conservation measures and gains in general energy efficiency, nearly all projections of future global energy use factor a substantial surge in demand for oil products, whether by continued high consumption in developed nations or projected increases in developing countries (Hallock Jr. et al., 2004). Crude oil has been the world economy's fuel of choice, supplying other petrochemicals like plastics and fertilizers, but it has come under increasing scrutiny over the last year as prices have soared, instigating a global economic slowdown.

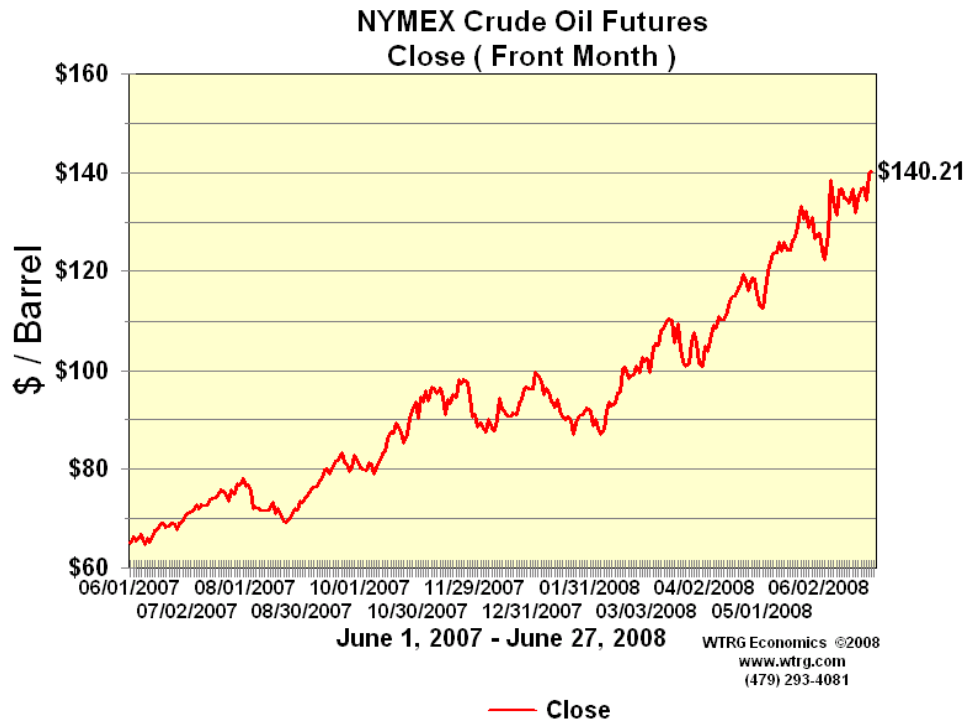


Figure 1.1: Crude Oil Futures (WTRG)

In the last year, oil prices per barrel have almost doubled, which has led to a major rethinking of economic and energy policies. Figure 1.1 shows a price jump of almost \$80 in the span of one year. China's spectacular economic growth within the last decade has imposed great pressure on world oil markets, with implications in international relations with Middle Eastern and African nations. With an economy and an industry so heavily depended on foreign oil, the United States is the most affected in terms of energy and economy, not to mention in terms of its political relations with Arab states, as well as with a Venezuela with Hugo Chavez at the helm.

The consumption of hydrocarbons has also fueled the concerns over climate change and the levels of carbon dioxide in the atmosphere. In the recent 2008 G8 summit, the eight industrial nations proposed non-binding initiatives to cut greenhouse gas emission in half by

2050: a measure seen as too little too late by unimpressed environmentalists. The United States has also never ratified the Kyoto Protocol, adopted in 1997 with the goal of cutting greenhouse gas emissions. US President George W. Bush claims that it places too much pressure on developed countries to cut emissions whilst large developing nations like India and China are free to pollute even as they economically compete with the United States and the rest of the world. Now the US Congress is debating whether or not to start drilling into oil reserves federal land in Alaska, which could create unpredictable damage to the its ecosystem.

## **Historic vulnerability**

The birth of modern day petro-politics arguably began with the formation of the Organization of the Petroleum Exporting Countries (OPEC) at the Baghdad Conference in September of 1960. The five founding members are Iran, Iraq, Kuwait, Saudi Arabia and Venezuela, and have been subsequently joined by Qatar (1961), Indonesia (1962) – set to leave OPEC with the expiration of its membership later this year (BBC), Libya (1962), United Arab Emirates (1967), Algeria (1969), Nigeria (1971), Ecuador (1973) -- suspended its membership from December 1992-October 2007, Angola (2007), and Gabon (1975–1994) (OPEC website). OPEC seeks to “ensure the stabilization of oil prices in international oil markets with a view to eliminating harmful and unnecessary fluctuations, due regard being given at all times to the interests of oil-producing nations and to a necessity of securing steady income for them” (OPEC website). According to the Energy Information Administration, as of 2006 they account for about 40 percent of the world’s total oil production, and 2/3 of its known reserves.

OPEC is used typically as an example of a profit-maximizing cartel in many economic textbooks (Alhajji and Huettner, 2000), although this is hardly the case by formal definition. Control over oil production is a powerful tool of leverage, especially in today’s uncertainty of

where future oil will come from. In retaliation for Western support for Israel in the Yom Kippur War (also known as the Ramadan War) of October of 1973, the Arab members of the OPEC placed various oil sanctions on Western states, including an embargo of oil to the United States. The panic triggered crude prices to soar to almost quadruple, from about \$3 to almost \$12 (CBC, 2007), and even after the embargo was lifted prices remained high throughout the 1970's, spurred by the Iranian revolution overthrowing the Shah in 1979.

## **Present predicament**

Now the United States finds itself in similar situation to what it faced 30 years ago. Gas prices at the pumps are seeing record highs, while the economy is staring recession in the eye. To be certain, there are new complications existing that were not in play during the 1970's. The war on terror, the emergence of economies like China and India, and issues of international humanitarian concern are just a few aspects that are changing the way the oil business is being run nowadays.

With so many states competing for the same oil, new deals and alliances will be made, ultimately shaping US foreign policy, and in some instances undermining global security. For example, when the US and Europe were trying to curb Iran's nuclear development program, to stop it from developing bomb technology, China has signed a \$70 billion energy deal with Iran, and had vowed to veto any sanctions that would have been imposed by the United Nations Security Council (Luft, 2005). In another instance, China blocked Security Council measures to impose sanctions on Darfur, one of China's main oil suppliers (Luft, 2005). The competition for oil between the United States (world's largest consumer) and China (world's fastest growing consumer) continues to shape international relations not only in the Middle East, but also in Africa and Venezuela.



The ongoing “War on Terror” exacerbates the complicated politics of oil, trapping the US in a very uncomfortable position. The resources already spent and estimated on the invasion and occupation of Iraq is resting comfortably in the cost of trillions of dollars (Herszenhorn, 2008), excluding other military spending, Afghanistan, and the financing of counter-terrorist operations around the globe. The current meteoric rise of crude oil prices translates to a significant transfer our wealth of the US, Japan, China, Europe into oil-producing countries, and there seems to be no stopping the trickle of oil money, official or otherwise, into Muslim extremist groups (Luft, 2005).

Compounded to these new realities is an old one: oil is running out. There is ongoing debate on whether or not the human race has passed its peak in terms of oil production, but what is not argued is that oil is being consumed in record quantities, and supply is without question finite. Table 1.2 shows various estimates of peak production years, as well as predicted levels of output.

Results of other recent world conventional oil production forecasts. Resource levels are in trillion barrels of oil (TBO). Production rates are in billions of barrels of oil per year (BBO year<sup>-1</sup>). Percents given for different scenarios are the annual rate of increase in production prior to peak

Author	Scenario		Year of peak or decline-point	Production at decline-point (BBO year <sup>-1</sup> )
	World EUR (TBO)	Annual production growth (%)		
Aleklett and Campbell [12]	1.9	0.0	2010	22.0
Bartlett [9]	2.0	Varies	2004	26.5
	3.0	Varies	2019	33.0
	4.0	Varies	2030	39.5
	2.3	2.0	2015–2020	NA
Cavallo [11] <sup>a</sup>	2.84	1.4	2020	33
Edwards [14]	2.25	1.0	2033	34.8
EIA [13]	2.25	2.0	2026	42.8
	2.25	3.0	2021	48.5
	3.0	1.0	2050	41.2
	3.0	2.0	2037	53.2
	3.0	3.0	2030	63.3
	3.9	1.0	2067	48.8
	3.9	2.0	2047	64.9
	3.9	3.0	2037	77.8

Source: Studies in author column.

<sup>a</sup> This study forecasted the peak of non-OPEC production only.

Table 1.2: Oil Production Forecasts (Hallock Jr. et al., 2004) <sup>1</sup>

A study conducted by Hallock Jr. et al (Reference) places the peak or decline point of global production of conventional oil between 2004 and 2037 at between 24 to 42 BBO per year. Even with the most optimistic forecasts, oil production will peak within the next generation. M.K. Hubbert, who accurately predicted in 1956 that US oil production would peak by 1970, accurately states the importance of the production peak (versus supply exhaustion):

*“Because gas and oil are exhaustible resources, the discovery history of these fuels in any particular area must be characterized by a beginning, a period of increase, a period of decline, and ultimately, an end. In this sequence, the most significant dates are neither those of the beginning or of the end, but that of the transition between the period of increase and the period of decline” (Duncan and Youngquist, 1999).*

<sup>1</sup> EUR is termed for “extractable ultimate resource”

Unconventional reserves are already being tapped into, such as reserves only accessible by deep sea drilling and “cooking” oil out of shale and tar sands, but with diminishing marginal returns. The impending scarcity of oil would trigger drastic changes in the modern way of life as the human race vies for the world’s remaining crude. Future alternatives have to be secured and developed whilst there are still resources and time to do so, even though no alternative energy source or combination thereof now known that can completely replace oil in all its many and varied uses, particularly with regard to the concentration of such a large amount of energy in such a convenient, easy to handle form for use in mobile machines, such as cars, trucks, tractors, airplanes, etc. (Duncan and Youngquist, 1999).

But if not oil, how else will the US be able to sustain its economy? Are the concepts of energy security and environmental friendliness indeed mutually exclusive? Thankfully no pressure is as compelling or as motivating as economic pressure, and there continue to be advances in energy productivity and efficiency research. The oil debate has now become as timely as ever, with the convergence of economic, energy, and environmental concerns. Quite simply, not enough measures are being taken in order to significantly reduce greenhouse gases, even as the burden of oil prices weigh heavy on national budgets.

Implementation of new technologies based on alternative, renewable sources of energy must be the next step towards satisfying the demand for energy against concerns for the environment. The US Department of Energy’s Alternative and Advanced Fuels Data Center recognizes alternative fuels like biodiesel, electricity, ethanol, hydrogen, propane, and natural gas (Energy Efficiency and Renewable Energy, 2008). There have also been advances in wind turbine design, seeing the spread of wind farms from California to Copenhagen. Competitions like the World Solar Challenge in Australia keep pushing the development of cars that run exclusively on solar power, pushing the bar in what is possible. Solar thermal plants and photovoltaic power stations can be seen in countries like Spain and Germany, whilst Portugal

and the UK lead in the construction of wave power farms.

## **The ethanol solution**

One fuel source that is gaining global momentum is fuel ethanol derived from crops, and that is why our eyes turn to Brazil, which has arguably the most developed alternative fuel infrastructure in the world. Running off domestically produced ethanol from sugarcane feedstock, Brazil is seeing a realistic shot at energy independence, a surprise legacy of the global oil crisis that dominated the 1970's. Being as vulnerable as other nations to the politics and economics of oil, the Brazilian government developed an ethanol infrastructure program that blossomed under decades of commitment. This report will focus on Brazil as a case study for the construction and implementation of a successfully ethanol fuel program.

# Biology

## Microorganism

The microorganism of choice for the efficient commercial fermentation of biomass into ethanol is *Saccharomyces cerevisiae*, a type of yeast. It is a eukaryotic, single cellular organism, which means it contains a clearly defined nucleus. Its nucleus is surrounded by a nuclear membrane, in which well-defined chromosomes are located. Eukaryotic cells also have organelles such as mitochondria (cellular powerhouses), a Golgi apparatus (secretory devices), an endoplasmic reticulum (an internal system of canal-like membranes), and lysosomes (digestive apparatus within many cell types).<sup>2</sup> *S. cerevisiae* cells are round or ovoid in shape, measuring about 5-10 micrometers in diameter, as shown below in Figure 2.1.

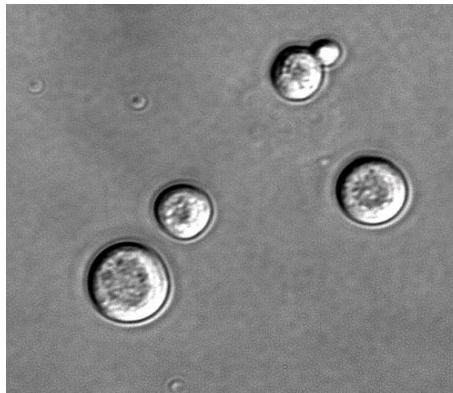


Figure 2.1: *S. cerevisiae* under DIC microscopy

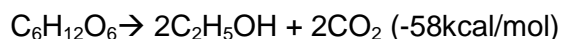
*S. cerevisiae* is the key component in fermenting sugars of crops like rice, wheat, barley, and corn to produce alcoholic beverages, also in the baking industry to expand, or raise, dough

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<sup>2</sup> Encyclopedia Britannica

(hence its alternative names such as “Baker's Yeast” or “Brewer's Yeast”). Like most fungi, yeasts perform aerobic respiration, but when air is absent, they can also produce energy by fermenting sugars and carbohydrates to produce ethanol and carbon dioxide.

Ethanol or ethyl alcohol is derived from the fermentation of glucose, a monosaccharide (or simple sugar). During the fermentation process the yeast convert the glucose initially into pyruvate through glycolysis. Pyruvate is converted into acetaldehyde by the action of the enzyme pyruvate decarboxylase with the release of carbon dioxide. Acetaldehyde is then converted to ethanol by the action of alcohol dehydrogenase. (Kavanaugh, 2005). The total reaction can be simplified to



*S. cerevisiae* is also known as a top-fermenting yeast because its hydrophobic surface causes the yeast flocs to adhere to carbon dioxide and rise to the top of the vessel during fermentation. One yeast cell can ferment approximately its own weight of glucose per hour (*Saccharomyces* Genome Database (SGD), 2008), or in other terms, as little as two pounds of yeast starter can raise 500 pounds of bread dough (Science@NASA). Under optimal conditions *S. cerevisiae* can produce up to 18 percent (by volume) ethanol (with 15 to 16 percent being the norm).

Along with its many attributes, yeast is also often used as a probiotic because it is 50 percent protein and is a rich source of B vitamins, niacin, and folic acid (SGD, 2008). Yeast's properties were discovered over its long history, almost as long as human civilization. Yeast microbes are also thought to be one of the earliest known domesticated organisms, used for fermentation and baking throughout the ages. Archaeologists found early grinding stones and baking chambers for yeasted bread in the ruins of Egypt, as well as drawings for 4,000-year old bakeries and breweries. Only since Louis Pasteur have scientists begun to explore the workings

of the yeast microbe, and it was Pasteur who first proposed that yeast was responsible for raising bread by its production of carbon dioxide, which exerts effort during fermentation (Science @NASA, 2008).

Although yeast fermentation has always been a part of food production, the 20<sup>th</sup> century saw the beginning of yeast's applications in energy. With today's ever-growing energy needs, yeast has broadened its scope from food into fuel production, as the industry keeps striving to increase the maximum yield from feedstocks and microorganisms. The performance of the microorganism is limited by the factors inherent to an environment that supports ethanol production. To protect against bacterial contamination and to keep the yeast batch sterile, the slurries are put through high heat, which would unfortunately indiscriminately affect both undesirable bacteria and useful fungi. To make matters more complicated, yeast also can only tolerate up to a certain concentration of ethanol, after which the concentration becomes too toxic for the yeast.

Improving the general resistances of yeast would increase yields and make the production process more efficient. With higher thermotolerance, contaminating bacteria can be minimized and chemical processes expedited with less harm to beneficial yeast. In yeast genes, the heat-shock proteins (HSPs) have been manipulated to protect the microbe against extremes of heat and cold (Science@NASA, 2008). When cells are exposed to heat, they synthesize HSPs which protect the cells from high temperatures, as well as other toxic agents (Lee and Goldberg, 1997) Some HSPs also promote rapid degeneration of abnormal proteins, such as damaged polypeptides. The biological community hopes that with more research, more than 50 to 100 additional microbes will also provide comprehensive genetic scripts for their life cycles, giving a better understanding of how these organisms are able to survive stressful environments such as in near-boiling water, deep ice, or even in the core of an active volcano vent and nuclear reactors (Science@NASA, 2008).

One way to build resistance is to artificially induce the production of HSPs. For example, when yeast cells growing at 25°C are shifted into an intermediate environment to stimulate induction of HSPs, such as at 37°C, the fraction of cells able to survive a subsequent exposure at 50°C increase substantially. The induction of heat shock response is also believed to protect cells against other forms of toxic exposure, such as to ethanol and hydrogen peroxide, and even other insults like heavy metals and oxidants (Lee and Goldberg, 1997).

A study by Lee and Goldberg (Reference) shows that inhibition of proteasome function by MG132 or the  $\beta$ -lactone, thereby preventing rapid degradation of abnormal proteins, causes induction of all of the HSPs tested and a dramatic increase in thermotolerance. This is also being challenged by some studies that dissociate thermotolerance from induction of HSPs due to an absence of clear correlation, despite resulting from the same physiological signals (Lee and Goldberg, 1997). Conditions that induce the heat shock response in *S. cerevisiae* also buildup trehalose, in part by stimulating its biosynthesis (Lee and Goldberg, 1997). Furthermore, the levels of trehalose, from accumulation upon heat shock to decline with return to normal temperature, correlated with the positive change in thermotolerance (Lee and Goldberg, 1997).

The key for the ethanol industry would be to further understand these functions in laboratory conditions and optimize them for use with microorganism strains in ethanol production facilities. Yeast in general is a popular subject of genetic study, since Baker's yeast is one of the microbes on Earth whose unique genome has been comprehensively deciphered (Science@NASA, 2008). This organism has a myriad of biological tools available to it, making it easy to manipulate and study in the laboratory. Furthermore, *S. cerevisiae* is the only microbe approved by the US Food and Drug Administration (FDA), making it an attractive organism to be used for commercial production of biofuels.



## **Sugarcane feedstock**

In Brazil, the most widely used feedstock is sugarcane. Also known by the scientific name *Saccharum officinarum*, sugarcane is a drought-tolerant, tropical and subtropical crop (shown in Figure 2.2). It is a highly adaptable crop, able to grow in fine to coarse soil textures, with high anaerobic tolerance as well as high hedge tolerance. It has also been reported to tolerate anthracnose, bacteria, disease, drought, fungus, herbicide, high pH, heavy soil, laterite, low pH, mildew, sodium, pesticide, rust, sand, smut, virus, and waterlog (Science@NASA, 2008).



Figure 2.2: *Saccharum officinarum*

Sugarcane contains a high sugar level, a disaccharide (two-sugar) of which 90 percent is sucrose and 10 percent glucose or fructose (Wheats et al., 1999), which is useful since yeast has an enzyme that breaks down sucrose into glucose. The average extraction efficiency to produce cane juice by crushing is approximately 95 percent and the remaining solid residue is cane fiber, as known as bagasse. A high growth and after harvest regrowth rate make it a very economical crop to produce, and is used to make products such as cane sugar, cane syrup, molasses, wax, rum, mulch and livestock feed. Different parts of the sugarcane are extracted then separated into order to convert it into its various utilities.

### **Components of sugarcane bagasse**

Apart from the sugarcane juice itself, there have also been developments in creating ethanol from sugarcane bagasse. Bagasse is a source lignocellulosic material (this is commonly

known as biomass). Lignocellulosic materials contain certain percentages of lignin, cellulose, and hemicellulose. The lignin, cellulose, and hemicellulose are contained in the cell walls of the sugarcane bagasse. The amount of cellulose, lignin, and hemicellulose contained in the biomass is dependent on the type of feedstock. In sugarcane bagasse, the composition varies but is approximately 45 percent cellulose, 26 percent hemicellulose, and 14 percent lignin (Rossell). In general, lignin surrounds interwoven strands of cellulose and hemicellulose. Both the cellulose and the hemicellulose can be used for production of ethanol because they are complex carbohydrates that can be broken down into fermentable sugars with the addition of water. With current technology, however, lignin cannot be used to produce ethanol. Table 2.1 shows a comparison of the lignocellulosic compositions of various agricultural byproducts.

Lignocellulosic Materials	Composition (% dry basis)		
	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Corn fiber	15	35	8
Corn cob	45	35	15
Corn stover	40	25	17
Rice straw	35	25	12
Wheat straw	30	50	20
Sugarcane bagasse	40	24	25
Switchgrass	45	30	12
Coastal Bermuda grass	25	35	6
Hardwoods stems	40-55	24-40	18-25
Softwood stems	45-50	25-35	25-35
Grasses	25-40	35-50	10-30
Paper	85-99	0	0-15

Table 2.1: Percentages of lignin, hemicellulose, and cellulose for different lignocellulosic materials (Lee, 2005).

On a molecular level, cellulose is comprised of many covalent bonds, as shown in Figure 2.3.

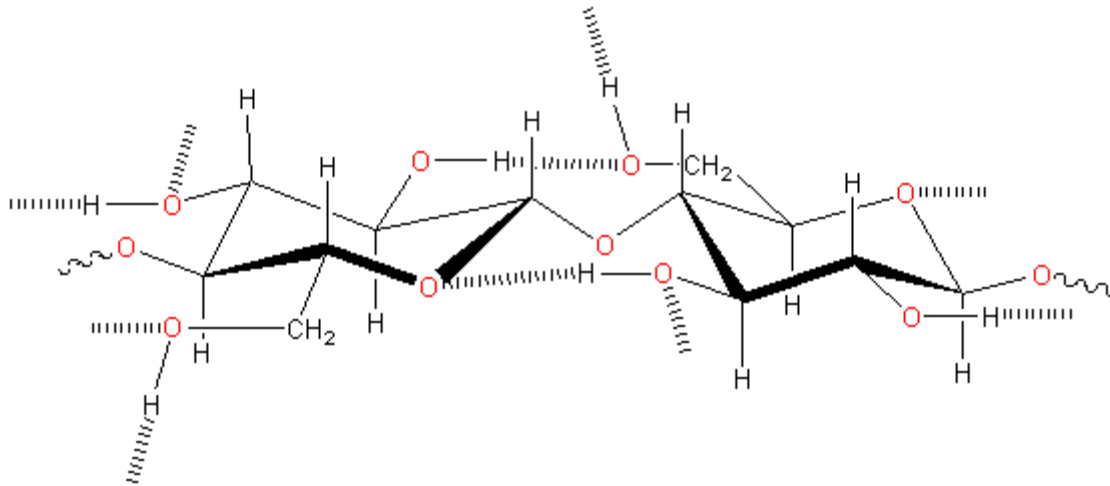


Figure 2.3: Molecular structure of cellulose. The solid lines are covalent C-H, C-O, or O-H bonds. The dashed lines are O-H hydrogen bonds between groups of molecules (Chaplin).

Cellulose comes in two varieties: amorphous and crystalline. The difference between amorphous and crystalline cellulose is the spacing between  $C_6H_{10}O_5$  groups. Crystalline cellulose is more closely packed than amorphous cellulose, which makes crystalline insoluble in water as opposed to amorphous which is soluble. Hydrolysis also takes longer with crystalline cellulose than amorphous. Typically, crystalline cellulose is surrounded by amorphous cellulose. Once the hydrogen bonds are broken, the simple glucose molecules can form, which can be used by *S. cerevisiae* for fermentation.

## Ethanol from cellulose

Producing ethanol from lignocellulosic wastes, such as sugarcane leaves and bagasse, has garnered plenty of major research attention because of their abundance and great potential for conversion into sugars and other fuels. Putting more research into various *S. cerevisiae* strains can be used to ascertain the optimal strain and parameters to be used in particular

applications, such as direct conversion of ethanol from cane juice or conversion of bagasse into ethanol.

Using the simultaneous saccharification and fermentation (SSF) process would increase ethanol output by minimizing product inhibition as well as eliminating separate reactors for saccharification and fermentation (Krishna et al. 2001). SSF is the combination of cellulose hydrolysis and fermentation into one step. The ethanogenic organism immediately consumes glucose produced by the hydrolysis, and only very low levels of cellobiose and glucose are observed in the system. This reduces the cellulase inhibition, which in turn increases sugar production rates, concentrations, and yields, and decreases enzyme loading requirements. Hydrolysis and fermentation are performed in the same bioreactor, saving on capital costs. As an added benefit, the presence of ethanol during hydrolysis reduces the likelihood of contamination, especially in the continuous operations of commercial interest (Wyman, 1996).

On the down side, SSF operation has been identified as the major contributor (>20 percent) to the cost of creating ethanol from biomass, as well as having the main disadvantage of having different optimum temperatures for saccharification (50°C) and fermentation (35°C). The upside is that sugarcane has been specifically identified as a potential cellulosic substrate (Krishna et al., 2001), and that using the leaves of sugarcane (the agro-residues burnt after harvesting the crop) could aid in furthering pollution abatement.

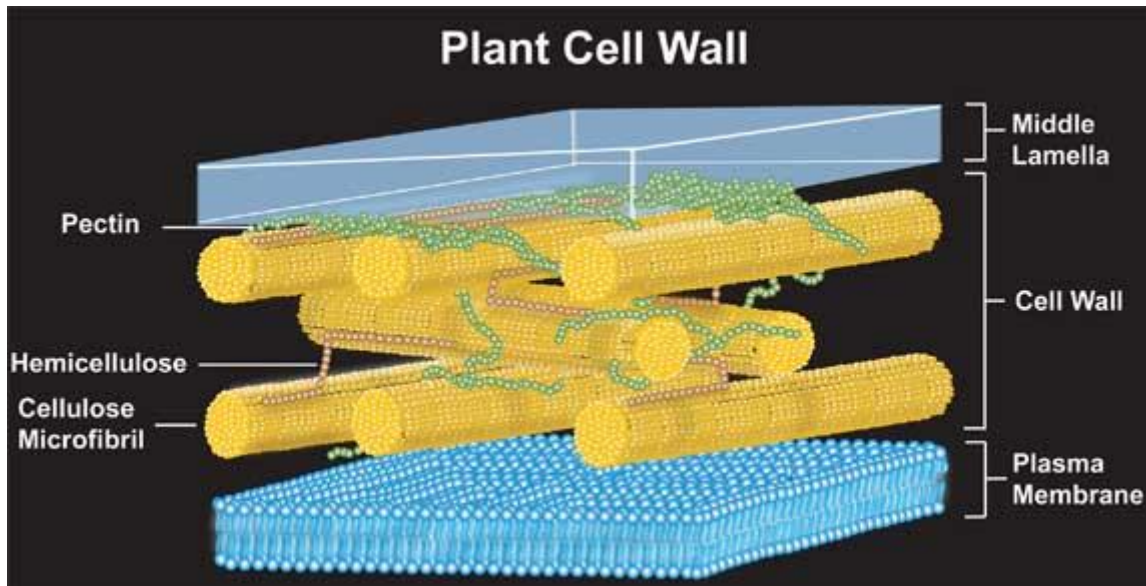


Figure 2.4: Typical cell wall structure. The cellulose and hemicellulose are interwoven in between the layer of lignin on the outside (Sigma-Aldrich Co, 2008a).

The next lignocellulosic component is hemicellulose. Hemicellulose is a polysaccharide similar to cellulose. Hemicellulose is usually interwoven in between the strands of cellulose in the plant's cell wall and acts like glue between the cellulose and lignin (Bon and Ferrara, 1996), as shown in Figure 2.4. It consists of anywhere from 300 to 3000 linked sugar molecules, making it much smaller than cellulose. Hemicellulose can be broken down into simple, fermentable sugars similar to cellulose. The main difference between cellulose and hemicellulose is that hemicellulose breaks down into sugar molecules that contain five carbon atoms such as xylose (the most abundant sugar in hemicellulose) as opposed to cellulose that breaks down into six carbon sugars such as glucose. Hemicellulose does not have the strength that cellulose has which makes it easier to break it down into simple sugars. This is partially because hemicellulose is almost always found in an amorphous state. All in all, hemicellulose is also useful, with industrial uses for cellulose and hemicellulose including use in food products,

adding a smooth texture because hemicellulose is water-soluble. Figure 2.5 shows another part of hemicellulose containing C<sub>5</sub> xylan connected together.

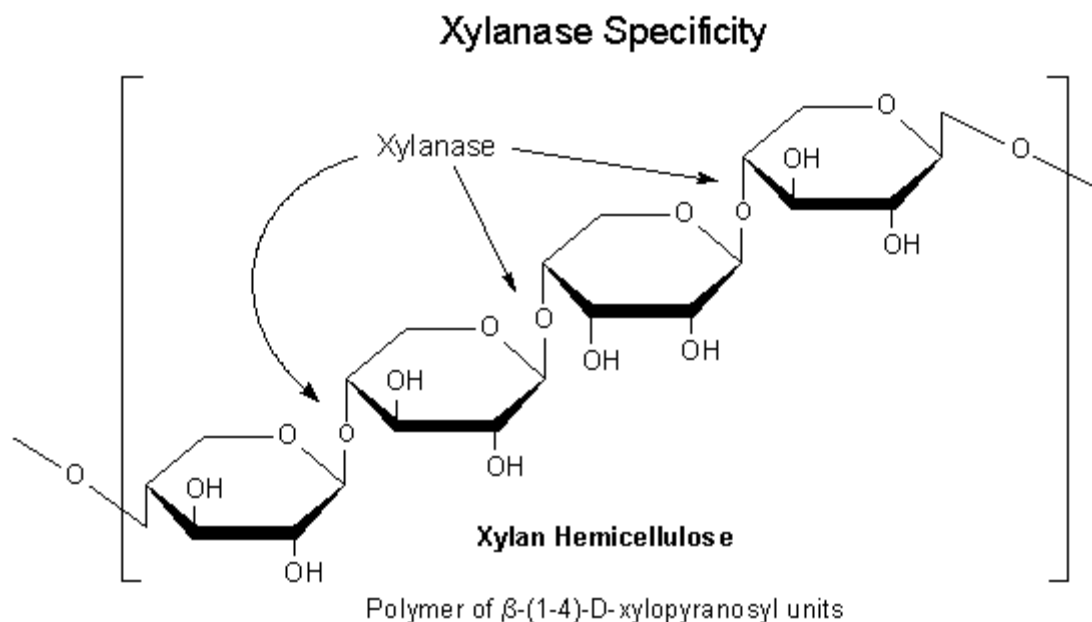


Figure 2.5: A portion of the chemical make-up of hemicellulose. Hemicellulose has a different chemical structure depending on the part of the hemicellulose that is observed. This section is a group of C<sub>5</sub> xylan connected together. After hydrolysis, this portion of hemicellulose becomes xylose, which can be fermented into ethanol (Sigma Aldrich Co, 2008b).

Finally there is lignin, which is still very useful despite its lack of participation in ethanol production. Lignin is the boundary that encases the hemicellulose and the cellulose on the outside of the cell wall. Lignin keeps everything together while ensuring that the cell walls are hard. Unlike hemicellulose and cellulose, lignin is not a carbohydrate. This means that it cannot be converted into ethanol by any means. Lignin resists growth of microorganisms and degradation from chemical or biological processes (Bon and Ferrara, 1996). The chemical structure of lignin is very complex and unordered, as shown in Figure 2.6. Next to cellulose, lignin is the most abundant renewable resource on this planet. Over 50 million tons of lignin is produced in paper processing mills alone (van Dam et al, 2008). Lignin burns very well, and so



distilleries burn the lignin to produce energy. Other uses for lignin include wood adhesive, UV stabilizer and coloring agent, biopolymer additive, surfactant, uses in radical technology, and durability enhancement (because of the hardness nature of lignin) (van Dam et al, 2008).

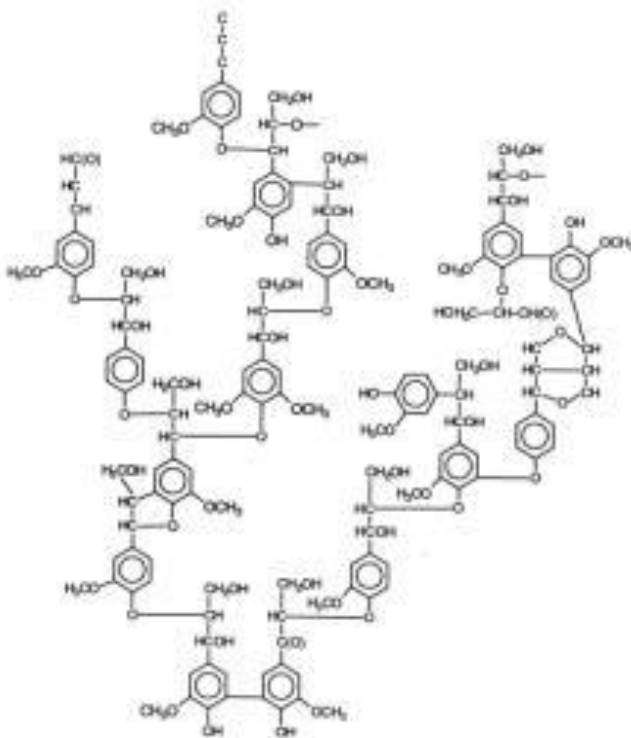


Figure 2.6: Chemical structure of lignin. Its amorphous structure and abundance of benzene rings allow it to be elastic while keeping its strength (van Dam et al, 2008).

## Technologies

To keep pricing competitive, companies strive in order to make the production of ethanol more efficient and cost-effective, reducing the energy used in the process, as well as production costs and residual emissions. New technologies are constantly being developed and employed to ensure maximum returns. This can be within anywhere from improving production plant logistics (location of processing vats, delivery schedules etc.), to discovering more efficient

processes (better fermentation, distillation etc). In terms of biological components, the two most important parts are the a) feedstock from which the starch or sugar is converted to ethanol, and b) the microorganism itself that performs the breakdown of sugars into ethanol and carbon dioxide. The scientific research community has generated a few possible techniques to incrementally increase yields, such as those outlined in the following pages.

## **Immobilization of the microorganism**

One method that could improve ethanol yield is the immobilization of the microorganism. Using microorganism cells immobilized onto a solid material seems to have many advantages over free cells, and there are even studies of ethanol production by fermentation using immobilized *Saccharomyces* sp. (Wendhausen et al., 2001). Fermentation profiles indicate that immobilized cells are more effective in ethanol production. Chrysotile, a magnesium silicate abundant in central Brazil, seems to be suitable for use as support for *Saccharomyces* sp. (Wendhausen et al., 2001). Table 2.2 details experimental results showing a marked improvement in ethanol yields, using immobilized yeast cells against free cells, in all but the lowest glucose concentration.

Glucose concentration (%)	(% of theoretical yield as measured by CO <sub>2</sub> evolution)	
	Immobilized cells <sup>a</sup>	Free cells <sup>b</sup>
10	87.0	90.0
20	92.0	88.6
30	96.0	77.8
40	72.4	54.6
50	57.8	31.6

<sup>a</sup> 0.60 g of cells onto 0.6 g of chrysotile.

<sup>b</sup> 0.60 g of cells.

Table 2.2: Fermentation yields using free and chrysotile immobilized yeast cells, at different glucose concentrations at 30°C (Wendhausen et al., 2001)

Table 2.3 shows that all studied *Saccharomyces* sp. strains show higher initial fermentation rates when supported onto chrysotile. Since sugarcane fermentation industries use a 20 percent sucrose solution in a free cell fermentation system, continuous fermentation cycles may improve upon the current (batch) industrial process, given that final ethanol conversion was higher with the same glucose concentrations.

Strain	Initial fermentation rate (g·CO <sub>2</sub> ·h <sup>-1</sup> ) <sup>a</sup>		Ratio of initial fermentation rates I/F	(% of the theoretical yield) <sup>b</sup>		Ethanol concentration (g·l <sup>-1</sup> ) <sup>c</sup>
	F	I		F	I	
Baker's yeast	0.04	0.05	1.3	76.6	87.7	15.7
CCT0762	0.07	0.13	1.9	80.0	80.4	13.3
CCT0292	0.06	0.07	1.2	84.5	96.4	19.4
CCT3174	0.07	0.09	1.3	78.5	96.4	19.4
CCT0294	0.05	0.08	1.6	76.7	92.0	18.4
CCT0290	0.04	0.10	2.5	76.0	86.4	15.4
FEA01	0.06	0.09	1.5	72.7	97.3	18.8

Table 2.3: Fermentation data of several *S. cerevisiae* strains free (F, 0.60 g) and immobilized onto chrysotile (I, 0.60 g/1.00g) on 30 percent glucose at 30°C (Wendhausen et al., 2001)

Other interesting studies (such as de Vasconcelos et al., 2004, and Wendhausen et al., 2001) suggest immobilizing yeast cells in order to produce continuous fermentation of sugarcane syrup, and continuous production of ethanol. Continuous cycle fermentation involves cultivating yeast under steady conditions and maintaining it at a particular stage of its growth cycle. Adding nutrients and extracting byproducts (like ethanol and carbon dioxide) at an equal rate keeps a constant reaction volume (Kavanaugh, 2005). The downside of continuous cycle fermentation is that it has traditionally been difficult and expensive to establish for fungi, although it is now routinely employed in producing mycoprotein and antibiotics.

In summary, cell immobilization ensures that a high cell density is maintained and that cells are not washed out of the bioreactor, reducing opportunity for contamination and removing growth inhibition due to the production of a toxic metabolite, such as ethanol. A disadvantage of immobilization is that fungal cell viability decreases over time and the immobilization system could break down over time (Kavanaugh, 2005). Further studies would have to be done in order to maximize the ethanol yields while keeping costs low.

There are also other possible options available via bed reactors such as packed and suspended bed reactors. Continuous packed bed reactors are the most widely used reactors for immobilized enzymes and immobilized microbial cells (Rensselaer Polytechnic Institute, 2008). Although studies show that packed bed reactors can be assembled using cells immobilized onto chrysotile and have higher productivity than batch and semi-continuous systems (Wendhausen et al., 2001), this type of reactor is not suitable for scaling up to industrial volumes. For scaling up, there is a need to test this support in suspended bed reactors.

Aside from improving the way *S. cerevisiae* produces ethanol, there are other challenges, one of them being *S. cerevisiae* sensitivity to heat. Although *S. cerevisiae* has been

traditionally used to produce ethanol, there are studies that show that perhaps other organisms that could be more efficient converters of glucose to ethanol.

## **Overcoming heat**

Because of the tropical or subtropical requirement for sugarcane growth, and the necessity to have processing facilities nearby in order to minimize travel costs and energy expenditure, tropical fermentation technologies in particular must be constantly developed to overcome vulnerabilities to heat. Conventional industrial yeast strains such as *S. cerevisiae* have limited thermotolerance and have some trouble with fermentation in tropical areas. The high ambient temperatures, especially in the summer months, combined with the exothermic fermentation reaction would inhibit the ability of yeast to ferment efficiently. Heat-tolerant contaminating bacteria and low-ethanol producing wild yeast strains might also contaminate the batch and compete with the commercial strain at such temperatures. Tropical fermentation technologies, specifically ethanol conversion by yeasts, must therefore be capable of high-efficiency substrate conversion above 40°C (Anderson et al., 1985). The distinct advantages of high-temperature (40- 50°C) yeast fermentation include faster rates of substrate conversion and ethanol formation, easier ethanol recovery, and considerable savings on capital and running costs of refrigerated temperature control (Anderson et al., 1985). On the other hand, it is accepted that higher temperatures increase the inhibitory effects of ethanol. With these considerations in mind, it might be worth identifying possible alternative microbes that could perform efficient fermentation at high temperatures.

Strains of *Kluyveromyces*, *Candida* and *Saccharomyces* have been seen to be effective in glucose fermentation at 40°C; although a major drawback was that high concentrations of ethanol (6-7 percent w/v) was only achieved after fermentation for 48 to 72 hours (Anderson et

al., 1985). In a study done by Anderson, McNeil, and Watson (Reference), a number of yeast strains were isolated from sugarcane mills and were identified as strains of *Kluyveromyces marxianus* var. *marxianus* and then studied for their ethanol-production capabilities at high temperatures.

The results of a study (Anderson et al., 1985) in the Table 2.4 identify *K. marxianus* var. *marxianus* strains 972 and 974 as producing the greatest theoretical yield with glucose and dilute sugarcane syrup as substrates, as well as falling within the basic criteria for effective commercial utilization.

Strain no.	Glucose <sup>b</sup> (% [wt/vol])	Ethanol production	
		% (wt/vol)	% Theoretical yield <sup>c</sup>
<i>K. marxianus</i> var. <i>marxianus</i> 974	0.39	6.26	85.6
<i>K. marxianus</i> var. <i>marxianus</i> 972	1.11	6.07	87.3
<i>K. marxianus</i> var. <i>marxianus</i> 469	1.17	5.88	85.0
<i>K. marxianus</i> var. <i>marxianus</i> 970	1.56	5.86	87.2
<i>K. marxianus</i> var. <i>marxianus</i> 467	1.51	5.80	85.9
<i>K. marxianus</i> var. <i>marxianus</i> 977	1.21	5.77	83.6
<i>K. marxianus</i> var. <i>marxianus</i> 951	1.97	5.74	88.0
<i>K. marxianus</i> var. <i>marxianus</i> 982	2.15	5.58	88.3
<i>K. marxianus</i> var. <i>marxianus</i> 976	1.45	5.68	83.8
<i>K. marxianus</i> var. <i>marxianus</i> 957	2.17	5.63	87.7
<i>K. marxianus</i> var. <i>marxianus</i> 973	1.87	5.61	85.4
<i>K. marxianus</i> var. <i>marxianus</i> 954	2.34	5.54	87.5
<i>K. marxianus</i> var. <i>marxianus</i> 985	2.10	5.53	85.7
<i>K. marxianus</i> var. <i>marxianus</i> 953	2.21	5.50	85.4
<i>K. marxianus</i> var. <i>marxianus</i> CBS 712	4.50	4.16	79.2
<i>K. marxianus</i> var. <i>marxianus</i> CBS 397	4.67	4.06	78.5
<i>K. marxianus</i> var. <i>bulgaricus</i> CBS 2762	10.43	1.08	47.6
<i>K. marxianus</i> var. <i>lactis</i> CBS 683	11.40	0.53	29.4
<i>K. wickerhamii</i> CBS 2745	11.95	0.26	16.7

<sup>a</sup> Fermentation was determined at 45°C with glucose (15% [wt/vol]) as substrate.

<sup>b</sup> Glucose remaining after 24 h.

<sup>c</sup> A molar reaction stoichiometry of glucose to ethanol to CO<sub>2</sub> of 1:2:2 has been assumed for a theoretical yield.

Table 2.4: Fermentation screen of various strains in order of decreasing ethanol production after 24 hours (Anderson et al., 1985)

Both aforementioned *K. marxianus* var. *marxianus* strains were able to ferment carbohydrates into ethanol at above 40°C, and rapidly producing >6 percent (w/v) ethanol after 12 h, with a high retention of cell viability (>80 percent viable cells) (Anderson et al., 1985). Both of these naturally occurring *Kluyveromyces* sp. strains were capable of fermentation of carbohydrates into ethanol at temperatures up to 47°C, which is close to the upper temperature

limit for the growth of yeast (Anderson et al., 1985), arguing that genetic manipulation might only yield marginal benefits.

In another study, Krishna et al. (Reference) research overcoming SSF problems by using a thermotolerant yeast, *Kluyveromyces fragilis* and comparing its effectiveness against the performance of *S. cerevisiae* in the SSF process using sugarcane and *Antigonum leptopus* leaves. Their findings are shown in Table 2.5, which is a table of different enzymes used in SSF with different substrates and yeast inoculums, and showing the resulting ethanol yields.

Enzyme	Units/g substrate	Time (h)	Ethanol yield (% w/v)					
			<i>A. leptopus</i>		Sugar cane		Solka floc	
			A	B	A	B	A	B
Cellulase	40 FPU	12	1.4	1.6	0.2	0.8	1.9	1.8
		24	1.7	2.0	0.4	1.5	2.2	2.5
		48	1.8	2.3	1.6	2.2	2.3	2.8
		72	1.9	2.3	1.8	2.5	2.3	3.0
		96	1.9	nd <sup>b</sup>	2.0	2.5	nd	3.0
Cellulase + $\beta$ -glucosidase	40 FPU + 50 U	12	1.8	2.0	0.8	1.5	2.2	2.0
		24	1.9	2.3	1.5	2.0	2.5	2.5
		48	2.1	2.7	2.0	2.5	2.5	3.3
		72	2.1	2.7	2.2	2.8	2.5	3.5
		96	nd	nd	2.2	2.8	nd	3.5

Table 2.5: SSF results (Krishna et al., 2001),<sup>4</sup>

Using both yeast strains and testing them against three different substrates (*A. leptopus*, sugarcane and Solka floc), Krishna et al. stress that *K. fragilis* was superior to *S. cerevisiae* because of the distinctly higher yields obtain in their controlled study, a result attributed to *K. fragilis*' thermotolerance. Many thermotolerant yeasts that have the ability to grow and produce ethanol at temperatures above 40°C have been studied for potential use in SSF processes (Krishna et al., 2001). Among the 58 strains tested in other studies, *Fabospora fragilis* was found to be the most suitable for ethanol production (56 g ethanol/l from 140 g glucose/l) at

<sup>4</sup> The values given were the average of duplicate experiments. Conditions: 10% (w/v) substrate; 10% (v/v) yeast inoculum (A – *S. cerevisiae*, B- *K. fragilis*) simultaneously added; 43°C for B; initial pH 5.1  
nd: Not determined



43°C (Krishna et al., 2001). With more research, *F. fragilis* could not be a viable alternative to *S. cerevisiae*, but also be used as the standard in ethanol production.

In other research, ethanol yields can be increased using thermotolerant yeasts for a shorter culture time (Krishna et al., 2001). In their studies to find the best substrate, the Solka floc has the highest rate of ethanol conversion, followed by *A. leptopus*, and then finally sugarcane. Although Solka floc appeared to be the better substrate, the best option was still to use the most economical material of out the three. The yields they extracted were about 2.5±3.5 percent (w/v) with all the substrates and the conversions were completed in about 48±72 hours. It was noted that an overall economic process (Krishna et al., 2001) must include achieving a high ethanol yield (>3.5 percent) at high substrate loading (>10 percent w/v) over short residence times (<4 days), some of which were attained in this study.

Overall, the advances in the biological aspect can be attributed to periodic developments and incremental improvements with regard to manipulation and treatment of microbe that ferments the glucose into ethanol. With a more comprehensive understanding of how the microbes function, the industry has been able to amplify desirable characteristics like ethanol and heat tolerance, as well as use newer technologies like cell immobilization to maximize ethanol output.

## Chemical Engineering

In addition to the biological components of ethanol production, chemical engineering processes serve as the means in which the primary feedstock is converted to fuel ethanol. The conversion of raw feedstock into ethanol is a long and detailed series of physical and chemical processes, involving extraction of sugarcane juice fermentation of glucose, and even the pretreatment of cellulose prior to its own ethanol conversion. The steps themselves are not vastly different from the production of alcohol for beverages, but are made simpler by disregarding palatability and taste, and a focus on maximum output.

The first main step is the extraction of the glucose from sugarcane, or in another case, the starch from a corn feedstock. There are two main production processes for converting feedstock into ethanol: wet milling and dry milling. The main difference between the two is the initial treatment of the grain. In dry milling, starchy grains are first ground into flour or "meal," then processed without separating the different components of the grain. The meal is mixed with water to form a "mash," after which enzymes are added to the mash to convert the starch to dextrose. Ammonia is added for pH control and as a nutrient to the yeast. To reduce bacteria levels ahead of fermentation, a high-temperature cooker processes the mash. The mash is then cooled and transferred to fermenters where yeast is added and the conversion of sugar to ethanol and carbon dioxide begins.

The fermentation process generally takes about 40 to 50 hours, during which the mash is agitated and kept cool, facilitating fermentation by yeast. After fermentation, the resulting beer-like mixture is transferred to distillation columns where the ethanol is separated from the remaining "stillage." The ethanol is concentrated to 190-proof using conventional distillation and then is put through a molecular sieve system, extracting the last of the water. The anhydrous

ethanol is then blended with about 5 percent denaturant (such as natural gasoline) to render it undrinkable and thus not subject to beverage alcohol tax. It is then ready for shipment to gasoline terminals or retailers.

The stillage is sent through a centrifuge that separates the coarse grain from the soluble material. The soluble materials are then concentrated to about 30 percent solids by evaporation, resulting in Condensed Distillers Solubles (CDS) or "syrup." The coarse grain and the syrup are then dried together to produce dried distillers grains with solubles (DDGS), a high quality, nutritious livestock feed. The carbon dioxide released during fermentation is also utilized, captured and sold for use in carbonating different beverages and in the manufacturing of dry ice.

In wet milling, the grain is steeped in water and dilute sulfurous acid for 24 to 48 hours. This steeping facilitates the separation of the grain into its many component parts. Wet milling was originally developed for the starch industry and subsequently adapted for fuel-ethanol production. Figure 3.1 shows a detailed chart for the wet milling of corn, a starchy feedstock, into ethanol.

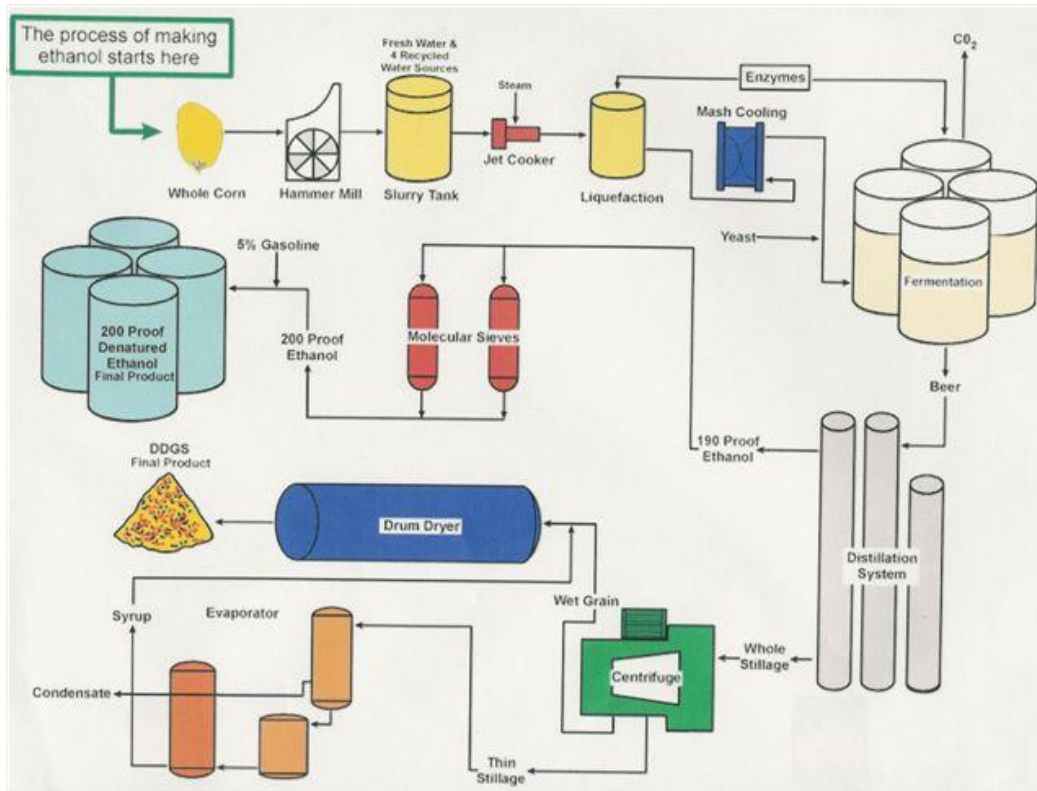


Figure 3.1: An example flow chart of one company's processes to produce ethanol. This company uses wet milling as the initial process to make corn into ethanol (Lincolnland, 2008).

After steeping, the corn slurry is processed through a series of grinders to separate the corn germ from the germ. The corn germ is then either extracted on-site or sold to crushers who extract the corn oil. The remaining fiber, gluten and starch components are further segregated using centrifugal, screen and hydroclonic separators.

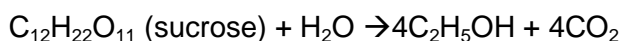
The steeping liquor is concentrated in an evaporator. This concentrated product, heavy steep water, is co-dried with the fiber component and is then sold as corn gluten feed to the livestock industry. Heavy steep water is also sold by itself as a feed ingredient and is used as a component in Ice Ban, an environmentally friendly alternative to salt for removing ice from roads. The gluten component (protein) is filtered and dried to produce the corn gluten meal co-product, which is highly sought after as a feed ingredient in poultry broiler operations.

The starch and remaining water from the mash can then be processed in one of three ways: fermented into ethanol, dried and sold as dried or modified corn starch, or processed into corn syrup. The fermentation process for ethanol is very similar to the dry mill process previously described.

In the case of sugarcane, ethanol is derived from sugar-based feedstock as opposed to a starch-based one. In factories that only produce ethanol, the cane juice is heated to high temperatures to reduce microbial contamination, decanted, sometimes concentrated by evaporation and then fermented. In combined sugar–ethanol plants (annexed distilleries), sucrose crystals that are formed after cane-juice concentration are removed by centrifugation, leaving a syrup (molasses) that contains up to 65 percent w/w sugars. Both sugarcane juice and molasses (after adjusting the sugar concentration) normally contain sufficient minerals and organic nutrients to be immediately suitable for ethanol production by fermentation with *Saccharomyces cerevisiae*.

## **A historic perspective on sugarcane processing**

Up until 1987, only the sugarcane juice was converted into ethanol. Sugarcane juice contains sucrose (a disaccharide) and water. The sugarcane juice is extracted by crushing the sugarcane stalk, and once the sugarcane juice is separated, it can be immediately fermented in a similar process to that of glucose and fructose. Yeast is then added to the sugarcane juice and heated (temperature depends on the yeast, but can be anywhere from 100-300°C), and from there the fermentation process can begin. The chemical process is the following:



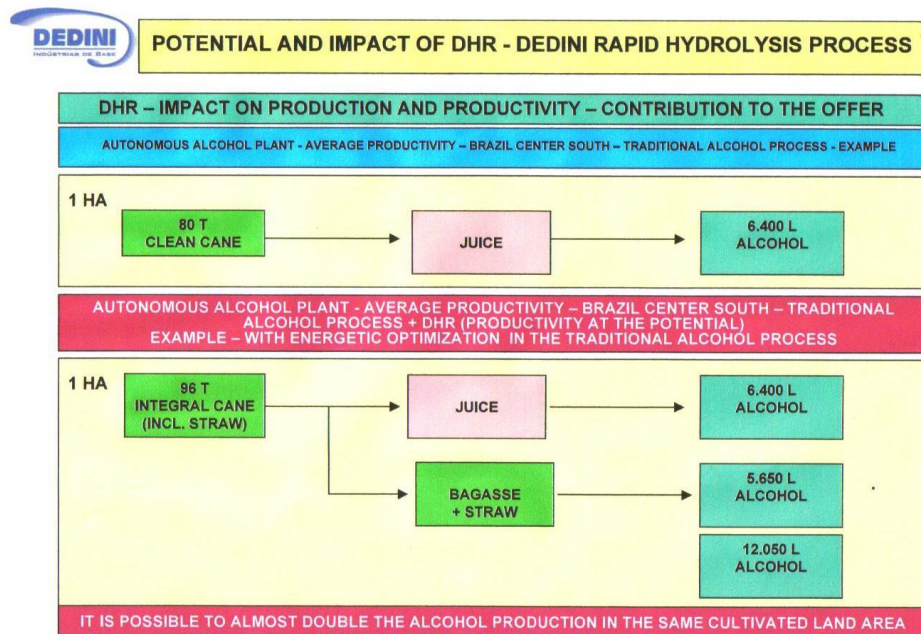
This mixture is then distilled to remove the remaining water and stored until ready to transport to ethanol stations.

The remaining portion of the sugarcane stalk (known as sugarcane bagasse) is not used to make the ethanol. Sugarcane bagasse is sometimes left out on the sugarcane fields as scrap even though it is also a good source of energy. Many processing plants burn the sugarcane bagasse to power part of their facilities. However, energy from the sugarcane bagasse is not very efficient. The maximum efficiency obtained from combustion of sugarcane bagasse is only about 26 percent. Furthermore, distilleries that use their sugarcane bagasse for power produce ash (a major health hazard) and carbon dioxide, which is a greenhouse gas (Das et al, 2004). Because of the high cellulose content of the sugarcane stalk, the sugarcane bagasse can also be processed to make paper products.

However, some plants do not even bother trying to make use of sugarcane bagasse. Often it is stored in the plant or sold to other farmers or companies. Eventually, research began to try to use sugarcane bagasse in a more efficient and economical way besides power and paper products.

In 1987, there was a push for converting the sugarcane bagasse into ethanol. This was a joint effort by many different people through the Pro-Alcohol program. In that same year, the Brazilian company Dedini, in Piracicaba, began the development of a biomass-to-ethanol production technology (called *Dedinihidroliserapida* (DHR), Portuguese for Dedine rapid hydrolysis), in partnership with Copersucar (presently the Centro de Tecnologia Canavieira) and the State of São Paulo Research Supporting Foundation (FAPESP), with funding from the World Bank (Bon and Ferrara, 1996). In order to try to increase the amount of ethanol production, many decided that the right way was to increase the area of sugarcane growing. However, the push for the advancement of technology could double the amount of ethanol

produced per hectare of land by using sugarcane bagasse to make ethanol in addition to the sugarcane juice. Therefore, sugarcane bagasse was viewed as more valuable for fuel production than for energy or pulp. Figure 3.2 outlines the impact of the DHR process on increasing the ethanol output with the same area of land.



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Figure 3.2: Theoretical amounts of ethanol created from one hectare of cultivated sugarcane land with and without using the sugarcane bagasse (Oliverio, 2004).

## Pretreatment

In general, the goal of a pretreatment process is to encompass as many of following attributes as possible:

- (1) Low cost of chemicals for pretreatment, neutralization, and subsequent conditioning.

- (2) Minimal waste production.
- (3) Limited size reduction because biomass milling is energy-intensive and expensive.
- (4) Fast reactions and/noncorrosive chemicals to minimize pretreatment reactor cost.
- (5) The concentration of hemicellulose sugars from pretreatment should be above 10 percent to keep fermentation reactor size and reasonable level and facilitate downstream recovery.
- (6) Pretreatment must promote high product yields in subsequent enzymatic hydrolysis or fermentation operations with minimal conditioning cost.
- (7) Hydrolysate conditioning in preparation for subsequent biological steps, should not form products that have processing or disposal challenges.
- (8) Low enzyme loading should be adequate to realize greater than 90 percent digestibility of pretreated cellulose in less than 5 days and preferably 3 days.
- (9) Pretreatment should facilitate recovery of lignin and other constituents for conversion to valuable co/products and to simplify downstream processing (Quintero-Ramirez, 2008).



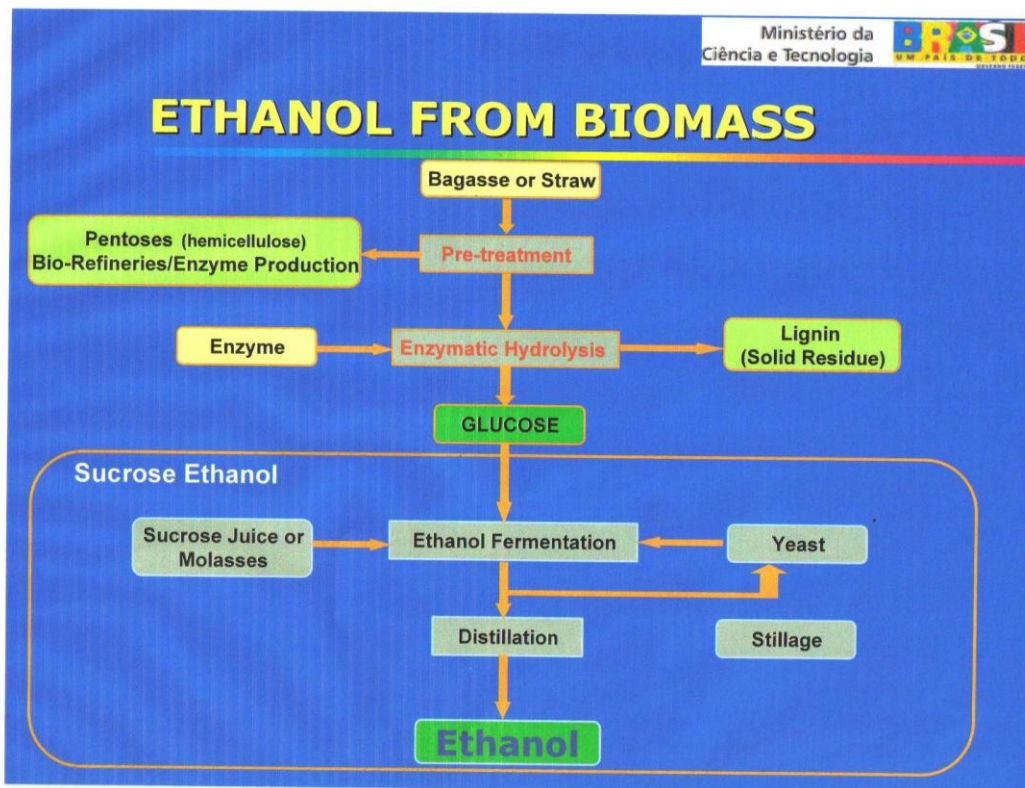


Figure 3.3: Basic processes to convert parts of the sugarcane stalk into ethanol. Inside the red oval is the process used to convert sugarcane juice into ethanol. Above the red oval is the process to convert sugarcane bagasse into fermentable sugars (Bon, 1996).

The conversion of biomass into ethanol is also outlined here in Figure 3.3, with pretreatment being the first step in converting sugarcane bagasse into ethanol. The purpose of a pretreatment is to separate the three parts of the sugarcane bagasse in order to make simple sugars. The goal of pretreatment is to improve the state of the sugarcane bagasse so that the next step in the process (hydrolysis) can be completed more efficiently.

Before pretreatment, the cellulose, hemicellulose, and lignin are all together in the cell walls of the plant. After pretreatment, the goal is to have each part separate so that further processes can begin. Typically, the sugarcane bagasse is crushed in the mill before

pretreatment can begin. Without pretreatment, many of the future processes will not run as efficiently. The moisture and ash that remains on the bagasse needs to be removed before the next step in the process of converting sugarcane bagasse into ethanol can begin. Figure 3.4 illustrates the end result of the pretreatment process on bagasse.

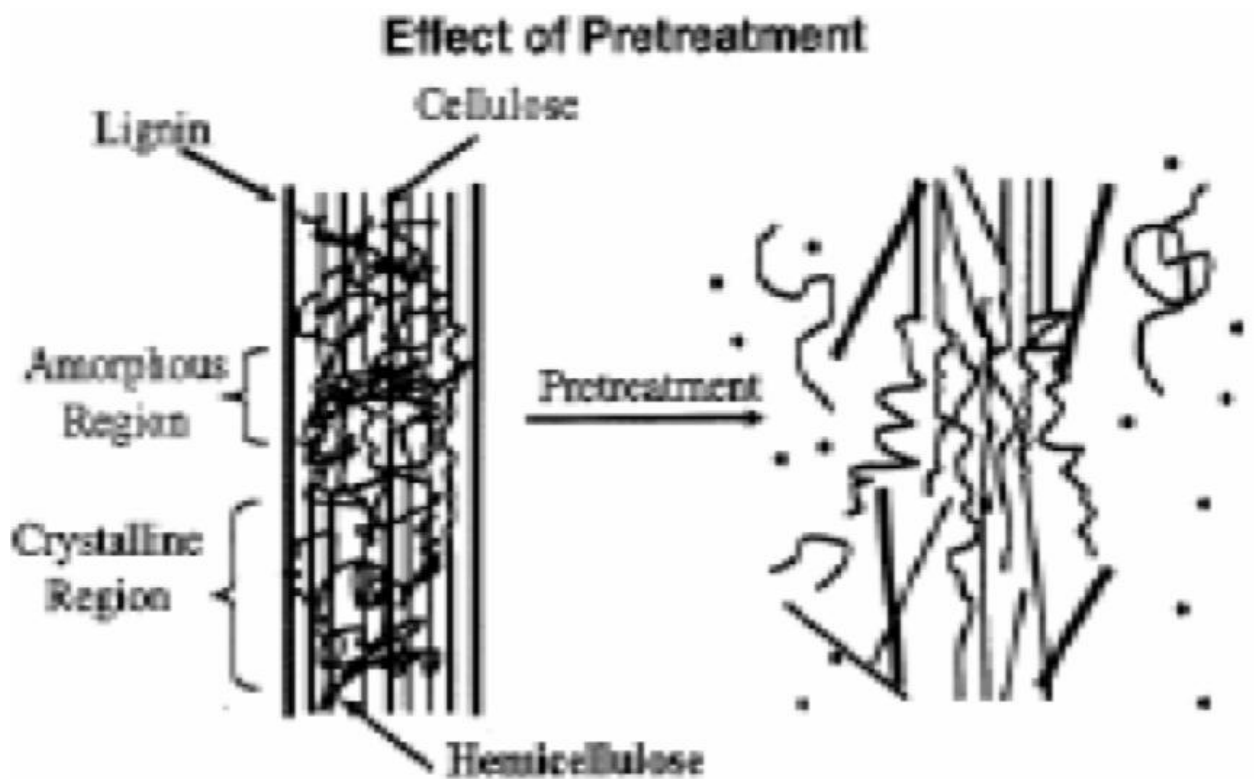


Figure 3.4: Diagram of the effect of pretreatment of sugarcane bagasse (Bon, 1996).

There are many different types of pretreatment processes used to separate the parts of the sugarcane bagasse. Research is being conducted all over the world to find the best combination of efficiency and economics so that distilleries can use such technology. Types of pretreatment methods include (but not limited to): mechanical pulverization, pyrolysis, concentrated acid, dilute acid, alkali, hydrogen peroxide, autohydrolysis, ammonia fiber

explosion (AFEX), wet-oxidation, lime, CO<sub>2</sub> explosion, and organic solvent treatment (Lee, 2005). Typically, mechanical pulverization involves crushing the sugarcane to create more surface area for hydrolysis, but it does not remove any unwanted parts of the bagasse. Pyrolysis involves act of heating the bagasse in the absence of oxygen to break it down into its parts. The char that remains after pyrolysis (at sometimes over 1000°C) is the cellulose and hemicellulose that is ready for hydrolysis. Some studies even look at the size of the bagasse particles that undergo pyrolysis, and there is clear evidence that size of the particles does matter (Zanzi et al, 1995). Autohydrolysis is a very effective pretreatment process in which the bagasse is heated to around 200°C and then pressure is rapidly reduced, leaving only the cellulose for hydrolysis. AFEX is similar and more effective than autohydrolysis but is not economical because of the price of ammonia. Acid hydrolysis can be an effective process as well because lignin can dissolve in some strong acids. Different experts recommend different processes based on effectiveness and the price of operation.

Some pretreatment strategies try to remove only the lignin because it is the only portion of the sugarcane bagasse that cannot be turned into fermentable sugars (like cellulose and hemicellulose). One study shows that soaking sugarcane bagasse in a weak concentration of basic Hydrogen Peroxide solution for just a couple of days can reduce the mass of the bagasse by over 60 percent (Dawson and Boopathy, 2008). This process removes small (if any) amounts of cellulose and hemicellulose. Because it prevents the degradation of cellulose and hemicellulose, lignin removal is a key part of pretreatment. Other studies suggest that removal of both hemicellulose and lignin as opposed to just lignin is the best way to optimize the amount of ethanol that can be produced from a given amount of sugarcane bagasse.

Some pretreatment studies are done in order to separate the cellulose from both the hemicellulose and lignin. One particular study examines the pretreatment of sugarcane

bagasse using hydrothermal treatment. In this type of treatment, the sugarcane bagasse is placed in the presence of steam under high pressure, as illustrated in Figure 3.5.

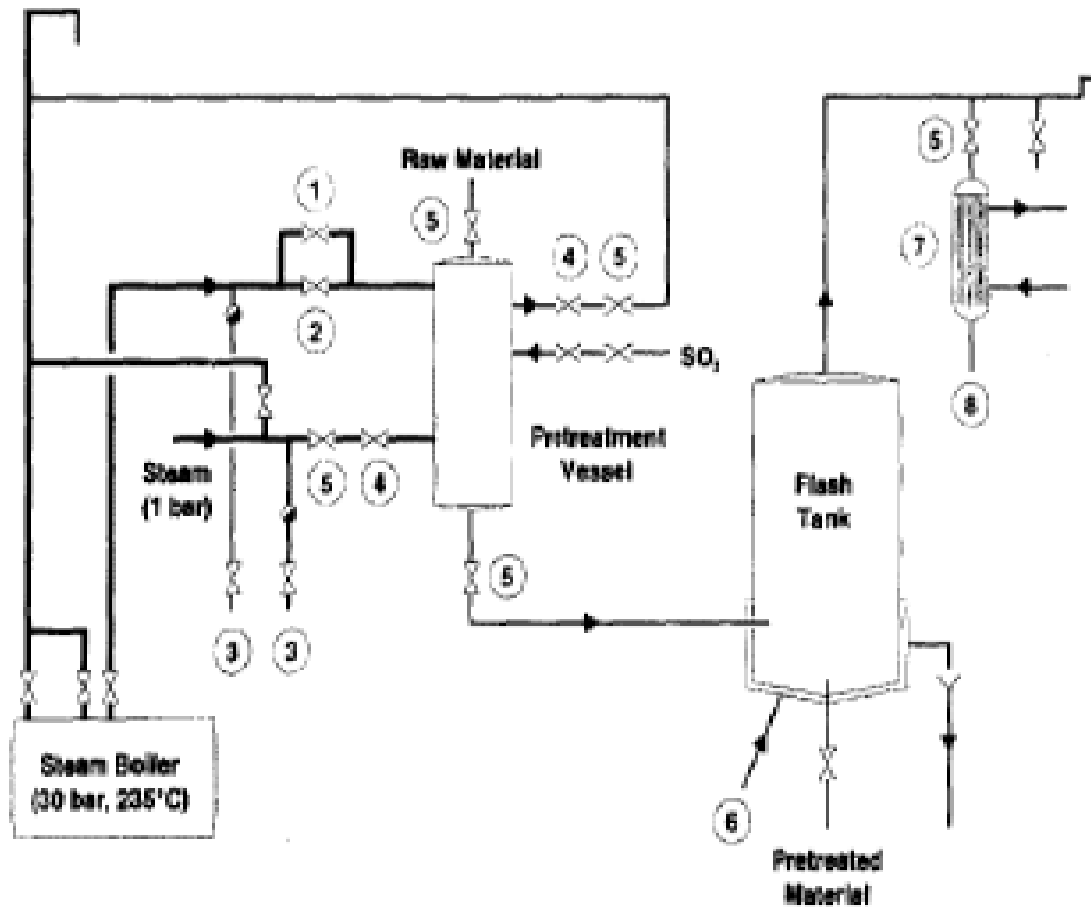


Figure 3.5: An example of the pretreatment stage of sugarcane bagasse. This particular set-up is used for steam pretreatment where the bagasse is heated in steam at moderately high temperatures and high pressures to break down the lignocellulosic material (Bon, 1996).

The rate of temperature increase in this type of experiment can determine the percentage yield of cellulose present after treatment. A study shows that hemicellulose and

lignin can be extracted from bagasse at different temperatures and pressures than cellulose (Sasaki et al, 2002). Studies similar to this one show economic and efficient ways to separate hemicellulose and lignin from the cellulose.

Other studies aim to identify pretreatment methods that can yield the highest amount of glucose after hydrolysis. One study done at Lund University in Sweden tested different steam pretreatments with Sulfur Dioxide to determine what percentage of Sulfur Dioxide and what time of pretreatments optimized the glucose production after hydrolysis. This study found that theoretical yields of glucose production as high as 90 percent can be reached with the correct pretreatment (Sendelius, 2005). Figure 3.6 depicts the positive correlation of xylose extraction and glucose yield in the Sendelius study.

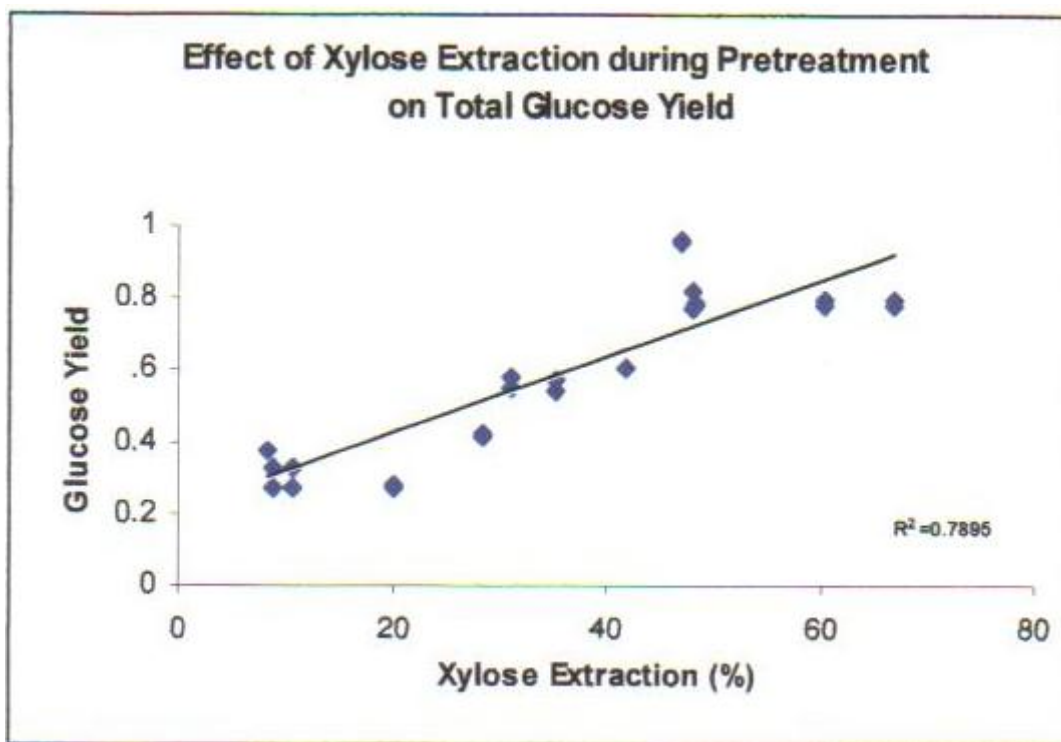


Figure 3.6: Result of removing hemicellulose during pretreatment of bagasse. Xylose is the  $C_5$  fermentable sugar that comes from hydrolysis of hemicellulose. The more hemicellulose that is removed results in more glucose for ethanol production after hydrolysis (Sendelius, 2005).

## Hydrolysis

The next stage in the lignocellulose conversion process is hydrolysis. This is the process where the complex carbohydrates are broken down into simple sugars by adding water. Because the hydrolysis of cellulose and hemicellulose is a time consuming process, typically either an acid or an enzyme is added as a catalyst. Water has difficulty penetrating the tight bonds of the cellulose (especially crystalline cellulose), which is another reason why an enzyme or an acid is needed (Wang, 2007). The hydrogen bonds in sugarcane bagasse make it more difficult to hydrolyze than starches and simple sugars. In order to proceed to the next step in the process (fermentation), the  $\beta$ -1,4-glucosidic linkages between sequential glucose units must be broken down to form glucose (in the case of cellulose), and similar bonds in hemicellulose must be broken down to form xylose or fructose (Lee, 2005).

Acid hydrolysis is one of the ways to hydrolyze the cellulose. Research is still being conducted to determine which acid to use, at what concentration, and how long to treat in order to maximize output. One of the big problems with the acid hydrolysis is finding the correct concentration. A strong concentration of acid breaks the linkages between the simple sugars, but it degrades the lignocellulosic material. A weak concentration of acid does not degrade the material, but it cannot penetrate the strong bonds in crystalline cellulose.

Acid hydrolysis is not the most efficient way to produce glucose. One study suggests that the maximum actual yield of glucose from acid hydrolysis of cellulose is always less than 70 percent (Quintero-Ramirez, 2008). Sometimes harmful byproducts can be created if the wrong acid is used. One of the benefits of using acid hydrolysis is that the pretreatment step and the hydrolysis step can be combined into one process if the correct acid is used at the right concentration, helping save money for distilleries. Some studies show that acid hydrolysis of hemicellulose can have yields of almost 90 percent. Because hemicellulose is an amorphous

compound, hydrolysis occurs under less severe conditions (Quintero-Ramirez, 2008). This process occurs at over 50°C less than that of cellulose. Figure 3.7 shows the laboratory setup to perform acid hydrolysis. The bonds between sugar groups are not as strong as the hydrogen bonds between glucose groups in cellulose, so the acid can be dilute while still completing the process.

Hydrolysis of hemicellulose also produces acetic acid that can act as a catalyst towards completing the process. One study shows that over 83 percent of possible xylose (C<sub>5</sub> sugar from hemicellulose) can be obtained through acid hydrolysis of bagasse (Pessoa Jr et al, 1997). In this study, bagasse was hydrolyzed in a solution of sulfuric acid with pressurized steam at no more than 150°C for 20 minutes or less. Processes similar to these may not be the most efficient, but they are the most economical.

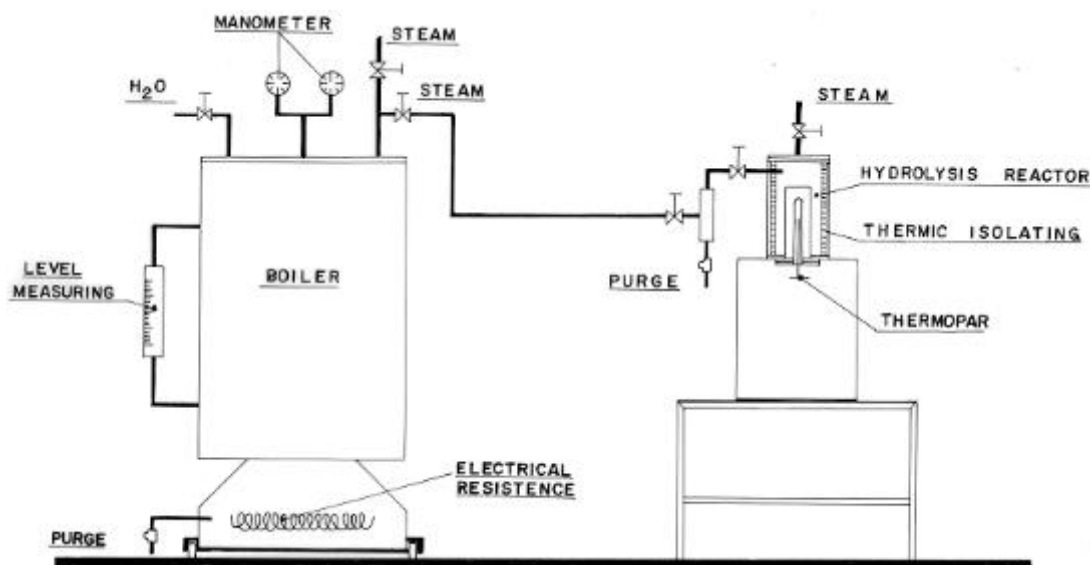


Figure 3.7: An example of a laboratory set-up to perform acid hydrolysis. The actual hydrolysis takes place in the hydrolysis reactor (Pessoa Jr et al, 1997).

The other way to complete the hydrolysis process is through enzyme hydrolysis. Instead of adding an acid to the pretreated bagasse, an enzyme is added in the presence of water or

steam. Typically, bacterial enzymes (called cellulases) are used for hydrolysis of cellulose. For enzyme hydrolysis of cellulose, fewer enzymes are needed because only one type of bond needs to be broken to obtain simple sugars from cellulose. For enzyme hydrolysis of hemicellulose, many different enzymes are needed because there is more than one type of simple sugar obtained from it. Figure 3.8 shows a few enzymes that are used to produce glucose. Unlike acid hydrolysis, enzyme hydrolysis does not need as much equipment to complete. For example, one way to achieve complete hydrolysis is to mix the pretreated bagasse with the enzyme using simultaneous agitation and heating (possibly altering the pH a little, which depending on the type of enzyme). The enzyme xylanase, recalled from Figure 2.5, is needed for enzyme hydrolysis of hemicelluloses to produce xylose. Enzyme hydrolysis can be very effective with some studies showing over 95 percent yield on fermentable sugars (Quintero-Ramirez, 2008). However, enzyme production is very expensive because of actual difficulties in the production process, as well as with poor reusability of prior stock. Some studies estimate that enzyme hydrolysis can be over 40 percent of the cost to produce ethanol (Miyamoto, 1997).



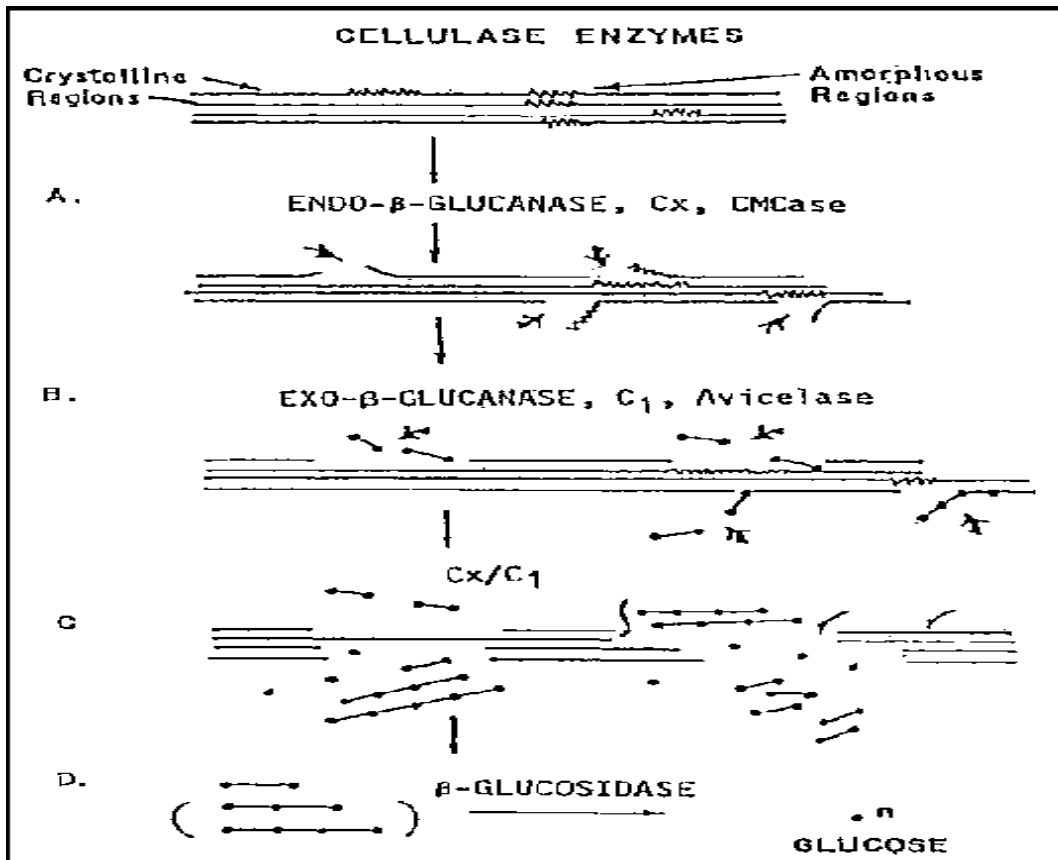


Figure 3.8: Diagram of processes for cellulase enzymes to produce glucose. This figure shows the three major groups of enzymes needed to break down the cellulose into glucose: Endo-β-Glucanase, Exo-β-Glucanase, and β-Glucosidase. All three of these enzyme groups are essential in converting cellulose into glucose. The similar process for hemicellulose is much more complicated and requires more enzymes (Miyamoto, 1997).

## Fermentation

The next process after hydrolysis is fermentation. The process of fermentation has not changed much over time. Current research focuses on determining the most efficient and economical ways to ferment the simple sugars. Many goals of future research include determining the best yeast to use in fermentation, the best way to move the ethanol/water mixture from fermentation to distillation, and the most efficient way to retain yeast after fermentation is completed.

In a typical mill, fermentation takes place in large fermentation vats. The process can take place continuously or in phases. Both the C<sub>5</sub> and C<sub>6</sub> (five-carbon and six-carbon molecules respectively) can be combined into the same vat because the same strain of yeast can produce ethanol from both types of carbon sources. These vats can be open to atmosphere (aerobic) or closed (mostly anaerobic). The benefits of a closed vat are higher efficiency so that the simple sugars go through fermentation rather than respiration (anaerobic process) as well as the ability to use the carbon dioxide to recover evaporated alcohol. The downfall of a closed vat is that it is more expensive to build and upkeep. The simple sugars/water mixture is incubated with yeast in approximately a 2 to 1 ratio. Fermentation takes approximately 4 to 12 hours to complete and takes place at around 32°C (Copersucar, 2008). Because the fermentation process is exothermic, the vats must be cooled, typically by water circulation. Figure 3.9 is a picture of typical fermentation vats.



Figure 3.9: Photograph of a group of typical fermentation vats (gray cylinders). The three towers on the far right are distillation towers for the next step in the process (Rediex, 2007).

After fermentation, nearly all of the original simple sugars are consumed. The remaining mixture, or vinasse, is sent to a centrifuge where all the solids (including the yeast) are removed and the remaining vinasse, which included alcohol at between 7 and 10 percent, is sent to distillation. The yeast is treated with strong sulfuric acid for no more than 3 hours before being returned to the vats to be used again in further fermentation reactions. In addition to alcohol and water, other liquid products are created throughout fermentation like acids, esters, aldehydes, and glycerin, which all must be removed in subsequent processes.

The focus of future research is eliminating the centrifugation process after fermentation. The cost of the centrifuge step is estimated to be between 10 and percent of the total processing cost to produce a liter of ethanol (Vasconcelos, 2007). Recent research has suggested that use of flocculent yeasts can eliminate the centrifuge step, possibly saving money for the mills. There are flocculent strains of the usual yeast for fermentation available, but there is a lack of technology to remove and treat the yeast after fermentation. In the early 1990s many mills used the flocculent yeasts because they were just as efficient as normal yeasts, but they did not have access to proper equipment to remove them. However, recent technology has closed the gap so that flocculent yeasts are now considered a strong possibility as an alternative to conventional ones.

Another issue is the presence of lactate ions. Many lactate ions are produced during the fermentation process in the form of calcium lactate or sodium lactate. These lactate products are not soluble in the vinasse so they must either be removed or dissolved. There are many current forms of technology that can help fight the production of unwanted salts. The easiest way to combat this is to keep the pH of the vinasse above the pKa of lactic acid, 3.8, so that there are minimal amounts of salts remaining in the vinasse after fermentation. Figure 3.10 shows fermentation as well as the byproducts formed in the process.

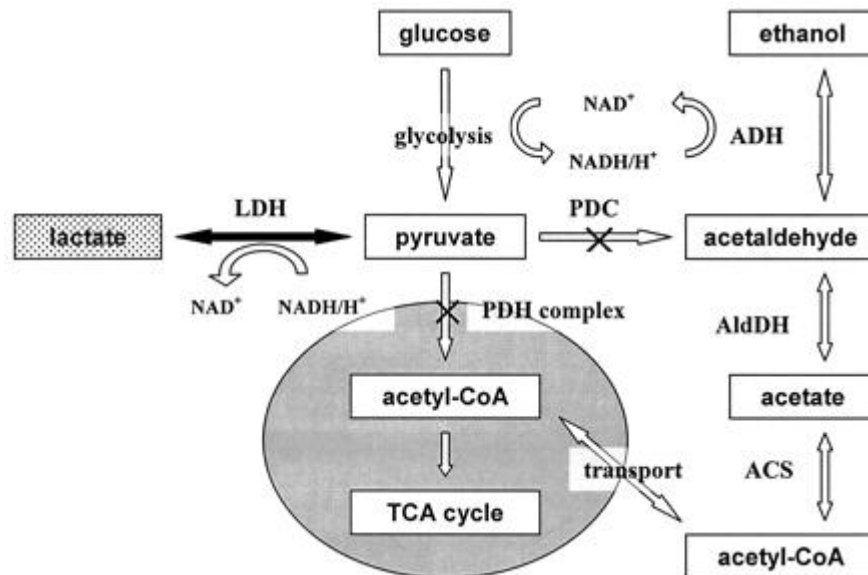


Figure 3.10: Fermentation process. These are the different routes to make ethanol starting from glucose as well as byproducts that can form such as lactate and acetate ions. The diagram is similar for xylose (Bianchi et al, 2001).

Different factors can sway the efficiency of the fermentation process. The sugar concentration can affect the efficiency of the fermentation process. Too little sugar indicates that there is too much water in the broth, meaning more distillation and wasted time and money because more alcohol could be produced in the same amount of time. A high sugar concentration can increase the osmotic pressure in the cells that can dramatically decrease the efficiency of fermentation. A sugar concentration of 16 to 18 percent is most often used (Gaur, 2006).

The temperature of the broth can have a serious effect on the efficiency as well, as clearly shown in Figure 3.11. An average mill usually ferments sugars at 25-35°C. A temperature that is too hot can decrease the cell viability and productivity (Gaur, 2006). Because fermentation is exothermic, the broth heats up on its own. Therefore, some mills have found it more economical to not keep the broth cool because it saves resources. Although the

amount of alcohol produced is not as much as normal, the production costs are down which can save money to many mills. The pH can also have an effect on the efficiency. This is important because the pH lowers during the fermentation process. If the pH is not controlled, it can have a detrimental effect on the yield of alcohol in the vinasse. Overall, the goal of all the adjustments is to achieve the highest possible alcohol content of the vinasse. Higher alcohol content allows for less energy for distillation, less volume of vinasse, and better control of contamination (Rediex, 2007). All three of these conditions allow for a more efficient fermentation process so that the mills can produce a liter of ethanol at the lowest cost.

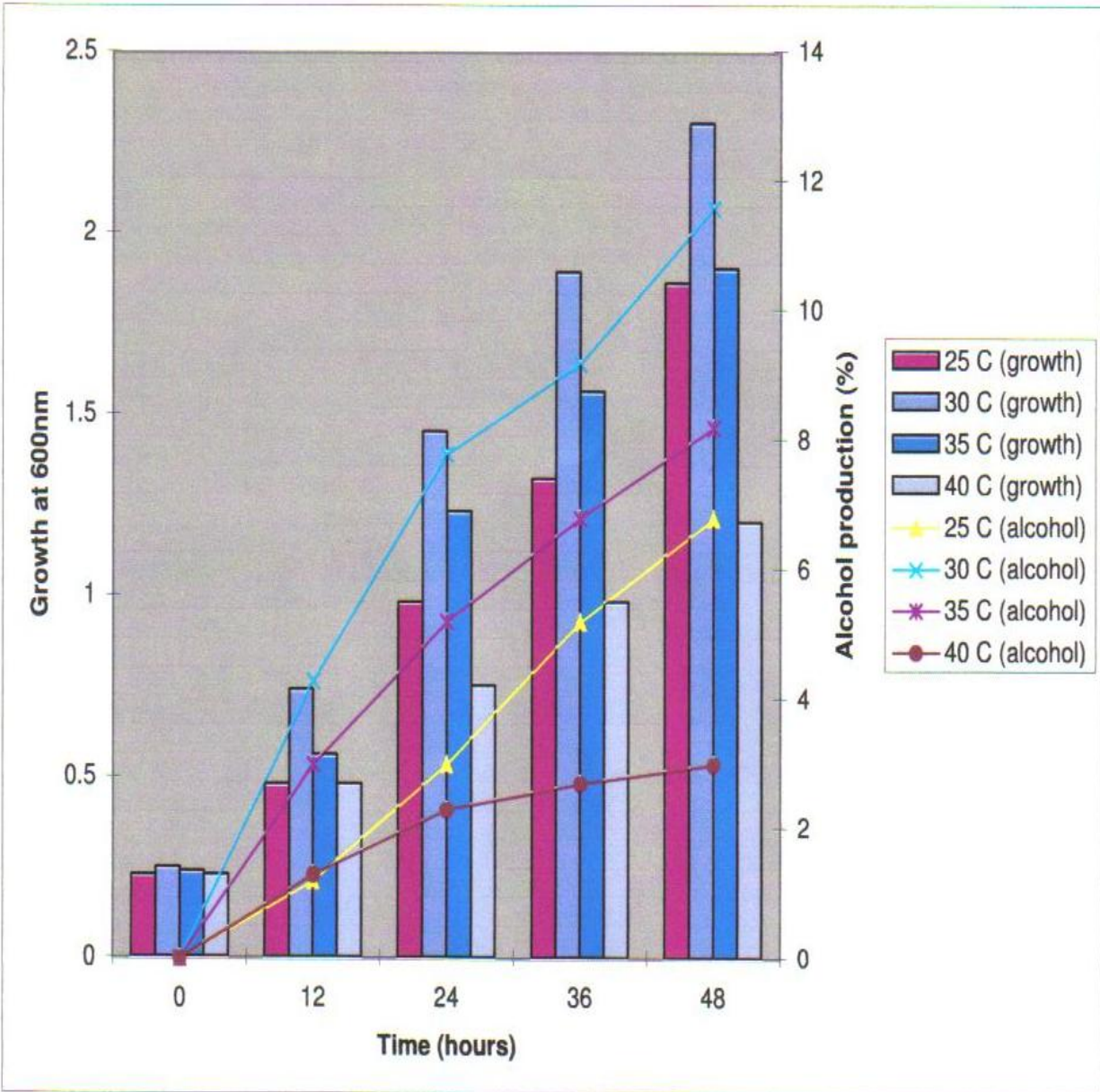


Figure 3.11: Percentage alcohol of broth during fermentation at different temperatures. All samples were maintained at a pH of 6 and an initial sugar concentration of 20 percent. Although this doesn't demonstrate an actual Brazilian mill fermenting sugars, it does show a serious effect on the temperature of the broth (Gaur, 2006).

## Distillation

The final process in the production of ethanol is the distillation of the vinasse. After distillation, which extracts the remaining water and increases the ethanol concentration, the production of ethanol is complete. Distillation works based on the difference in boiling points of water and alcohol. The boiling point of water is  $100^{\circ}\text{C}$  while the boiling point of ethanol is  $78^{\circ}\text{C}$ , making it possible to evaporate and separate the ethanol from the water.

Current processes use columns in sequential order to complete the distillation. All three columns are kept at certain temperatures and pressures. The vinasse is normally fed into the top of the first column from the fermentation vats. The first column is often referred to as the stripping column. In this column, kept at around  $110^{\circ}\text{C}$ , the vinasse is fed to the top where saturated steam is fed into the bottom. The purpose of the first column is to separate the dirt and debris by sending the vinasse through a series of trays which take out as many solid particles and liquid impurities as possible, as well as sending all of the ethanol into the gaseous phase (Marquini et al). A very small percentage of ethanol remains at the bottom of the first column. Figure 3.12 shows an example of a typical distillation column.

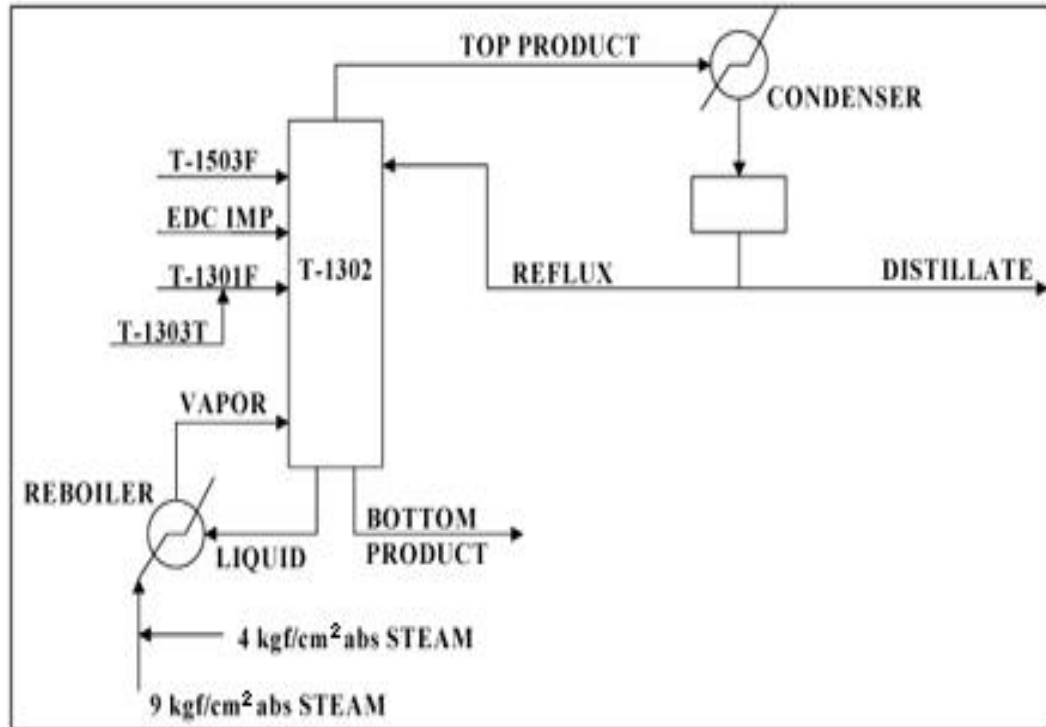


Figure 3.12: An average column used for distillation of vinasse. The liquid is boiled, sent into the column with pressurized steam sent into the bottom. The vapor at the top is sent to a condenser that sends it to the next column (Araujo et al, 2007).

After the first column, the mixture, or phlegm, (approximately half ethanol and half water) is fed into the second column. The temperature and pressure of the second column depends on the amount of ethanol fed into it. However, the temperature is almost always between 78°C and 100°C to evaporate the ethanol and leave the water. The second column also has trays to remove more impurities from the mixture. After the ethanol is evaporated and condensed, the phlegm is now 95 percent ethanol and 5 percent water (190-proof). This is the maximum percentage of ethanol that can be obtained by conventional distillation processes because ethanol and water form an azeotrope. An azeotrope is a phenomenon such that when an azeotrope is boiled, the resulting vapor has the same percentage of ethanol and water as the liquid. A portion of this 190-proof ethanol is sent for storage because it is used as hydrated



ethanol. The alcohol fuel at the pumps in Brazil is this 190-proof ethanol. The remaining portion is sent for more dehydration to form pure 200-proof ethanol.

In order to create anhydrous ethanol, two more columns must be used. The portion of 190-proof alcohol that is not stored is sent to another column. There are a few ways in which the industry makes anhydrous ethanol. In all of the processes, the separation occurs in the first column while the recovery of the water and other substances occurs in the second column.

One way to remove the water is by the addition of cyclohexane. The ethanol, water, and cyclohexane combination form an azeotrope whose boiling point is a meager 63°C. Given that the boiling point of ethanol is less than both water and cyclohexane (81°C), the water can be removed at the top of the column while the ethanol vapors can travel through the top of the column (there is still a very small amount of water remaining however). The water and cyclohexane are sent to the second column where the cyclohexane is recovered and reused.

Another way to remove the water is by using ethylene glycol. The ethylene glycol traps the water while the ethanol vapors are allowed to rise to the top of the column. The mixture of ethylene glycol and water is sent to the second column where it is separated and the parts are used again. Another way to recover the pure ethanol is to vaporize the hydrated ethanol before it enters the column. In the column, a molecular sieve (a metal) is placed throughout so that the water vapors can be captured by it (Copersucar, 2008). The molecular sieve must be cleaned and replaced as part of regular maintenance. The anhydrous ethanol is then sent to storage.

Research is still being conducted to improve the quality and efficiency of the distillation process. One group of scientists is trying to improve the way in which the percentage of ethanol is determined after the first and second distillations. Currently, the phlegm after the first and second distillation columns must be checked for its percentage of ethanol before proceeding to distillation, and can be a very time consuming process. A group of scientists is using optics to

determine the percentage of ethanol in the mixture. By sending an optical sensor system with a detector, a light source, and optical fibers as well as measuring the index of refraction of the mixture, one can determine the percentage of ethanol (Gusken et al, 2008). The index of refraction of water is 1.33 while that of ethanol is 1.37. This simple procedure would be a time saver.

Another group of scientists is researching a more efficient way to dehydrate the hydrated ethanol. This group is trying to use one column to remove the water from ethanol instead of two columns. In this proposed research, the hydrated ethanol would enter the column of pressurized steam at around 270°C with a mixture of bioglycerol. The bioglycerol extracts the water from the hydrated ethanol so that ethanol at 99.3 percent can leave the column while the water and the bioglycerol leave the column in separate ways (Dias et al). The bioglycerol is recycled and reused. This process uses about 70 percent of the energy of conventional distillation processes while using a renewable resource in bioglycerol instead of a substance recovered from a fossil fuel such as ethylene glycol.

## **Problems with the process**

Another issue with ethanol production is the amount of water used to produce a gallon of ethanol. Many of the processes from the planting of the cane to the fermentation of the simple sugars require water. One study shows that over 25 percent of the water used in producing ethanol comes from the washing of the sugarcane stalks (Moreira, 2006). Table 3.1 breaks down the amount of water used in each step of a typical mill in Brazil in 1996.

Sector	Process	Mean use of water		Distribution
		m <sup>3</sup> /ton cane	gal/ton cane	Percent
Feeding	Sugarcane washing	5.33	20.18	25.4
Extraction (grinding)	Inhibition	0.25	0.95	1.2
Extraction (grinding)	Bearing cooling	0.15	0.57	0.7
Juice Treatment	Preparation of lime mixture	0.01	0.04	0.1
Juice Treatment	Cooling sulphiting	0.05	0.19	0.2
Juice Treatment	Filter inhibition	0.04	0.15	0.2
Juice Treatment	Filter condensers	0.30	1.14	1.4
Juice Concentration	Condensers/multijets evaporation(1)	2.00	7.57	9.5
Juice Concentration	Condensers/multijets heaters (1)	4.00	15.14	19.0
Juice Concentration	Molasses dilution	0.03	0.11	0.1
Juice Concentration	Crystallizer cooling (1)	0.05	0.19	0.2
Juice Concentration	Sugar washing (1)	0.01	0.04	0
Electrical power generation	Steam production	0.5	1.89	2.4
Electrical power generation	Turbo generator cooling	0.2	0.76	1
Fermentation	Juice cooling (2)	1.00	3.79	4.8
Fermentation	Fermentation cooling (2)	3.00	11.36	14.3
Distillery	Condenser cooling (2)	4.00	15.14	19.0
Other	Floor & equipment cleaning	0.05	0.19	0.2
Other	Drinking	0.03	0.11	0.1
Total water use		21.00	79.49	100

Table 3.1: Water use by an average mill in Brazil in 1996. Processes with (1) are only for processing sugar while processes with (2) are only for processing ethanol. This figure assumes processing half sugar and half ethanol. If all sugarcane was devoted to ethanol, the amount of water use would rise to 86 gallons per ton of sugarcane (Moreira, 2006).

Today, technology has significantly reduced the amount of water needed to produce ethanol. Almost every single sugarcane plantation in Brazil is non-irrigated land (Coelho and Goldemberg, 2005), using no additional water used aside from rainfall. Even in the plains and deserts where there is typically less rainfall than most other places, there are almost no sugarcane plantations with irrigation.

Many ethanol distilleries are now trying to reuse water not only to save money but also based on better technology. One study suggests that as of 2005, 92 percent of all water used in the mills is reused (Coelho and Goldemberg, 2005). Another study shows that the amount of water used by the mill per ton of sugarcane in 2005 is about a third of the amount in 1990 (Moreira, 2006). In the same study, net water consumption (water brought in minus water reused) in 1997 of all mills in Brazil was about half of that in 1990 (Moreira, 2006). Some mills can also use wastewater that could not be used to treat and sell to the Brazilian people. This is partially because some of the yeasts used in fermentation can help treat contaminated wastewater especially with high acid content. As technology gets better, the mills will consume less water.

Ethanol, hydrated or anhydrous, cannot be stored at the mill due to their volatility and combustibility. They are transported to long-term storage containers off-site. From these long-term storage containers, they are sent by truck to gasoline pumps where cars are fueled.

There has been a lot of research conducted in the area of ethanol production from the milling to the distillation. More research focuses mainly on creating the ethanol from the bagasse as opposed to the sugarcane sap. Some research focuses on the possibility of combining the hydrolysis and pretreatment steps into one incubation step. The crux of all research is to create the easiest, most efficient, and most economical way to produce ethanol from the entire sugarcane stalk, not just the sap.

## **Business and Economics**

Switching between ethanol and gasoline has affected the way Brazilian people do business. Towards the beginning of the switch to ethanol, the economy suffered because of the money and resources poured into the ethanol industry in order to boost the production of ethanol instead of depending on foreign oil. The purpose of this chapter is to demonstrate how doing business in general was changed by the introduction of a push for ethanol as well as how the economy both diminished and prospered through the growth of the ethanol business.

Before the push for ethanol in 1975, Brazil primarily grew the agriculture business by expanding into new and unused lands. In the early 1950s, many people started moving into unused land and cultivating it to grow crops such as coffee, soybeans, sugarcane, wheat, cotton, and some citrus fruits. At the time, the growth of agriculture helped boost Brazil's economy. From 1949 to 1969, the growth of the agricultural Gross Domestic Product was 4.2 percent per year, greater than the population growth of 2.7 percent per year during the same time period (FloridaBrasil.com, 1997a). Throughout this time period, the amount of land increase by one crop depended on the market price for that crop. However, this increase was about the same from year to year for each specific crop. The amount of jobs in agriculture only slightly increased by a margin of about 1.3 percent per year, and the percentage of total employment in agriculture dropped from 60 percent in 1950 to 44 percent in 1970 (FloridaBrasil.com, 1997b). Considering the significant difference between growth of jobs and GDP as well as the limited number of machines being used on the harvested land, the agriculture sector was doing very well.

There were a couple of government regulations that helped such significant growth. The Land Statute Law of 1964 helped to modify the structure of the agriculture system as well as

increase output with the given amount of land available (Encyclopedia of the Nations, 2007). The goal of this law was to increase the productivity of cultivated land by allowing the government to buy underutilized land using cash or bonds depending on the amount of land being bought. The construction of many roadways allowed for the incorporation of this new land. However, by the late 1960s, the amount of land available for expansion was diminishing, so laws like the Land Statute Law of 1964 allowed for greater production of the land available instead of expanding into new land. The government also gave tax incentives to different landowners and farmers who came together to form cooperatives in order to increase production. A cooperative was described as follows:

*A cooperative is a private business organized and joined by members to fulfill their mutual economic needs as patrons of the business, with the key control, ownership, and income distribution decisions based on patronage proportions; namely, member voting, equity capital investment by patrons, and distribution of net income to patrons are proportional to use of the cooperative (Barton 1989).*

In a cooperative, members work together in order to assure that the final product is homogeneous, with no discrepancies. Some of the benefits of being a member of a cooperative are arranging timing and scheduling of delivery, assigning transportation and delivery costs, setting delivery location, and securing prices (Downing et al, 1998). The formation of certain cooperatives such as Copersucar allowed greater production and profits by working together as opposed to each separate farm.

Once the government started the Pro-Alcohol program in 1975, many different changes began in agriculture, particularly in the sugarcane industry. The Pro-Alcohol program was government-advised procedure to increase the amount of ethanol being produced in response to a dramatic increase in oil prices. In order to make more ethanol, the demand for sugarcane dramatically increased as well as the amount of distilleries needed to be built. As a result of the strong push for more sugarcane, many crops suffered for a small period of time. However, once

increased growth of sugarcane stabilized, the other crops began to increase production once again.

The way in which sugarcane farmers were paid dramatically changed over time. The cost of Pro-Alcohol hurt the Brazilian economy throughout the 1980s and into the 1990s. However, the push for ethanol and more sugarcane helped boost the Brazilian economy in the early 2000s once oil prices began to start increasing once again. Once the push for alternative fuels began in the early 2000s across the world, many countries started to put protective tariffs on Brazilian ethanol because Brazil was the only country producing enough ethanol to sustain itself. This push forced other countries to produce their own ethanol.

Once the push for ethanol began in 1975, there was a dramatic increase in production of sugarcane and construction of distilleries. More of the new land available was being used for sugarcane to accommodate the increase in the demand for ethanol. Figure 4.1 shows the increase of land allocated to sugarcane from 1947 to 2005. More distilleries needed to be constructed to keep up with the demand for ethanol.

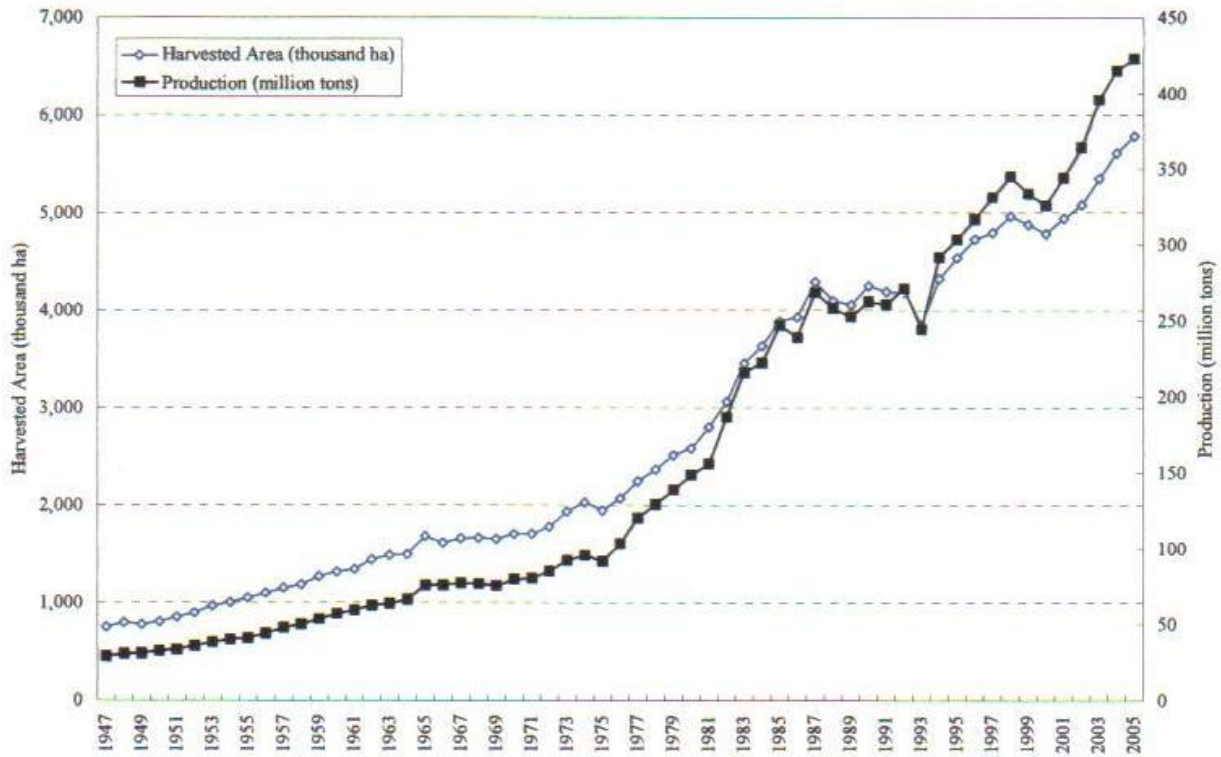


Figure 4.1: Overall area of sugarcane harvested in Brazil (combined for both sugar and ethanol). The annual increase in the amount of sugarcane harvested from 1947 until 1975 is generally constant. Once the government enacted the Pro-Alcohol program in 1975, the annual increase is much higher to keep up with ethanol production levels. The production portion of the figure is the production of sugar (Ueki 2007).

Unfortunately, towards the beginning of Pro-Alcohol, the agriculture frontier had reached some natural forests of Brazil. Farmers used land that was part of the Atlantic forest biome for planting sugarcane instead of converting some of the more arid parts of the country. This destroyed some of the natural habitat for many plants and animals, and as a result only 7 percent of this Atlantic forest biome remains as of 2007 (Rodrigues and Ortiz, 2007). Many farmers at the time had little or no concern for the land that was being converted into farms for sugarcane because of the sharp increase for demand of ethanol. For the first five years, the production of ethanol increased by approximately 600 percent. Although some of the increased production was sugarcane taken from the land originally used to process sugar, much of the



new production was coming from new land. The construction of more distilleries meant that more government money had to be used in order to keep up with the increasing demand for sugarcane and ethanol. These new distilleries could not only process the sugarcane into ethanol but also sugar so that the industry could change production depending on the markets. Most of these modern distilleries were constructed near São Paulo in the Central-South area of Brazil (shown in Figure 4.2) because of the increased population of São Paulo. Building and maintaining these new distilleries cost the Brazilian government money, but the returns on investment were high.



Figure 4.2: Map of Brazil showing the different states throughout the country. The green represents the North. The blue represents the Northeast. The magenta represents the Central-West. The red represents the Southeast. The orange represents the South (American Radio Relay League, 2003).

## **Initial suffering of small cane farmers**

During the military regime of Brazil from 1964-1985, many sugarcane farmers and workers suffered. In 1964, a coup d'état helped the military overtake the democratic government for the next 21 years. During this time period, there was little political power in the hands of the people. For the first seven years, Brazil's economy was growing at a higher rate than ever seen before. The new military regime helped grow the economy by carrying out the following activities:

- i) the expansion of consumer credit, stimulating the consumption of durable goods;
- ii) a reform of the financial system that supported the construction of housing units and the growth of the industry;
- iii) the public investment in infrastructure;
- iv) the subsidy to exports; and
- v) a monetary expansion (Iunes and Monteiro, 1993).

However, the oil crisis of 1973 and the collapse of these new programs crumbled the thriving economy of Brazil. Figure 4.3 shows the Brazilian inflation rate spiraling out of control, set off by the oil crisis. The military regime was not able to balance the budget for a long time. Once Pro-Alcohol was enacted in 1975 and the demand for sugarcane increased, sugarcane farmers were put in a bad position. Many farm owners could not afford to pay the farmers because of the failing economy.

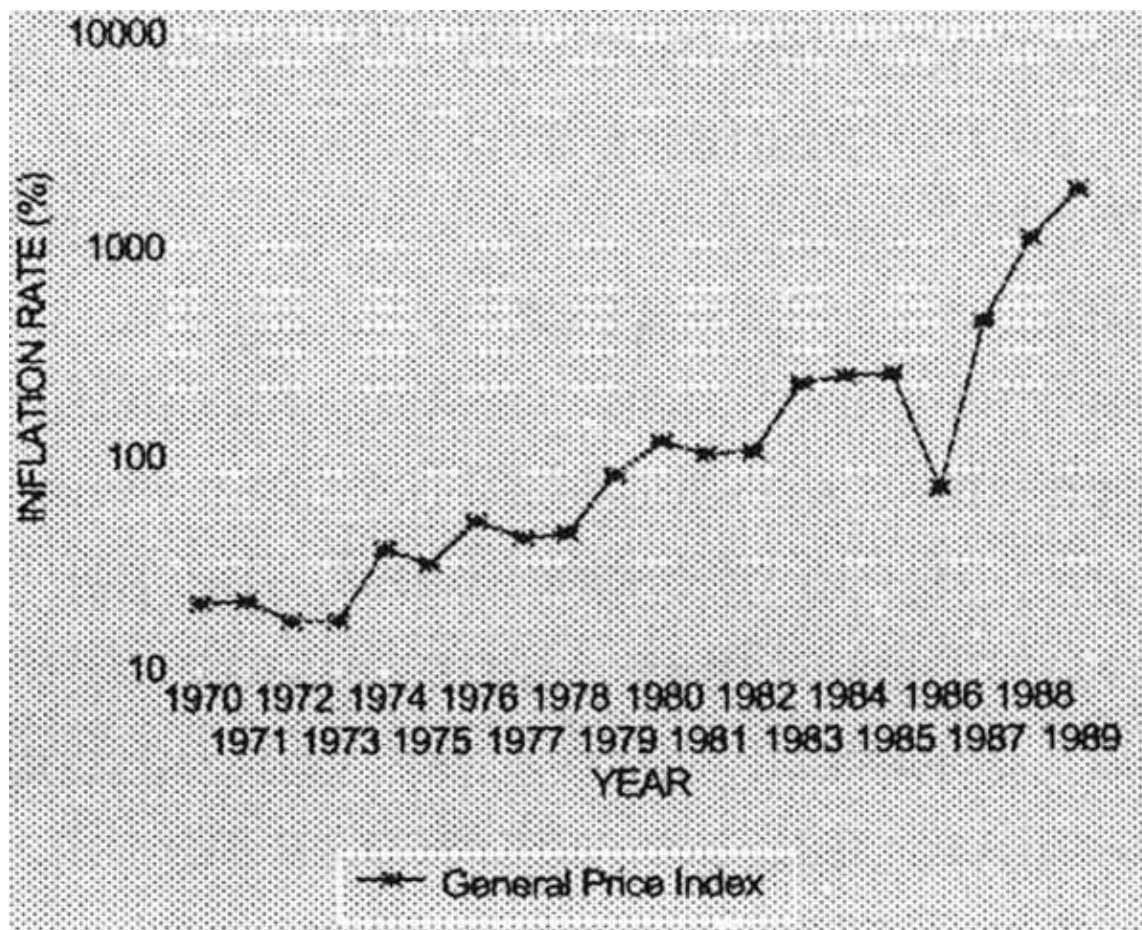


Figure 4.3: Brazil's annual inflation rate from 1970 to 1989. During the “miracle years” up to 1973, the inflation rate was kept at a minimum. However, on account of the oil crisis of 1973 and collapse of government programs, the economy started to fall and the inflation rate began to rise. By the end of the 1980s, the annual inflation rate topped 1000 percent. This inflation rate increase did not slow down until the government started the Real program in 1994 (lunes and Monteiro, 1993).

As a result of the failing economy and a military regime whose main concern was the greatest profits, sugarcane farmers suffered through the tough times. Although the government encouraged the formation of cooperatives, the unions between farmers such as the Peasant Leagues were abolished by the military regime. This new government wanted to maximize profits from the sugarcane farmers instead of giving the rights back to the people. Throughout these years, many small farmers who owned private land lost it to the government, and workers

from the countryside lost their jobs as a result (Pereira, 2003). In addition to a failing economy at the time, many lower class farmers were going through a rough period. The Land Statute Law brought the focus to higher production in the land being used. However, the government still managed to buy over 30 million hectares of land from the public sector and sell it back to owners in the private sector who had the highest production of sugarcane (Pereira, 2003).

Small farmers and lower class farmers were not as productive as those who were members of cooperatives that could make lots of profits. During this time period, the government could boast that it helped the small farmers by giving assistance such as pensions and health benefits in the poor North-Northeast region of Brazil (Pereira, 2003). The government could also claim that unemployment in Brazil was kept at a low average of 5 percent throughout the 1980s (Papageorgiou, 2005). However, the underlying facts were that 44 percent of workers in agriculture during 1988 (three years after the government changed from a military regime to a republic) made less than the minimum wage (53 US dollars per month at the time) and that only 5 percent of agriculture workers made five times the minimum wage (Papageorgiou, 2005). Needless to say, the agricultural industry was not very attractive to many Brazilian workers looking for a job.

### **Life of a cane farmer -Then**

The working conditions for the farmers in general were not good but got much better as time went on. In general, a cane farmer gathers sugarcane stalks by cutting them down with a machete and carries them back to a given site. Many cane farmers have a certain quota that must be reached per day. Cane farmers get paid based on the amount of sugarcane brought in each day (not the amount of hours), and the owner of the farm typically pays them every two weeks. Cutting sugarcane can be very dangerous. Many sugarcane farmers get cuts and

scrapes from machete cuts. The North-Northeast sections of the country have a hot, arid atmosphere that is very uncomfortable for a 12-hour workday.

Sugarcane farming can be very dangerous. Towards the beginning of Pro-Alcohol, many farmers were paid under minimum wage while working in conditions that borderline slavery. Depending on the geography of the farm, the climate of the area, and whether or not the owner decides to burn the sugarcane before harvesting, sugarcane farmers average different amounts of sugarcane (measured in tons) per day. Many farmers wear metal grill goggles, heavy gloves and body armor to protect themselves from the tough cane stalks, which are only accessible after setting controlled fires (Adams, 2005).

Burning the sugarcane before harvesting it has also been a popular option. Although a farm loses about 20 percent of its sugarcane when it is burned, the cane stalks are harvested much easier because it removed 80-90 percent of the foliage surrounding the sugarcane stalks (Hirsch et al, 2002). Harmful animals such as snakes and scorpions are also killed from the burning, so many cane farmers prefer working in burnt fields, although some land is Organic Certified, meaning that it is forbidden by law to burn the sugarcane.

The amount brought in by the average sugarcane farmer can be as low as 3 tons per day or as high as 12 tons per day depending on how hard the sugarcane workers push themselves. Some farmers can work themselves to death over harvesting sugarcane because they do not know any better. Even in 2005, there were twelve reported cases of sudden deaths on the sugarcane farms that can be contributed to over exhaustion (Maciel, 2002). In spite of this, the farmers continued to push themselves to work hard in fear of losing their job.

Many sugarcane workers do not have a choice to work in the fields because most of them cannot hold a skilled position in the work force. Many farm owners take advantage of this

by forcing these sugarcane cutters to work in awful conditions. Many sugarcane cutters do not have much schooling so they cannot find a better job in the industry.

## **Life of a cane farmer – Today**

Today, the government has tried to step in to make conditions better for sugarcane cutters. Sugarcane farmer Ronaldo Visentim agrees: “Our lunches aren’t cold anymore” (Adams 2005). Sugarcane farming now also pays more than most low-skilled positions. For example, Jose Dalmir, a sugarcane cutter, explains: “I cut some eight tons of cane every day and make about 600 reals (\$315) a month. I used to make half as much as an assistant stonemason” (Lehman, 2007).<sup>5</sup> However, they must continue throughout the day because if they do not make the given quota of a certain amount of cane per day, they could be fired.

The sugar/ethanol industry employs a little over one million people per year in Brazil. Of those jobs, about 550,000 of them are on the sugarcane farms (Moraes 2008). Of those 550,000 jobs on the sugarcane farms, sixty percent of those jobs are low-skill jobs, ten percent are medium-skill jobs such as machine operating and truck driving, and the remaining thirty percent are high-skill jobs such as supervisors or industrial workers (Papageorgiou 2005). The government has tried to crack down on unlawful farm owners who subject their cane cutters to harsh treatments. In Para (a north state), law enforcement caught a farm owner who was supposedly forcing over 1,000 sugarcane farmers to work 13-plus hour days under conditions similar to slavery. If convicted of abusing workers, the company who owns the sugarcane plantation could be subjected to a fine of over 1 million dollars plus over 15 years of jail time (Lehman 2007). Because of the increase in demand for ethanol (and therefore sugarcane), many farm owners tried to push their current sugarcane workers harder rather than hiring more

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<sup>5</sup> The minimum wage at the time that the article was written was 209 US dollars.

workers to harvest. Most sugarcane workers are secluded from society and families while living on the sugarcane farm, so most of them are at the mercy of their employer. Cane farmers usually had relatively few years of schooling, as seen in Figure 4.4. Many people were stuck harvesting sugarcane because they could not find another low-skilled position that paid well enough to support themselves and their families. As Raimundo Gomes da Silva, a sugarcane farmer, points out: “By the end of the day your entire body hurts so much you think you are going to die. But it is all we know how to do, so we will continue doing the same thing, day after day, until we drop dead” (Lehman 2007).

### Average Years of Education of Cane Farmer

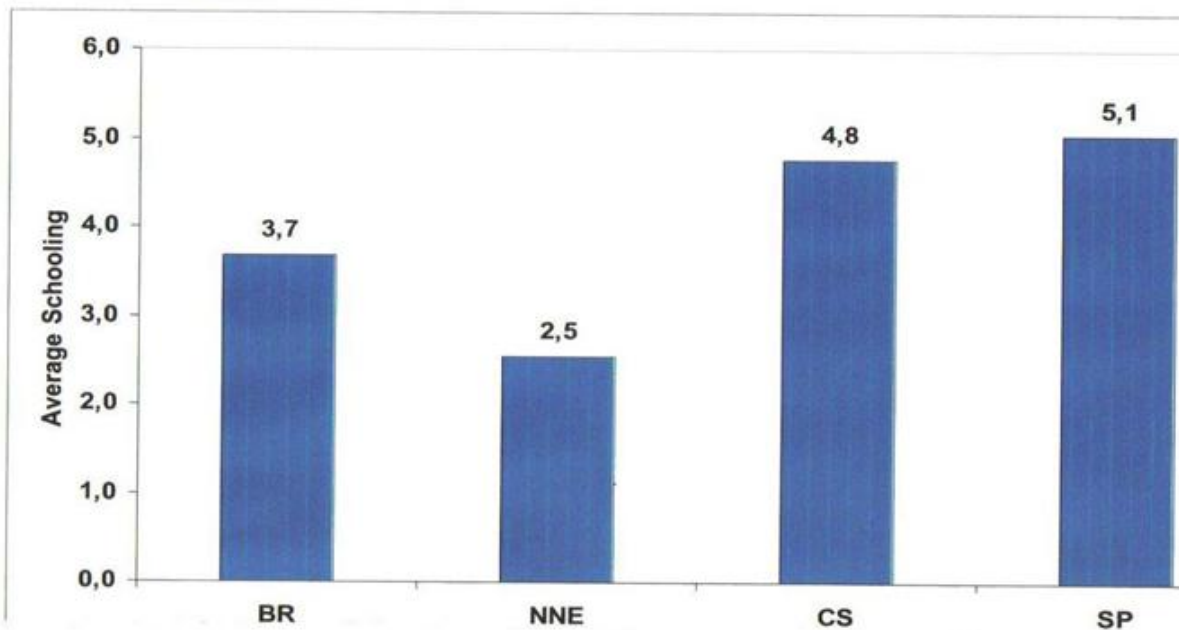


Figure 4.4: Average number of years of schooling of sugarcane farmers in different areas of Brazil. BR represents the total average of Brazil. NNE represents the North-Northeast sector. CS represents the South-Central sector. SP represents the São Paulo sector. It should also be noted that 77 percent of all workers in the sugarcane sector have 4 years or less of schooling and that 29 percent are illiterate (Moraes, 2008).

## Movement of production from North-Northeast to Central-South

Since the enactment of Pro-Alcohol, there was a switch from the majority of the sugarcane crop being grown in the North-Northeast section of the country to the South-Central portion. Up until 1975, the majority of the sugarcane crop being grown was in the North-Northeast. However, there was a gradual change in production amounts towards the South-Central region. There were many reasons for this change. Once Pro-Alcohol was enacted, many new distilleries were constructed, and most of them were built in the South-Central region. Part of this has to do with the urbanization of Brazil through the second half of the 20<sup>th</sup> century as well as the growth in the economy of São Paulo. Figure 4.5 shows the population shift from 1960 to 1990. By the end of the 20<sup>th</sup> century, some of the older distilleries in the North-Northeast sector were obsolete compared to the ones in the South-Central. It was harder to cut in the hilly Northeast sector as opposed to the flat portion of the South-Central region. The economy of the Northeast is very poor when compared to the rest of the country.

	1960	1970	1980	1990
Brazil	44.7	55.9	67.6	72.6
Northeast	33.9	40.2	50.4	57.3
Southeast	57.0	71.7	83.0	85.9

Table 4.1: Percent urban population in Brazil, the Northeast, and the Southeast. The percent of people living in the city dramatically increases over time (Lunes and Monteiro 1993).

Even before the enactment of Pro-Alcohol in 1975, the South-Central region was modernizing at a greater rate than the North-Northeast region. Overall area for all crops was growing at a higher rate in the South-Central region than in the North-Northeast region. Cultivated area grew 117 percent in the North and 218 percent in the Central from 1960 to 1975 (Graziano da Silva and Kohl, 1984). During this modernization, many different technologies



were implemented across the country. The use of tractors and plows increased dramatically throughout this period of time. However, these devices were used more in the South-Central region than in the North-Northeast. In 1975, São Paulo and the South region together represented about 20 percent of the agricultural land in the country. In addition, these two regions accounted for more than 70 percent of all tractors, plows, farm vehicles, and product storage capacity in the country. Moreover, in 1975 these regions absorbed more than 50 percent of total agricultural credit (Graziano da Silva and Kohl, 1984). Table 4.2 shows the distributed values of per area and per farmer by region. By using more tractors, plows, and such items to help farm the land, the South-Central region produced more profit per hectare of land cultivated. The Land Statute Law also helped increase this production by allowing agricultural credit given to the farm owners. Before Pro-Alcohol was even enacted, the South-Central region had a head start on the production of all crops, not just sugarcane, over the North-Northeast region.

Index of Sales Value, Investment<sup>a</sup> and Net Income<sup>b</sup> Per Exploited Hectare and Farm Laborer

	<i>São Paulo</i>	<i>South</i>	<i>North-east</i>	<i>Center-West</i>	<i>North</i>	<i>South-east*</i>	<i>Total</i>
<b>Per exploited ha.:</b>							
Sales value	282	264	75	27	28	93	100
Investment value	286	194	86	43	19	122	100
<b>Per farm laborer:</b>							
Investment value	291	118	43	218	27	139	100
Net income	295	162	42	132	44	119	100

\*Minus São Paulo.

a. Monetary value of installations, land improvements (permanent crops), forestry improvements, livestock, machines, tools and farm vehicles.

b. Sales value minus production costs.

Table 4.2: Value of Land in different regions in Brazil in 1975. The North and Northeast regions have much smaller productivity than the other regions especially the São Paulo state. Because

of this value, the investment into sugarcane land and construction of distilleries was present mostly in São Paulo and the Central-South region (Graziano da Silva and Kohl, 1984).

After the enactment of Pro-Alcohol, it was not only more economical to invest in the South-Central region as opposed to the North-Northeast, but it was also easier to produce ethanol and sugar based on the difference between developments of the two regions over the previous 15 years. In 1975, the year of the enactment of Pro-Alcohol, the South-Central region already possessed over 60 percent of the sugarcane area (Ueki, 2007). The cost to produce ethanol in the South-Central region was much less than that of the North-Northeast region. This was in part due to the increase in the number of distilleries in the South-Central as well as the more modern distilleries present in the South-Central based on the fact that most new distilleries were being built near the São Paulo state.

Initially, most of the older distilleries present in both areas were annexed distilleries, which are labor intensive. The newer distilleries being built in the South-Central region were autonomous distilleries that are more efficient and require less labor. However, because these autonomous distilleries require 5 or 6 years to reach peak efficiency, the annexed distilleries could produce ethanol at a cheaper amount per barrel (Rask, 1995). By the end of the 1980s, many of the new autonomous distilleries had reached peak efficiency, making them cheaper and more efficient than the older annexed distilleries. At the end of 2006, there were a total of 363 processing mills to produce either sugar or ethanol. Of those 363, 281 were located in the South-Central region while the remaining 82 were located in the North-Northeast (Ueki, 2007).

The economy of the South-Central region was much stronger than that of the North-Northeast region. The South-Central region is a better place to live than the poor North-Northeast, so many sugarcane workers wanted to move to the South-Central for better living

conditions and more pay. Table 4.3 shows that the Center-South region lost the least amount to ethanol production from 1978-1987, making it the best economically.

**REGIONAL AND TOTAL SOCIAL GAINS TO ETHANOL PRODUCTION IN BRAZIL:  
1978-87 ANNUAL TOTALS AND 1987 NET PRESENT VALUE (NPV)**

Year	Center-South Region (1)	North-Northeast Region (2)	Brazilian Total (1) + (2)	1987 NPV for Brazil*
1978	-215.16	-61.23	-276.39	-766.46
1979	-375.23	-106.99	-482.22	-1,193.88
1980	63.91	-116.26	-52.35	-115.72
1981	-59.98	-245.52	-305.50	-603.00
1982	34.25	-321.81	-287.56	-506.79
1983	287.48	-152.37	135.11	212.60
1984	213.12	-165.94	47.18	66.29
1985	77.76	-224.43	-146.67	-183.99
1986	-678.28	-481.47	-1,159.75	-1,298.92
1987	-337.44	-594.66	-932.10	-932.11
<b>Total</b>	<b>-989.57</b>	<b>-2,470.68</b>	<b>-3,460.25</b>	<b>-5,322.07</b>

NOTE.—All values are in millions of 1987 US\$.

\* The net present value (NPV) of benefits is calculated with a 12% social discount rate.

Table 4.3: Total gains and losses of ethanol production in Brazil from 1978 to 1987. The North-Northeast region never produced a positive gain and always had a loss more than the South-Central region in every year except for 1986 (Rask, 1995).

Another reason for the switch in production from the North-Northeast to the South-Central region was the better working conditions. A typical sugarcane cutter can make as much as twice the salary working in the South-Central region. The climate is better in the South-Central region. The land is flatter in the South-Central region as opposed to the hilly North-Northeast region. Table 4.4 shows that the Center-South region consistently outperformed the North-Northeast in terms of output.

	1975	1980	1985	1990	1995	2000	2005
Area Harvested (in 1,000 hectares)							
Brazil	1,969	2,608	3,912	4,322	4,638	4,882	5,815
<b>North-Northeast</b>	<b>782</b>	<b>1,036</b>	<b>1,337</b>	<b>1,511</b>	<b>1,328</b>	<b>1,150</b>	<b>1,152</b>
North	15	10	7	17	16	17	21
Northeast	766	1,026	1,330	1,494	1,312	1,133	1,131
<b>Center-South</b>	<b>1,188</b>	<b>1,572</b>	<b>2,575</b>	<b>2,811</b>	<b>3,310</b>	<b>3,730</b>	<b>4,664</b>
Southeast except SP	439	410	542	552	470	495	582
São Paulo (SP)	621	1,008	1,666	1,812	2,259	2,485	3,085
South	104	113	196	207	292	376	454
Center-West	23	41	171	240	290	373	543
(Percentage of the total harvested area)							
North-Northeast	39.7	39.7	34.2	35.0	28.6	23.6	19.8
Center-South except SP	28.8	21.6	23.2	23.1	22.7	25.5	27.2
São Paulo	31.5	38.7	42.6	41.9	48.7	50.9	53.0
Production (in 1,000 tons)							
Brazil	91,525	148,651	247,199	262,674	303,699	326,121	422,957
<b>North-Northeast</b>	<b>34,686</b>	<b>48,394</b>	<b>68,050</b>	<b>72,473</b>	<b>61,384</b>	<b>59,772</b>	<b>61,960</b>
North	458	458	405	784	725	916	1,085
Northeast	34,228	47,935	67,645	71,689	60,659	58,856	60,875
<b>Center-South</b>	<b>56,839</b>	<b>100,257</b>	<b>179,150</b>	<b>190,201</b>	<b>242,316</b>	<b>266,349</b>	<b>360,997</b>
Southeast except SP	16,295	18,474	29,859	24,609	26,092	28,168	37,181
São Paulo (SP)	35,600	73,041	125,872	137,835	174,960	189,040	254,810
South	4,033	6,491	12,478	13,630	21,687	24,660	31,228
Center-West	911	2,250	10,941	14,126	19,577	24,481	37,778
(Percentage of the total production)							
North-Northeast	37.9	32.6	27.5	27.6	20.2	18.3	14.6
Center-South except SP	23.2	18.3	21.6	19.9	22.2	23.7	25.1
São Paulo	38.9	49.1	50.9	52.5	57.6	58.0	60.2
Yields (in tons/ha)							
Brazil	46.5	57.0	63.2	60.8	65.5	66.8	72.7
<b>North-Northeast</b>	<b>44.4</b>	<b>46.7</b>	<b>50.9</b>	<b>48.0</b>	<b>46.2</b>	<b>52.0</b>	<b>53.8</b>
North	29.6	46.6	59.6	44.9	44.6	54.2	52.7
Northeast	44.7	46.7	50.9	48.0	46.2	51.9	53.8
<b>Center-South</b>	<b>47.9</b>	<b>63.8</b>	<b>69.6</b>	<b>67.7</b>	<b>73.2</b>	<b>71.4</b>	<b>77.4</b>
Southeast except SP	37.1	45.1	55.1	44.6	55.6	56.9	63.9
São Paulo (SP)	57.3	72.4	75.5	76.1	77.5	76.1	82.6
South	38.6	57.5	63.7	65.7	74.3	65.5	68.8
Center-West	38.9	54.7	64.0	58.9	67.6	65.6	69.5

Table 4.4: Area harvested, production, and yields of sugarcane in both the North-Northeast and the Center-South region. The production of sugarcane from the Center-South region ends up almost six times the amount from the North-Northeast (Ueki, 2007).

Most of the sugarcane farms owned in the North-Northeast region are family owned, and many of these families will put children as young as 7 years old to work in the sugarcane fields. One example is the federal state of Pernambuco in the North-Northeast region. Although not all

states in the North-Northeast exhibited the same trends as Pernambuco, most were very similar. In 1993, 25 percent of cane cutters were children ages 7-17, 42 percent of these children were not paid, and 89 percent of these children were not legally registered as cane cutters (Rodrigues and Ortiz, 2007). Also in Pernambuco, there were 240,000 people employed in agriculture in 1987, but this number was cut in half by 2002 to 120,000. This can be attributed to a decline in the economy, the closing of sugarcane plants and mills, and the Center-South region (Hirsch et al, 2002). Some examples of poor living conditions in Pernambuco were the following (statistics from 1998):

- The income of 68.4% of all heads of families is below the legal minimum wage.
- The mortality rate in Mata Sul (southern part of the cultivation zone in Pernambuco) reached the frightening level of 123.7/1,000 newborns in 1993.
- 67.5% of all housing is built of clay, only 14.9% with bricks and mortar.
- 66.2% of the rural population actually lives in cities, i.e. in slums, owing to the concentration of land ownership and mass redundancies of farm workers.
- 86.45% of the total agricultural cultivation area is used to grow sugarcane (Hirsch et al, 2002).

Another way to see the poorer living conditions is to use the Human Development Index (HDI). The HDI is a way of quantifying the living conditions ranging from 0 to 1 by considering the life expectancy at birth, the education and literacy rate, and the GDP per capita. An HDI above 0.8 is considered highly developed while an HDI below 0.5 is considered under developed. Table 4.5 demonstrates the HDI of different federal states, showing wide discrepancies:

<b>Federal State</b>	<b>HDI</b>	<b>Ranking among all federal states (out of 27)</b>
São Paulo	0.850	3
Parana	0.827	6
Mato Grosso do Sul	0.826	7
Minas Gerais	0.779	11
Goiás	0.760	13
Pernambuco	0.577	20
Alagoas	0.500	25

Table 4.5: Human Development Index in federal states producing sugarcane. The two states with the lowest HDI in this table are from the North-Northeast region. The other five are from the Center-South region with much higher HDI's indicating a better standard of living (Hirsch et al, 2002).

Clearly the states with the lowest HDI are in the North-Northeast which makes the switch from the North-Northeast to the Center-South much more favorable. Most sugarcane workers would like to make the switch from the North-Northeast to the Center-South region, but most are too poor to do so.

Sugarcane production has created many jobs, but some modern technologies have limited the growth of jobs in recent years. The harvesting season depends on the region of Brazil. In the North-Northeast region, the harvesting season goes from November to May. In the Center-South region, the harvesting season goes from May to November. Because fewer workers are required on the farm outside of harvesting season, many sugarcane cutters and workers migrate from region to region because of the increased demand for work. Many employers do not pay as well outside of harvesting season. Workers can make up to twice the salary during harvesting season as opposed to outside the harvesting season. This can help workers get a better salary throughout the entire year through migration between regions. It is estimated that about 20 percent of the 1.1 million workers currently in the

sugarcane/sugar/ethanol industry are migrant workers (Maciel, 2002). However, migrant workers are typically hired without legal labor registration or by illegal contract mediators called “gatos” (Rodrigues and Ortiz, 2007). Because they are migrant workers, many of them are not protected by workers unions or pastoral agencies. More jobs are created through the addition of sugarcane land and production of sugarcane. One study predicts that every “1 million tons of sugarcane processed per year generates 2,200 direct jobs (1,600 in agriculture, and 600 in industry) and around 660 indirect jobs” (Papageorgiou, 2005). The 660 indirect jobs are typically repair, engineering, and manufacturing as well as other areas. The jobs created pay more than the average job in Brazil. As of 2005, an average family of sugarcane cutters makes 50 percent more than the average family in all of Brazil (Papageorgiou 2005). Creating sugarcane farms is an easy way of creating jobs.

### **Linking technology to growth and loss of jobs**

Technology has limited the growth of jobs over the years. In the beginning of Pro-Alcohol, there were more workers in the fields than current times. This can be attributed to the limited pay that cane cutters were making in the 1970s, the urbanization of the people of Brazil, and the increase in demand for work in the newly constructed distilleries, among other reasons. Figure 4.5 displays increasing annual sugarcane production over more than 20 years, but actual employment fluctuating in a downward progression.

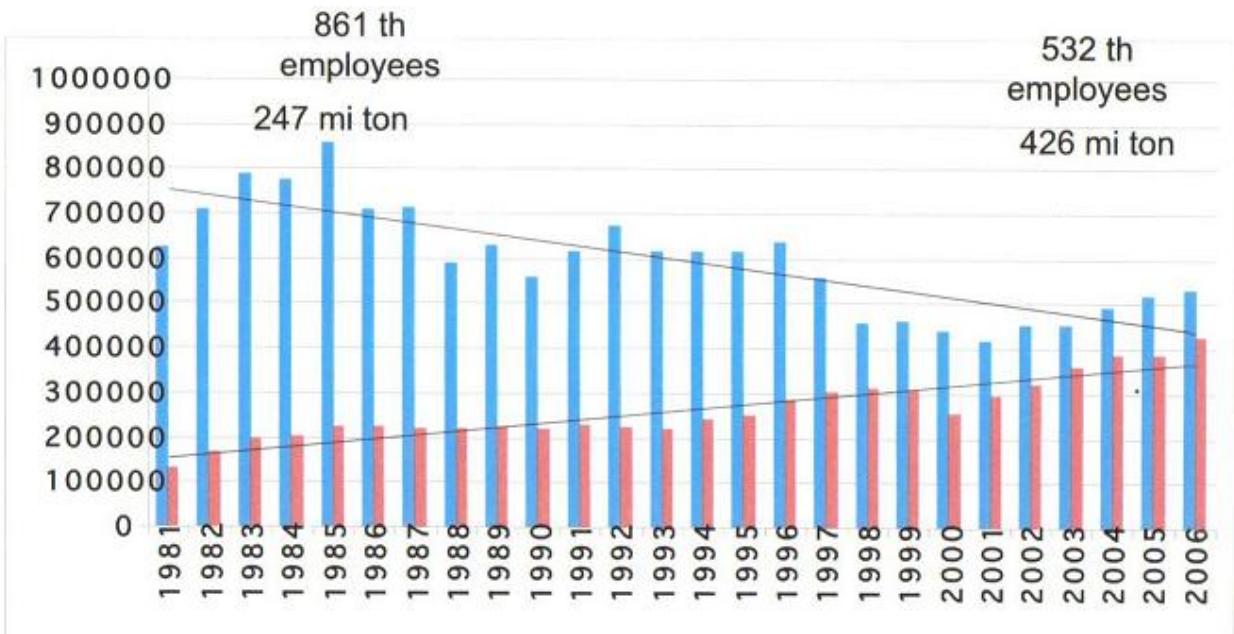


Figure 4.5: Amount of sugarcane employees on the farm itself (blue) and the sugarcane production (red). The amount of workers fluctuates throughout the years, but typically decreases based on a number of factors. In recent years, the amount of workers has grown because the rate of expansion of sugarcane farmland is greater than the rate of mechanized farming (Moraes 2008).

The proliferation of modern farm machines has also removed the human farmhand from the fields. The amount of jobs cut by using machines varies by the type of machine, ranging from about 15 jobs cut per mechanical loading into the trucks to about 2000 jobs cut by using mechanized cane cutting in the fields. Not all of the land in Brazil can be mechanically harvested. In the North-Northeast, only 25 percent of land can be mechanically harvested because of the steep incline of the land. In the federal state of São Paulo only about 1 million km<sup>2</sup> of the total 2.8 million km<sup>2</sup> of cultivation area is suitable for mechanization. Moreover, the machines can only be employed profitably on areas larger than 500 ha, or where production reaches 60,000 tons or more (Hirsch et al, 2002). Therefore, it is not profitable for small farms to employ machines to harvest sugarcane, thus retaining more jobs. These machines being



used also require energy and spill chemicals, oil, and other substances into the sugarcane farm, degrading the quality of the soil for the following years of cultivation.

## **Expansion of cultivated sugarcane land**

Unlike most countries around the world, Brazil has the ability to expand its farmland to plant more sugarcane without harming other crops or industries as much as other countries. There are many views held by different people on the issue of whether or not Brazil has the available land to expand sugarcane industry to meet rising demands. Brazil currently harvests less than 10 million hectares of land for sugarcane. Some news articles are in favor of the ethanol expansion based on the vast land area of Brazil. According to one source, there are 90 million hectares of savannahs not being used for anything productive and 100 million hectares of degraded pastures where distilleries could be planted, making a total of 190 million additional hectares of land available for planting crops like sugarcane (Rideg and Smith, 2007). However, other people suggest that the rise in ethanol production would grow into the Amazon rainforest. Achim Steiner, head of the United Nations Environment Program, suggested that expansion would increase the rate of deforestation of the Amazon rainforest by saying:

*"I think at the end of the day...it's a question of whether the Amazon is sufficiently protected and whether the expansion of the ethanol production happens in the context of government policies that try and direct that growth potential in a sustainable base (Associated Press, 2007).*

Many environmentalists side with Steiner in fearing that the Amazon rainforest will be destroyed as a result of rising ethanol production. Others say that ethanol is being produced at such an efficient rate that the expansion of land is not a problem. One source says that the beef industry is using up lots of land and that they could free up 260 million acres (105 million hectares) without a hassle by reducing the amount of land per head of cattle by half (McClatchy

Washington Bureau, 2008). Even Suani Teixeira, Vice Secretary of the Secretariat of the Environment, has said the following about the cattle industry in an interview on July 2006:

*"We have monitored the expansion of sugarcane and seen which activities have been substituted. Basically they are cattle-raising areas. And where do the cattle go? We have observed that cattle-raising area has been reducing in size, while head of cattle per hectare has been increasing. This means that cattle-raising has been intensifying, going from 1.1 to 1.2 head of cattle per hectare. Translated this means that there is no pressure on the production of food nor the migration of economic activities to other areas." (Rodrigues and Ortiz, 2007)*

The expansion of sugarcane farms is going into unused land in the vast country of Brazil and not into the Amazon rainforest. The statistics on the availability of land are astounding as shown in Table 4.6. The amount of ethanol produced from sugarcane could increase very quickly once the majority of unused land is harvested with sugarcane and more distilleries are built.

Land use	(in hectare)
Total Brazil area	851.404.680
Non agriculturable (roads, cities, legal Amazon etc)	497.793.441
Agriculturable area	353.611.239
Area with perennial agriculture	7.541.626
Area with annual agriculture (a)	34.252.829
Area occupied with sugar cane (2004) (b)	6.252.023
% Area with Sugar cane (b/a)	18,30%
Repose area (c)	8.310.029
Natural pasture area (d)	78.048.463
Artificial pasture area	99.652.009
Natural forest area	88.897.582
forestry area	5.396.016
Area non utilized (e)	16.360.085
Agriculture inapt areas	15.152.600
Possible expansion area for sugar cane [(c + d + e)/2]	51.359.289

Table 4.6: Land available for sugarcane. Although this is a rough estimate, this is a much smaller estimate than many other sources predict as land available for the expansion of sugarcane (Rodrigues and Ortiz, 2007).

Although the amount of land devoted for sugarcane has increased, the production of other crops has not been significantly altered. Brazil's agriculture is a very important part of the national economy. The agriculture sector brings in than 10 percent of the entire country's GDP, but is still one of the most profitable businesses of Brazil. In 2001, exports generated the largest positive trade balance of any sector of the Brazilian economy, amounting to US\$19 billion in 2001 (Periera, 2003). Brazil is one of the few self-sustaining countries in the world that

could survive based solely on its domestic production. Brazil has more than doubled its agricultural production since 1980. In 1999, Brazil produced more corn, soybeans, and oranges than sugarcane (Encyclopedia of the Nations, 2007). Some crops have taken a fall as a result of the growing area of sugarcane. Coffee, for example, has not been grown to the extent that it has in the past. There has been a reduction in growing area in the federal states of Minas Gerais, Espírito Santo, and São Paulo (all Center-South states), all as a result of sugarcane growth. Some research also suggests that the reduction of tomatoes, peanuts, and oranges in the São Paulo area can also be attributed to the expansion of the sugarcane crop (Rodrigues and Ortiz, 2007). It is also worth noting that the cultivated area of some crops is growing for other reasons than a higher demand or a use for more of a certain crop. Table 4.7 displays the allocation of land used to grow crops in Brazil. The cultivated area of soybeans is continuing to grow because of its use in renewable resources such as biodiesel fuel, but the growth of sugarcane still has a definite effect on the rest of the crops typically grown in Brazil.

Table 1 - Agricultural land use in Brazil.

Land Use	Area 10 <sup>6</sup> ha	Proportion	
		Agricultural land ----- % -----	Territory
Cultivated Pasture <sup>1</sup>	99.7	43.0	11.6
Rangeland <sup>1</sup>	78.0	33.7	9.1
Soya beans <sup>2</sup>	16.4	7.1	1.9
Corn <sup>2</sup>	12.3	5.3	1.4
Sugarcane <sup>2</sup>	5.2	2.2	0.6
Beans ( <i>Phaseolus sp.</i> ) <sup>2</sup>	4.3	1.9	0.5
Rice <sup>2</sup>	3.2	1.4	0.4
Coffee <sup>2</sup>	2.4	1.0	0.3
Wheat <sup>2</sup>	2.2	0.9	0.3
Cassava <sup>2</sup>	1.7	0.8	0.2
Orange tree <sup>2</sup>	0.8	0.4	0.1
Cotton <sup>2</sup>	0.8	0.3	0.1
Other agricultural land use <sup>2</sup>	4.7	2.0	0.5
Total	231.7	100.0	27.0

<sup>1</sup>Source: 1995/96 Census of agriculture (IBGE, 1998).<sup>2</sup> Source: Municipal agriculture production (IBGE, 2002).

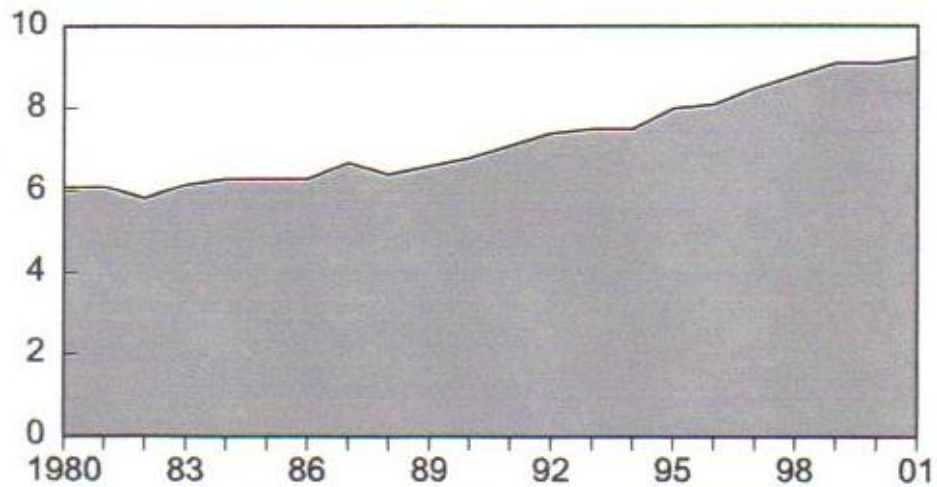
Table 4.7: Agricultural land use in Brazil in 1995 (Sparovek et al, 2007).

## Use of sugar in Brazil

Despite the use of sugarcane to produce ethanol, Brazil still consumes much of the world's sugar made from sugarcane stalks. Because most distilleries in Brazil process sugarcane into both ethanol and sugar, the processed sugar is made at the same place as the ethanol. Brazil consumes about half of its processed sugar and exports the remaining percentage. The amount of sugar exported is based on a number of factors including the value of the Brazilian currency, alcohol prices, and the global price of sugar. Brazil currently consumes over 10 million tons of sugar per year, or about 55kg per capita. Sugar is an inelastic product, meaning that the demand of sugar is based only on the number of people (which goes up every year) and not on the price of sugar. This means that the demand for sugar rises each year with population growth, which explains why it is so important to increase the amount of sugarcane grown each year (Knapp, 2003). The larger portion of the sugar is purchased and used by the people of Brazil. Food manufacturers, including those that produce carbonated drinks, chocolate, ice cream, crackers, and pasta account for approximately 35 to 45 percent of domestic sugar consumption. The remaining 55 to 65 percent is direct consumption (Bolling and Suarez, 2001). As the amount of sugar in processed foods continues to increase, the amount of sugar used by the manufacturers will also increase. Figure 4.6 affirms this growth, showing the increase of total sugar consumption in Brazil over the last couple of decades.

## Brazil: Total sugar consumption

Mil. metric tons



Source: Economic Research Service, USDA.

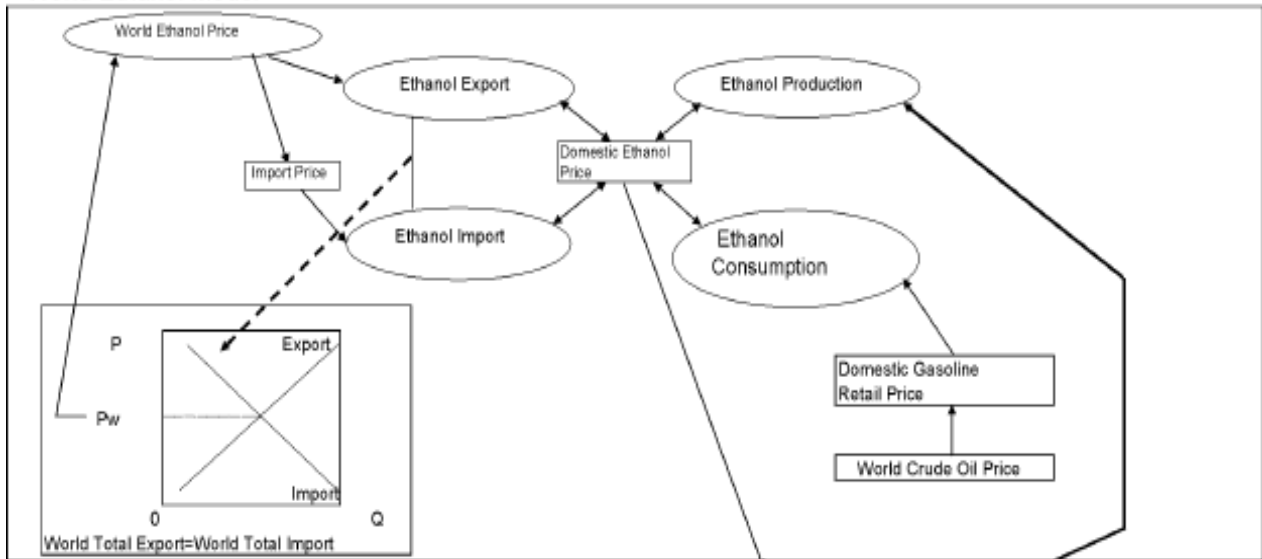
Figure 4.6: Brazil's domestic consumption of sugar from 1980-2001. Other than a few small dips and peaks, the total consumption will continue to increase over time (Bolling and Suarez, 2001).

## Global markets

One issue that is keeping Brazil from expanding its global market of ethanol is the use of tariffs and tax credits for countries to protect themselves from relying too much on foreign products. Many countries are trying to research alternative fuels using feedstock other than sugarcane (such as corn in the United States or sugar beets in Europe), and importing Brazilian ethanol could just delay the inevitable switch from relying on oil from the Middle East to ethanol from Brazil. The United States, for example, not only gives a 51 cent tax credit to petroleum blenders who use ethanol in their blend of gasoline but also puts a 54 cent and 2.5 percent tariff on imported ethanol. However, Caribbean ethanol has an advantage because of a 7 percent quota in place such that any amount of imported ethanol less than 7 percent of the annual United States production level of ethanol does not get the tariff. Above that, 35 million gallons

of ethanol containing at least 30 percent local sugarcane can come from the Caribbean without the tariff. In addition, Caribbean ethanol can come into the United States without the tariff if it contains at least 50 percent local feedstock (Severinghaus, 2005). Figure 4.7 models the general exchange and trade of sugar and ethanol in world markets, showing a tight cohesion between the two. Despite tariffs, the United States still imports ethanol because the rate of increasing production is lower than the rate of increasing demand. Brazil also gets around the ethanol tariff by building plants in Jamaica and El Salvador so that they can process Brazilian ethanol in those countries and import to the United States without the tariff (Severinghaus, 2005).

<World Ethanol Model>



<World Sugar Model ( Raw Sugar Equivalent )>

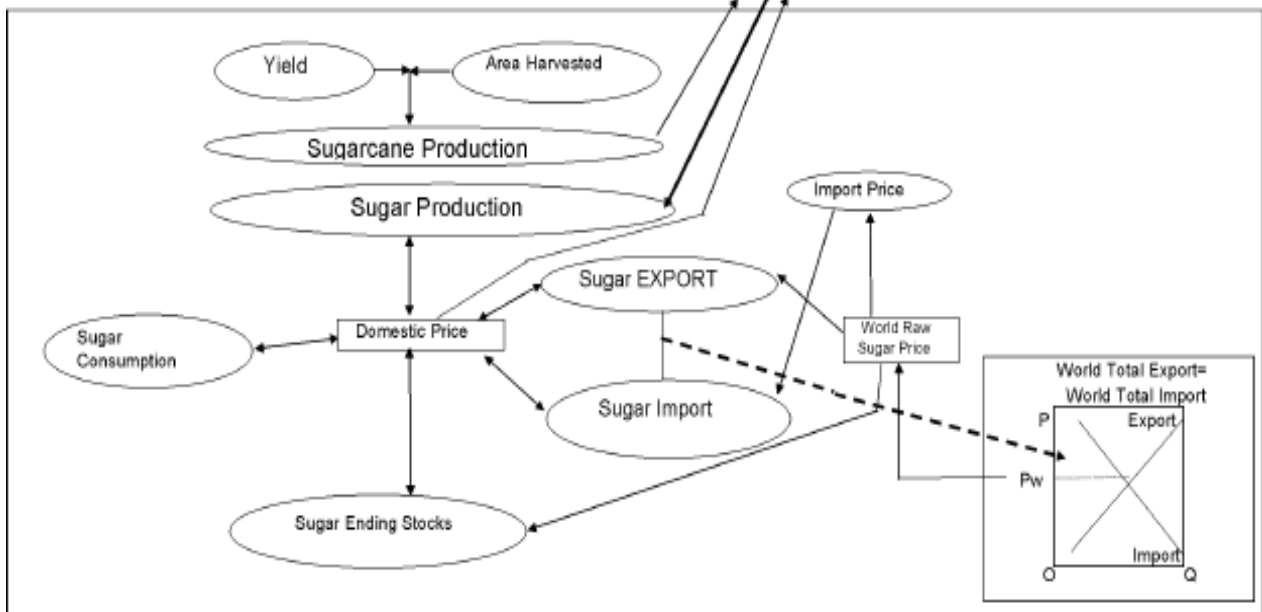


Figure 4.7: An example of the World Sugar and World Ethanol markets as well as how they are linked together. Brazil has a major influence in these two markets (Koizumi, 2003).



## **Government and Legal**

Sugarcane has always been the main crop grown in Brazil. Since as early as 1687, Brazil's government has been regulating price and production of sugar made from sugarcane. Making ethanol-based fuel was once a mere idea, but then the government intervened and helped with the transition from sugar production to both sugar and ethanol. The government of Brazil has created programs such as The Sugar and Alcohol Institute (IAA) and Pro-Alcohol to help regulate the amount of sugar and ethanol produced. The government also gave tax incentives to companies and producers who make ethanol. The purpose of this chapter is to demonstrate how Brazil's government helped to switch itself from gasoline made from imported oil to both ethanol and a gasoline fuel that requires a percentage of alcohol.

### **History of sugar production up until 1975**

Sugar production has always been a point of interest for the Brazilian government. During the early colonial times of Brazil's history, the government had to stop the price-fixing of sugar because of its massive production and profitability (Gordon-Ashworth, 1980). During its early history, Brazil's sugar trade to Latin America and the Caribbean was an important part of its economy. It eventually got to the point where producers of sugar formed a trust to regulate the price. However, that was changed when the global and national prices of sugar began to fall in 1929. The government stepped in to help out the farmers and producers of sugar in order to keep the production of sugar from stopping. The farmers were not accumulating enough profit to keep growing more sugarcane. In 1931, Dictator Getúlio Dorneles Vargas established the Commission for the Defense of Sugar Production (CDPA) to help the farmers out when the price of sugar fell below a certain level. At this point, Vargas started to assess the possibility of

producing anhydrous alcohol to use as a form of fuel in order to help the farmers once the sugar prices fell below a certain level.

In 1933, the CDPA became a permanent government organization known as the Institute of Sugar and Alcohol (IAA). The IAA helped to continue the production of anhydrous alcohol by taxing the sugar and regulating the amount of sugar produced by instituting a quota (Gordon-Ashworth, 1980). If a sugar producer produced more than the national quota, the IAA would buy the sugar and sell it on the international market (which was a lower price than the national price). The IAA was generally successful for the next decade in regulating the amount of sugar. The IAA also helped with the growth of production of anhydrous alcohol for fuel although the majority of the fuel used was made from fossil fuels like oil.

However, even with this regulation of the amount of sugar produced and the huge growth of anhydrous alcohol production, there was an over-production of sugar in the late 1940's. The IAA carried out their goals of starting to produce some alcohol while processing most of the sugarcane into sugar. The IAA encouraged millers to produce sugar like past years, but unlike before, the IAA did not encourage more production of alcohol. During the late 1960's and early 1970's, the IAA strongly encouraged sugar production instead of alcohol because of the rising price of sugar. In addition to encouraging development of new technologies, the IAA wanted "to modernize and expand Brazil's capacity to export sugar" (Barzelay and Pearson, 1982). The price of sugar continued to rise and eventually spike in 1975. After 1975, the price of sugar began to fall, shown in Figure 5.1, and the IAA's continued program of exporting sugar was no longer as profitable.

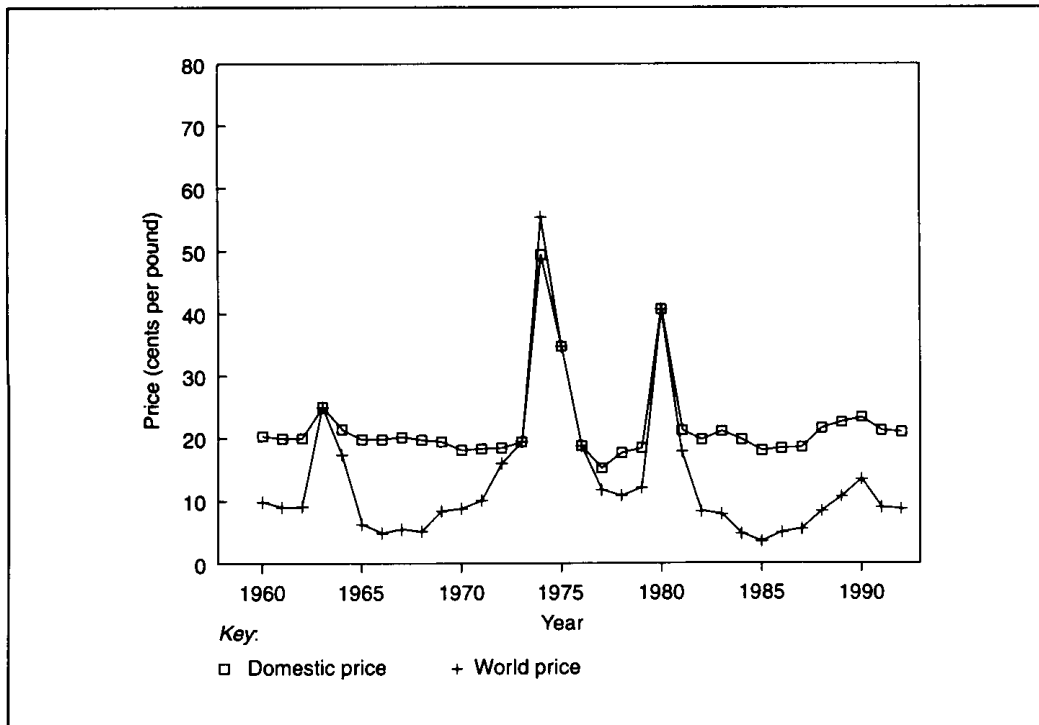


Figure 5.1: World price of sugar (Domestic price is in the United States). The world price of sugar begins to climb in the late 1960's, so the Brazilian government takes advantage by encouraging production of sugar instead of alcohol in order to boost the economy. The price peaks in 1974 and drops off during subsequent years, so the IAA abandons its programs encouraging the production of sugar (Uri and Boyd, 1994).

In the late 1960's many of the millers and producers began to come together and act as one large conglomeration. By the mid-1960's, the majority of the production of sugarcane switched from the northeastern part of the country to the southern region near São Paulo. Many of the millers came together to form one large group called Copersucar. The initial goal of Copersucar was to "finance and market the alcohol and sugar of its associated firms" (Nunberg 1986). Copersucar tried to link the industry and agriculture together. Copersucar represented 41 percent of all Brazil's sugar production and 64 percent of all Brazil's alcohol production (Nunberg 1986). With this amount of production of sugar and alcohol, Copersucar was a political force in Brazil. For example, in 1974, the military government of Brazil tried to pass legislation that would fix the national price of sugar on account of the fluctuation in world sugar

prices. Because of Copersucar's influence in the media and the fact that the millers that were part of Copersucar did not want a fixed national price of sugar, the legislation was not passed. On the other hand, Copersucar also had the political influence to help the government pass certain legislature. In the early 1970's, the price of oil and fuel began to rise, chronicled by Figure 5.2, and the Brazilian economy was starting to plummet. At this point, the members of Copersucar began to lobby for a change in sugar production. Copersucar wanted to process sugarcane to make ethanol for use as a fuel in order to reduce the dependence on foreign oil. With no immediate way to stop the increase of oil prices, the military government took a risk by proposing new legislation for a serious push of making ethanol from sugarcane. Since both industry and government wanted to make more alcohol, the National Program of Alcohol (Pro-Alcohol) was created as a response to the industry's encouragement, the low cost of sugar, and the rising price of oil.

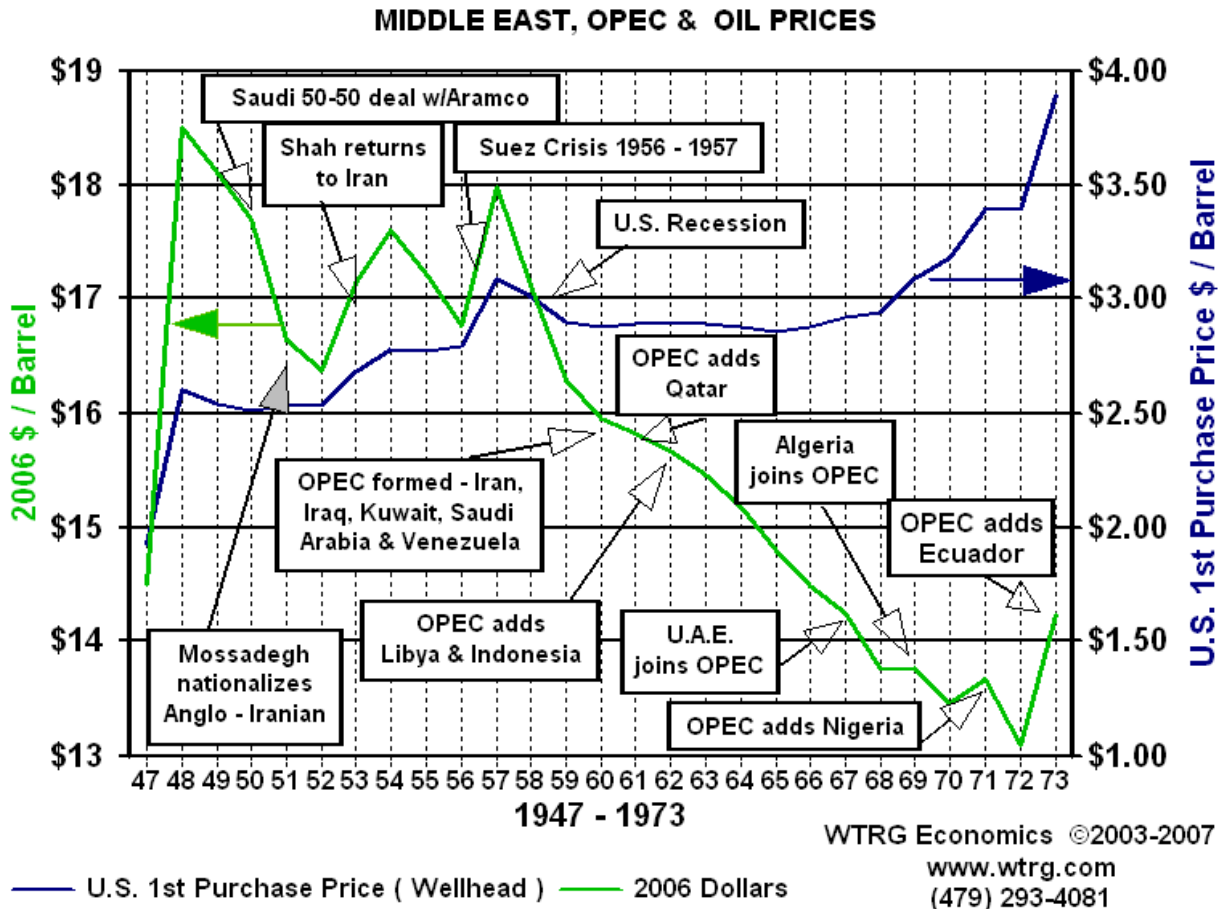


Figure 5.2: World price of oil from 1947-1973. In 1972, the price of oil begins to spike, and this trend would continue over the next 7 years. Therefore, the government of Brazil decided to step in to attempt to use alternative sources of energy in a hope of reducing its dependence on foreign oil (Pondelok, 2008).

### Enactment of Pro-Alcohol in 1975

Pro-Alcohol was a huge push for alternative fuels in the forms of pure ethanol and an anhydrous alcohol-gasoline mixture. The overall purpose of Pro-Alcohol was to support energy independence as well as the nation's agriculture and economy (Serafim, 2006). Pro-Alcohol made a push for using pure ethanol in the fuel as opposed to gasoline that required importing oil. Initially, Pro-Alcohol's first phase lasted for three years, which required all motor races in

Brazil to be run on pure alcohol (Moore, 2004). Pro-Alcohol also gave many tax incentives to both public and government vehicles such as taxi cabs and police cars for switching to alcohol fuel instead of gasoline. Pro-Alcohol gave tax incentives to companies who started to develop cars and engines that would run on pure ethanol. Pro-Alcohol also helped build many new plants across the country that could only produce alcohol and not sugar. This was an attempt to minimize the correlation between the price of sugar and the amount of alcohol being produced. Pro-Alcohol also required a higher percentage of anhydrous alcohol to be mixed in with the gasoline to support growth of ethanol production. Overall, the goals of Pro-Alcohol were achieved by doing the following:

- \* Guaranteed alcohol price lower than gasoline price
- \* Guaranteed remuneration to the producer
- \* Loans for alcohol producers to increase their capacity
- \* Tax reduction for alcohol cars
- \* Mandatory alcohol selling in Gas stations
- \* Maintenance of strategic alcohol stocks (Xavier, 2007)

Once the amount of distilleries and plants was sufficient, the government could begin phase two of Pro-Alcohol. The government and car companies made agreements to start producing cars that ran on ethanol with tax incentives for improving technology. As early as 1980, companies began selling cars that run on ethanol. This drastically changed the market for selling cars as well as starting the first step in becoming energy independent. Increased production of ethanol-based cars came with increased production of ethanol, and Figure 5.4 tracks the growth of new alcohol-running car sales in the early years of the program. In 1980, Pro-Alcohol set a goal of 10.7 billion liters of ethanol production per year. The government created the National Council for Alcohol and the National Executive Commission in order to insure that this production goal was accomplished. The government increased production by helping to build more plants and distilleries rather than increasing the amount of land used for

growing sugarcane. Figure 5.3 shows that the goal of 10.7 billion liters of ethanol production was indeed surpassed.

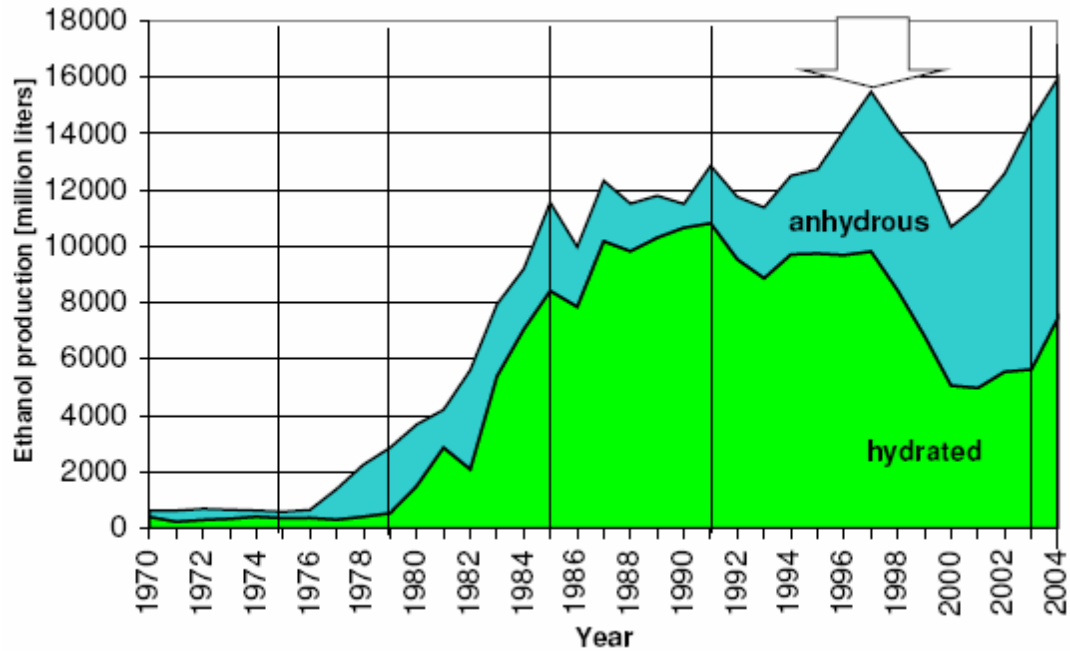
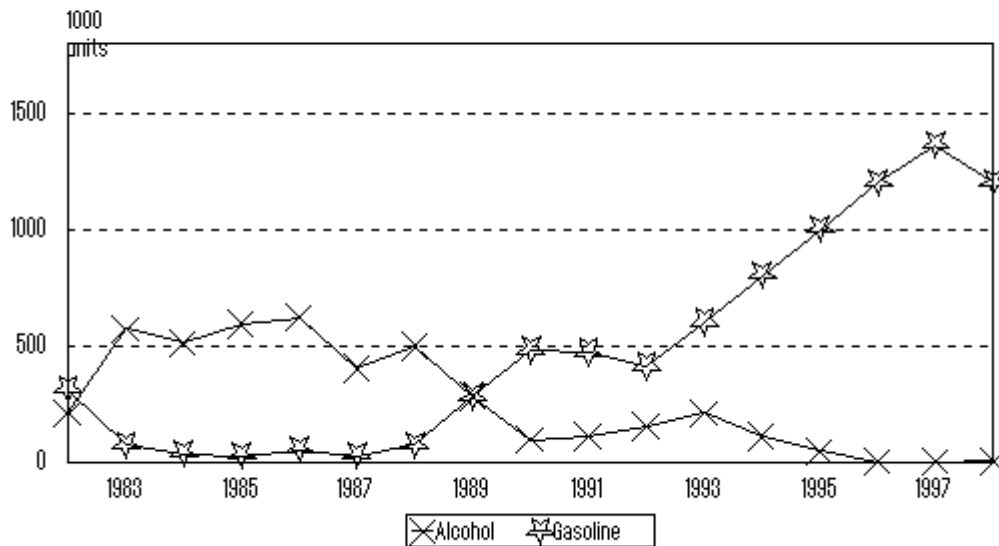


Figure 5.3: Production of Alcohol in Brazil. Alcohol production started to increase in 1976 after the enactment of Pro-Alcohol. Pro-Alcohol's goal of producing 10.7 billion liters set in 1980 was not only reached but surpassed by about 500 million liters (Papageorgiou, 2005).

During the second phase, the government required all pumps in Brazil to pump both gasoline and ethanol. The ethanol at the pump was hydrated ethanol, which means that the majority of the fuel is ethanol with less than 5 percent water. The gasoline was a mixture of gasoline and anhydrous ethanol (pure ethanol with no water). The mixture varied, but was typically between 20 and 25 percent anhydrous ethanol depending on the year. Alcohol soon dominated the Brazilian market because of the available tax incentives, wide availability of models and a cheaper price at the pump (Moore, 2004). The industry was also provided with low interest rates on loans needed to build more distilleries. This was a good first step towards becoming energy independent especially with the spike in oil prices towards the early 1980's even though the program was not economical.

# Brazil - Sales of New Cars

gasoline vs alcohol



Source: Anfavea

Figure 5.4: Sale of cars in Brazil from 1982-1998. Towards the beginning of phase two of Pro-Alcohol in 1982, the amount of cars increased considerably, and very few gasoline-based cars were sold during the same time frame (Berg, 1999).

## Economics of Pro-Alcohol

Overall, the first two phases of Pro-Alcohol were not good for Brazil's economy. The second phase of Pro-Alcohol was not very economical on account of the rising oil prices. From Figure 5.3, most of the alcohol being produced was hydrated alcohol because of the rise in demand through ethanol-based cars. Thus most of the fuel being used was made from ethanol instead of gasoline. Therefore, the surplus of gasoline created had to be exported out of the country, costing Brazil a lot of money. The government of Brazil went into the worst economic recession in history in late 1980, and part of it was because of Pro-Alcohol. The inflation rates for Brazil topped 100 percent for a span of at least five years. The government signed a 250



million dollar loan from the World Bank to help pay for Pro-Alcohol (Barzelay and Pearson, 1982). The government also regulated both the price of ethanol and gasoline such that purchasing ethanol was more economical than gasoline (ethanol is about 70 percent as efficient as gasoline). Sustaining a market for ethanol had indeed cost the Brazilian government dearly.

It is difficult to determine the exact amount of money to produce a liter of ethanol that would make it more economically efficient than buying a barrel of oil. However, Copersucar provides the most accurate data because it comes from millers who produce the ethanol itself. The factors that determine the cost to produce include, but are not exclusive to: the price to grow sugarcane, the cost of maintaining the distillery, the amount of labor in the distillery, the transportation of the sugarcane to the distillery, and many others. During the 1980-1981 season after taking into account all variables, the projected loss for producing and selling a liter of ethanol was 6 US cents with the cost of making a liter of ethanol being 24 US cents and the return of making a liter of ethanol being 18 cents (Barzelay and Pearson, 1982). The return of a liter of ethanol is also based on the value of the cruzeiro (Brazil's currency at the time) especially when exporting ethanol to other countries. Because of the recession in Brazil's economy, the Brazilian cruzeiro was heavily devaluated, so the return on exported ethanol was not high. Although the cost of making a liter of gasoline at the same time frame was also 24 US cents, the return was much higher than that of ethanol, making it more economical to use gasoline instead of ethanol. This was a risk to produce ethanol instead of gasoline. When the price of gasoline is not getting lower, the return for a liter of ethanol would either stay the same or lower. However, the cost of producing ethanol generally stays the same or reduces with time and better technology. Therefore, it was a risk worth taking at the time despite the economic costs to Brazil, documented in Table 5.1.

**TABLE 3**  
**NET SOCIAL LOSSES OF ALCOHOL PRODUCTION, 1979–83**

	1979	1980	1981	1982	1983
<b>Per liter:</b>					
Social costs (anhydrous and hydrated)	.21	.21	.21	.19	.19
Social value (anhydrous)	.13	.19	.20	.19	.17
Social value (hydrated)	...	.16	.17	.16	.14
Net losses (anhydrous)	.08	.02	.01	.00	.02
Net losses (hydrated)	...	.05	.04	.03	.05
<b>Total production:</b>					
Anhydrous alcohol (billion liters)	2.20	2.25	1.15	2.02	2.02*
Hydrated alcohol (billion liters)	...	.43	1.40	1.70	1.70*
<b>Total losses:</b>					
Anhydrous alcohol (1979 US\$ millions)	176	45	12	0	40
Hydrated alcohol (1979 US\$ millions)	...	22	56	51	85

NOTE.—Figures are in 1979 US\$. No additional sugarcane opportunity costs in 1980–81.

\* In the absence of comparable data for 1983, we assume 1982 production levels.

Table 5.1 Losses of alcohol production from 1979-1983 (1983 was estimated from the data from 1982). The key numbers to look at are the social costs and social value for anhydrous and hydrated ethanol. Overall, making alcohol at the time was not economical. As production increased in correlation with figure 3, the economy of Brazil suffered more because more money was lost for every liter of alcohol produced (Barzelay and Pearson, 1985).

### **Abandonment of Pro-Alcohol in late 1980's**

During the late 1980's, many factors began to take a toll on the goals of Pro-Alcohol and the thought of energy independence. In 1985, the percentage of ethanol cars on the roads in Brazil was 95.8 percent, and this number would never get higher (Rosillo-Calle and Cortez, 1997). By 1989, this number would shrink to about 50 percent. As shown in figure 3, the amount of alcohol produced by Brazil fluctuated throughout the late 1980's instead of increasing like the early 1980's. The supply of ethanol cars kept getting larger, and it was difficult to keep

up with the demand of the consumers. Between 1980 and 1986, Brazil exported at least 250 million liters of ethanol to other countries; however, from 1987 until the end of the decade, Brazil never exported over 100 million liters (Papageorgiou, 2005). Brazil struggled to produce enough ethanol to keep up with the domestic demands so it did not have enough excess ethanol to export. During 1985, the government of Brazil changed from a military-based dictatorship to a republic, giving the people of Brazil more influence in political decisions. Because of the inability for the industry to keep up with the demand of ethanol, the people of Brazil were losing faith in Pro-Alcohol. There was more political influence from the people of Brazil to change the direction of the ethanol production. The price of oil began to fall again in the mid-1980's back to around 15 US dollars per barrel, shown in Figure 5.5, which was a decrease from about 40 US dollars per barrel in the early 1980's (Lemos, 2007). Therefore, many farmers decided to switch back to processing sugar rather than trying to produce ethanol to a market on the decline.

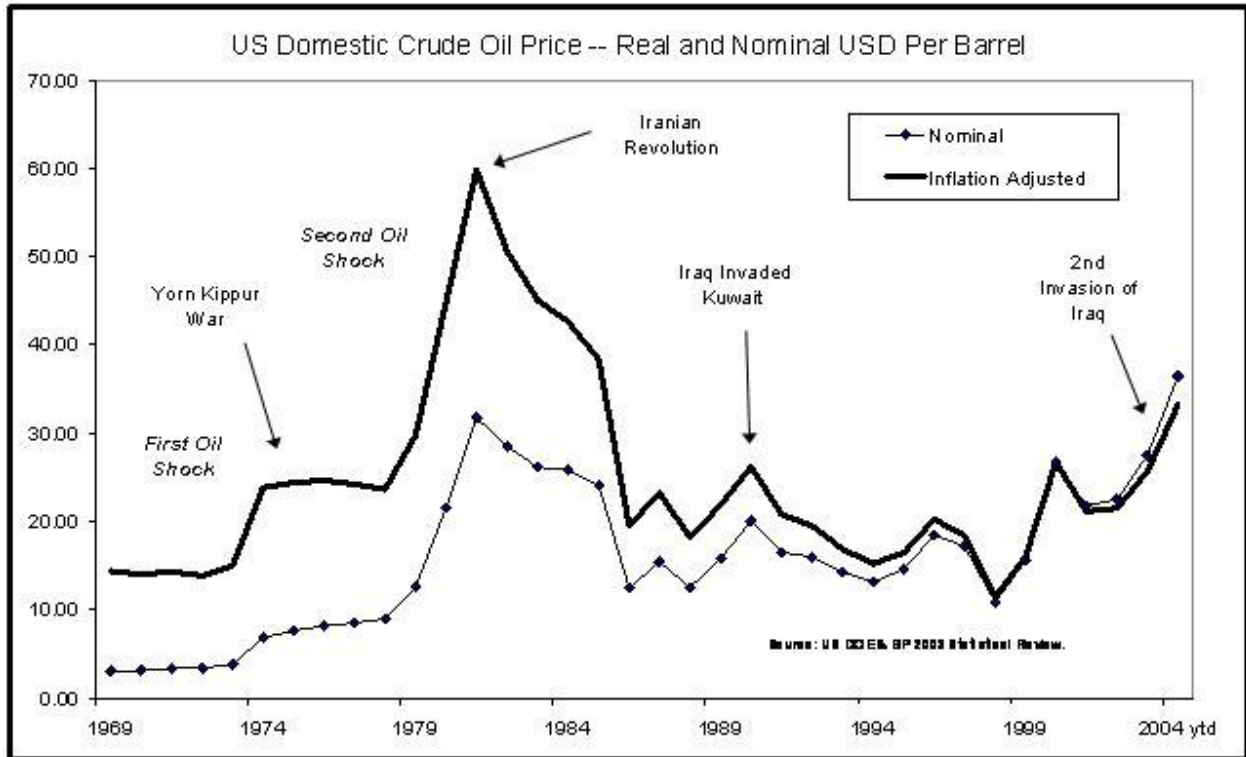


Figure 5.5: Inflation adjusted oil prices from 1969 to 2004. After the spike in the price during 1980, the price of oil begins to decline for the next 5 years. Beginning in 1985, the price of oil begins to level off at nearly a third of the price during 1980, making it more economical to begin a switch back to using gasoline as a fuel instead of ethanol (Raffan, 2004).

During the 1990's, the country switched back to using gasoline-based fuel instead of pure ethanol. In February 1991, the government of Brazil abandoned the use of Pro-Alcohol because many people were starting to reject the idea of ethanol-powered cars. The government also lost a large amount of money over the years to continue Pro-Alcohol, and continuing the program without any returns to the people of Brazil was no longer worth the investment. Government control over growing sugarcane and ethanol production was discontinued (Serafim, 2006), and the private sectors would now determine how much ethanol to produce and how much sugar to process. The price of oil started to fall again so gasoline

was now the more economical choice of fuel. Production of ethanol, as shown in Figure 5.3 and Figure 5.6, was still increasing based on more sugarcane being planted and improvements in technology. The research of flex-fuel technology, where an engine can run on any mixture of ethanol and gasoline, began in 1993. This kept the production of hydrated ethanol increasing. However, with the amount of ethanol cars on the road, the production could not keep up with the demand. As shown back in Figure 5.4, the amount of ethanol cars sold in 1995 and after was close to zero.

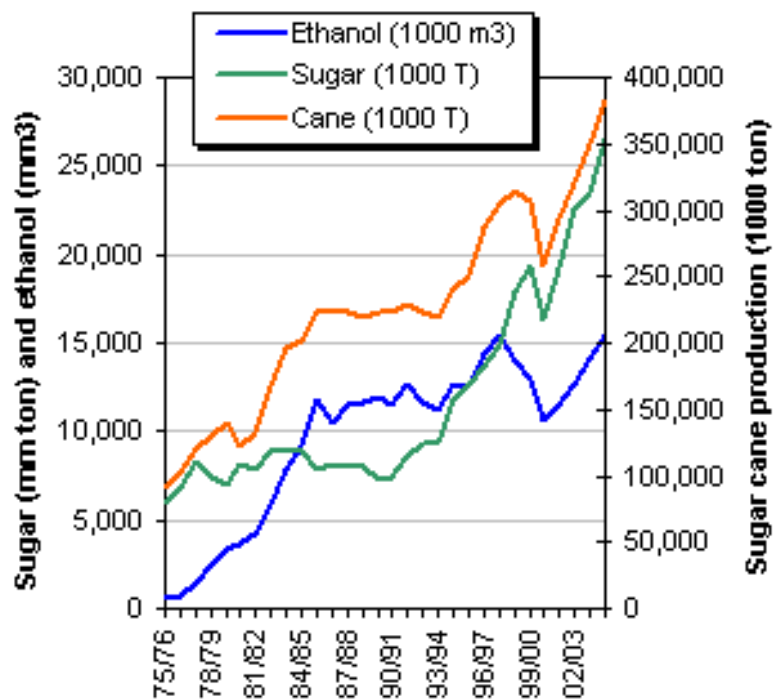


Figure 5.6: Amount of sugarcane produced per year and the percentages of that sugarcane used to produce ethanol and sugar from 1975-2003. In the mid-1990's, the amount of sugarcane produced per year changed based on the climate. The amount of ethanol produced started to drop based on the rising price of sugar and the increase in the value of Brazilian currency (Martines-Filho et al, 2006).

Throughout the 1990's, the government had no clear path towards the future of Pro-Alcohol or any ethanol fuel plan like the previous 15 years. The government just tried to

encourage increase in productivity for both the sugar and ethanol industry (Rosillo-Calle and Cortez, 1997). With no direction from the government, it was up to the farmers and the millers on whether to increase the amount of ethanol or refine sugar from the sugarcane. The government even got rid of the price regulations of gasoline and ethanol in 1998 in order to try and save money.

### **Problems with producing ethanol in 1990's**

One problem that hurt the production of ethanol was the climate of Brazil. The amount of sugarcane that was produced each year depended on the climate. Although the amount of sugarcane produced per hectare was increasing each year based on technological improvements, it strongly affected the amount of ethanol being produced each year. Another problem that hurt ethanol production was the volatility of the sugar market. The global price of sugar changed very quickly over time. During the late 1990's, the price of sugar began to rise each year, shown in Figure 5.7, allowing the millers to produce more sugar to get a better value for each given amount of sugarcane grown. The amount of hydrated alcohol produced drastically decreased for the rest of the decade while the amount of anhydrous alcohol produced stayed the same, as also shown back in Figure 5.3. This was because anhydrous alcohol was still needed to mix with the gasoline that was refined from oil to produce the gasoline fuel sold at the pump. Brazil also went through an economic transformation during 1994 that lowered the inflation rate to below 10 percent, and more importantly, raised the value of Brazilian currency so that there were higher returns on exports like sugar. Because of the higher return for sugar as opposed to hydrated alcohol, there was a decrease in the amount of pure ethanol fuel production until the early 2000's. The government did not have much control over the choice of sugar or ethanol until the invention of fuel-flex technology in 2003.

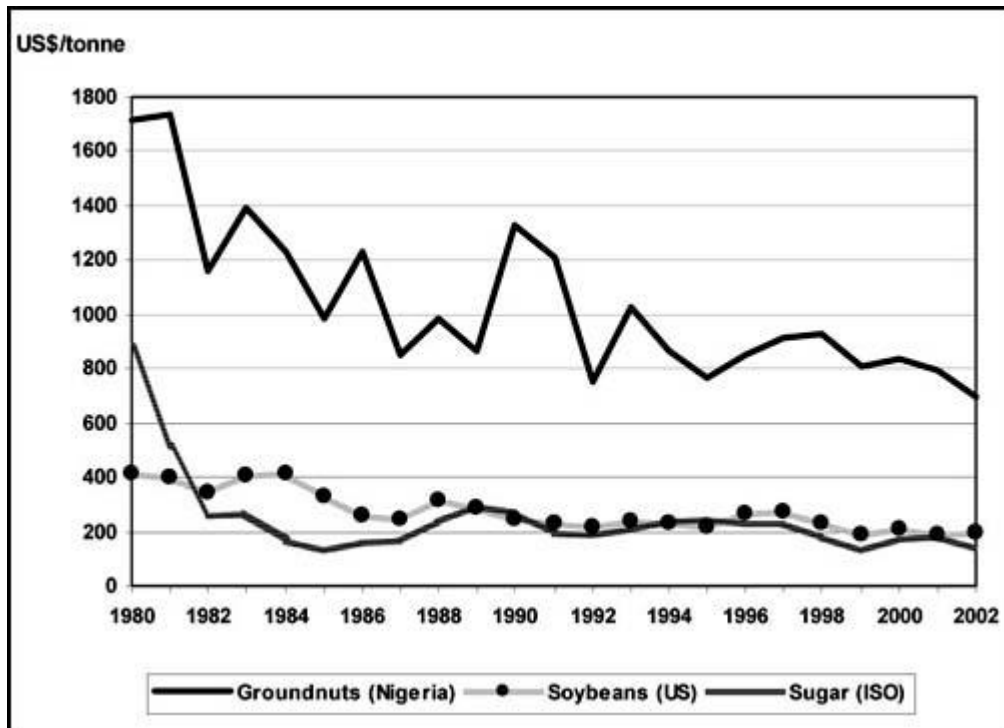


Figure 5.7: The global price of sugar from 1980-2002 (top line in chart). In general, the price both fluctuates and decreases until about 1995. The price begins to rise (although it tumbles in 1997) initiating the selling of sugar instead of production of ethanol in direct correlation with Figure 5.3. (Conforti and Rapsomanikis, 2005)

### Introduction of flex-fuel in 2003

With the introduction of flex-fuel automobiles into the industry in 2003, the ethanol market began to rise again, and the government stepped back in to regulate and encourage the ethanol production. The price of sugar began to fall again after 2000, making it more economical to produce ethanol again. Because the supply of ethanol began to increase again, the price of the ethanol began to drop to the point where it was 40 percent of the price of gasoline (Moore, 2004). However, with little to no ethanol cars on the road, there was a surplus of ethanol that needed to be exported instead of used by the local economy. At this point, alcohol cars began to look profitable for the first time in 20 years. With the production of flex-

fuel automobiles and the increase in the price of oil (as shown in Figure 5.5), over 70 percent of the cars sold during 2005 were flex-fuel automobiles (Serafim, 2006), shown by Figure 5.8. The government began to give tax incentives again to companies who were producing flex-fuel vehicles and to Brazilian people who purchased ethanol. For example, ethanol was not taxed nearly as much as the gasoline. On a national level, the difference between taxes on ethanol and gasoline was 0.30 reais (Brazilian currency at that time). On a state level, the difference between taxes on ethanol and gasoline was 0.50 reais. The price at the pump was 1.14 reais for a liter of ethanol and 2.22 reais for a liter of gasoline (Serafim, 2006). Because the price for a liter of ethanol was more economical than the price of gasoline, more people would buy the ethanol instead of the gasoline. Without the tax incentives placed by the government, more people would buy the gasoline because it is more economical. However, this type of government regulation helped the ethanol market thrive again and was a step in the right direction towards energy independence.

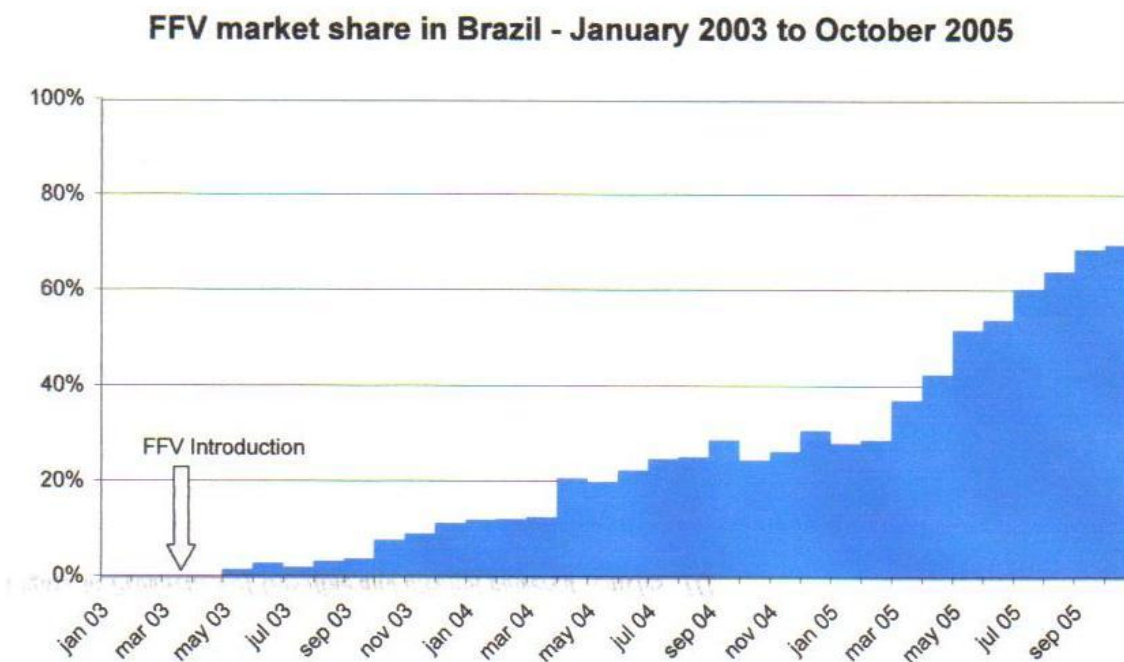


Figure 5.8: Percent of sales that were flex-fuel vehicles from the introduction until October 2005. The flex-fuel technology gave people the option of purchasing either ethanol or gasoline



depending on the market. Therefore, an ethanol market had the possibility to thrive again for the first time since the early 1980's (Brandao, 2007).

## **Push for biodiesel in 2005**

The government of Brazil also tapped into research for biodiesel in order to add some renewable resources to the existing diesel fuel. In 2005, a federal law stated that diesel fuel must contain at least 2 percent biodiesel by 2008 with the goal of 5 percent biodiesel by 2013. The biodiesel consumption per year in Brazil is about 40 billion liters (most of which is consumed by transportation), and about 4 billion liters is imported (Serafim, 2006). Biodiesel is a fuel used for compression-ignition engines, which is made from a renewable resource instead of oil. In 2004, the government created the National Biodiesel Production Program (PNPB) to help promote and sustain stable production of biodiesel. The PNPB poured money into research of different feedstock to make the most efficient form of biodiesel. At present time, biodiesel is typically made from soybeans. Like the ethanol, there were tax incentives placed on biodiesel in order to promote research and improve the internal market. In Brazil, there are two main tax components on automobiles:

**CIDE:** Funds raised via this fuel tax are, in theory, used to finance infrastructure works and maintenance of the transportation system. For regular diesel, CIDE is fixed at R\$ 0.07/liter.

**PIS/COFINS:** These two taxes are charged together in one basket. For diesel, a fixed assessment of R\$ 0.148/liter is charged to the manufacturer upon sale to distributors. (Serafim, 2006)

The government gave tax incentives to producers who manufactured biodiesel fuel, shown in Table 5.2. Although production of biodiesel fuel is at an infant stage, the government of Brazil is still investing money and resources into this market to help the economy thrive and become less independent on fossil fuels.

Federal Taxes Incentives for Biofuel Production in Brazil (R\$/liter)					
Tax Incentive	Biodiesel				Regular Diesel
	Subsistence Agriculture North, Northeast regions w/ castor or palm	Subsistence Agriculture	Medium-Large Farmers North Northeast regions w/ castor or palm	All others	
IPI	full exemption	full exemption	full exemption	full exemption	full exemption
CIDE	full exemption	full exemption	full exemption	full exemption	0.07
PIS/COFINS	100% reduction (R\$ 0.000)	68% reduction (R\$ 0.070)	32% reduction (R\$ 0.151)	0.218	0.148
Federal Tax sum	100% reduction (R\$ 0.000)	68% reduction (R\$ 0.070)	32% reduction (R\$ 0.151)	0.218	0.218

Source: Government of Brazil, Executive Orders # 5,297/04, 5,298/04 and 5,457/05.

Table 5.2: Tax incentives given out to producers of biodiesel. Different incentives are given out based on location and type of raw material (Serafim, 2006).

Since 1975, the push for ethanol as an alternative source of fuel was a huge gamble. Economically, Brazil endured multiple years where the inflation percentage was well over 1000 percent. However, it is now economical to produce, use, and export ethanol with today's oil and gasoline prices. Pro-Alcohol helped begin the push for ethanol 1975 and completely transformed the market for the next 10 years. In the late 1980s through the entire 1990s, ethanol was on the decline based on the economics of Brazil, falling oil prices, and rising sugar prices. With the introduction of flex-fuel vehicles in 2003, the push for ethanol and biodiesel was ignited once again. With record-high oil prices today, ethanol is more economical to produce than to import oil. The ethanol market has helped the Brazilian Real to gain significant value over the past 5 years. It took over 30 years, but Pro-Alcohol has finally paid off.

## Discussion

Recently, Brazil has made the move to become energy independent. It has done so through thirty years of ups and downs with economy, technology, and laws. Brazil's economy and agriculture has suffered through the route to energy independence. With rising energy costs across the world, many countries are attempting to follow in Brazil's footsteps. Brazil is the only country of such a high population to make the move to energy independence. Other countries are trying to implement similar laws, technology, and business models as Brazil. However, none have currently had the type of success that Brazil has achieved.

United States has a more difficult route towards energy independence than Brazil does. The United States has a population of over 300 million people while Brazil has less than 200 million people. The United States also consumes more oil than Brazil does. According to one study, the United States consumption per capita of oil is over six times that of Brazil (Philpott and Feller, 2006). Although the United States produces much more oil per capita than Brazil, the gap between production and consumption of oil in the United States is much larger than that of Brazil, and Figure 6.1 shows some of the oil that has to be imported to account for the difference. Regardless of the type of energy that replaces oil in the future, a major overhaul of government and business models is necessary in order to get rid of the dependence on foreign energy. Importing Brazilian ethanol is just as bad as importing oil from the Middle East and South America. The United States needs create its own path to energy independence.

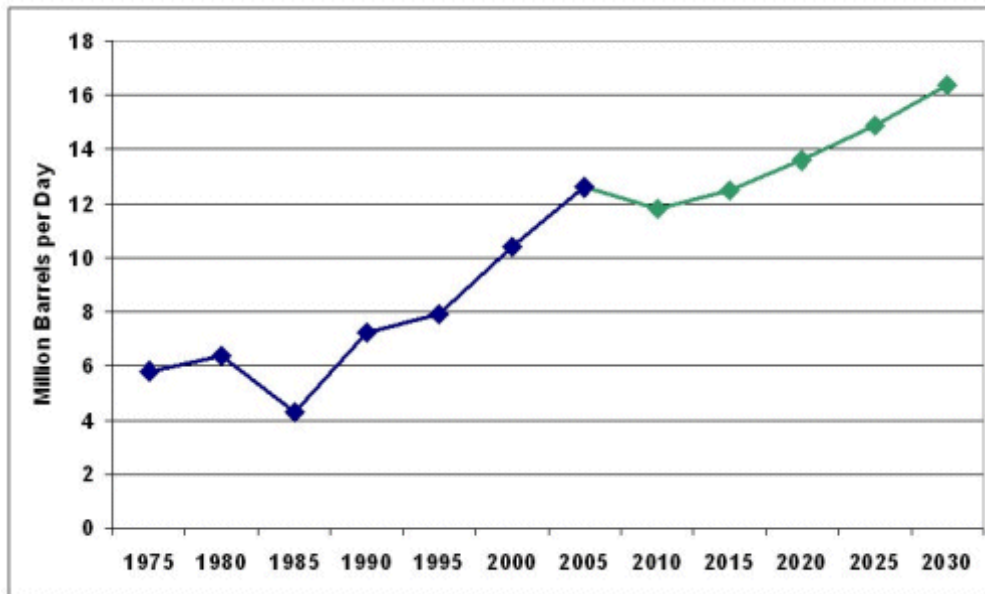


Figure 6.1: Diagram of total oil imports to the United States from 1975 through 2005 as well as projected data. The blue represents historical data (up to 2005) and the green represents projected values up to 2030. The diagram shows that the amount of imported oil increases each year (US Department of Energy, 2007).

## Laws for the United States

Brazil took over 30 years to create an energy independent society. It is possible to do the same in the United States even if the road is long and hard. If the United States chooses to become energy independent with ethanol-based energy as the fuel of choice, this section will show how they can do that based on the choices that Brazil has made over the last thirty years.

The United States has put in a few laws recently that have helped production of ethanol and the push towards energy independence. The Volumetric Ethanol Excise Tax Credit (VEETC) in 2004 tried to push for more ethanol added into gasoline. VEETC forced blenders to pay the full tax of 18.4 cents per gallon of gasoline-ethanol mixture, but allowed for a 51 cent tax credit for each gallon of ethanol used in the mixture. VEETC tried to get blenders to use more ethanol in the fuel. President Bush signed the Energy Policy Act of 2005 in early August 2005,

creating an initial push towards energy independence by giving tax breaks to many forms of alternative energy including ethanol production, nuclear power, and renewable electricity. Increased ethanol production was a small part of the bill, which also included research for wind power and tax breaks to citizens who use environmentally friendly resources in their homes. As far as ethanol production, the bill promised an annual 50 million dollar budget towards biofuel research. In addition, the bill increased the production of ethanol mixed with gasoline to increase from 4 billion gallons in 2006 to 6.1 gallons in 2009 and 7.5 gallons by 2012. The amount of money set aside for alternative fuels such as ethanol is less than for nuclear power, fossil fuel production, and clean coal technology. The Energy Independence and Security Act (EISA), signed in December of 2007 by President Bush, built on the biofuel production aspect of the Energy Policy Act. EISA made a push towards ethanol production by setting a Renewable Fuel Standard of 36 billion gallons of renewable fuel by 2022 (the United States produced 4.7 billion gallons in 2007). EISA also increases highway standards of motor vehicles up to 35 miles per gallon by 2020.

The United States government is on the right track towards using renewable fuels as a replacement for oil. The Energy Independence and Security Act is similar to the first stage of Pro-Alcohol that Brazil implemented in 1975. While Pro-Alcohol pushed for a five-fold increase in five years, EISA calls for over a six-fold increase in ethanol production over a 15-year span, being the much-needed jumpstart toward energy independence.

The United States cannot afford to have the economic turmoil that Brazil had during the 1980s as a result of ethanol, but it is possible to have similar success without pouring a significant portion of the economy into biofuels. The tax incentives placed by the Energy Policy Act are important towards the success of renewable fuels. These tax incentives will help research be conducted so that technology can advance quickly. EISA is going to cost the

United States money before its ethanol production goal in 2022, but it will pay off if it works. This is a similar risk to that of Brazil, but it is paying off for Brazil's economy thirty years later.

There are a few things that the government has to watch out for in the future which could hinder the progress of the ethanol production goal in 2022. Less than one percent of all pumps across the United States sell E85 (85 percent ethanol). However, there are few flex-fuel cars on the road that can use either ethanol or gasoline. Once E85 becomes available at the majority of the pumps across the country, the government needs to make sure that ethanol is more economical to use in vehicles than gasoline. In the 1980s, Brazil ran into this problem with falling oil prices. The national price of gasoline dropped in Brazil so many people decided to move away from the ethanol. This hurt the economy of Brazil at the time, but it still allowed for an ethanol market and the advancement of technology. Now Brazil is reaping the benefits of a continued ethanol market and advanced technology.

## **Separate food from fuel**

Another thing that the United States government has to watch out for is the rising food prices. Because the bulk of the ethanol in the United States comes from corn, farmers have the choice to sell a bushel of corn for ethanol production or food. Farmers will make the choice to use the corn for food or fuel based on the product that will make the highest profit. Brazil saw this problem with rising sugar prices because sugarcane can either be used for ethanol or processed sugar. Because of the rising sugar prices in the early 1990s, millers decided to produce sugar instead of ethanol, blocking ethanol production. If ethanol production is going to continue, the government has to give tax incentives to make sure that the corn needed for ethanol production does not go towards food.

It was very important for the United States to take steps towards energy independence because many other countries in the world are trying to repeat Brazil's success, as in the increase in world ethanol production in Figure 6.2. Europe is trying a similar strategy with sugar beets while Japan is trying with rice. However, no feedstock on the planet is efficient like sugarcane. Other countries are still trying to reduce the dependence on oil because of the volatile market and the depleting supply.

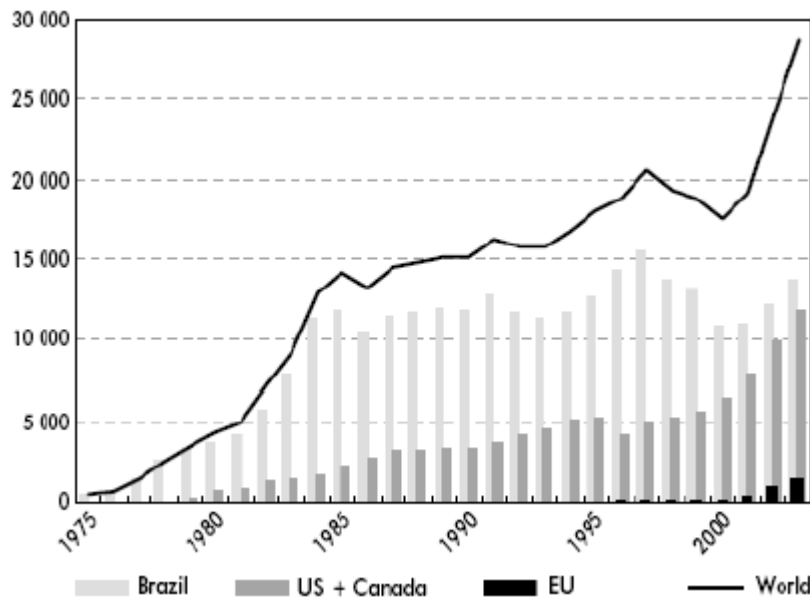


Figure 6.2: World production of ethanol from 1975 to 2003. The y-axis is millions of liters of ethanol. Many countries are trying to produce their own energy so they don't have to rely on other countries for it (Vessia, 2006).

## Economics and business

The global oil and ethanol markets are intertwined such that when one changes, the other will respond. If a large country such as France or England decides to switch a portion of its oil imports to ethanol production, both the global oil and ethanol markets will respond in a certain way. If one country decides to put a tariff on imported ethanol, the markets will also respond in a certain way.

The United States has put a tariff on Brazilian ethanol, and there has been much debate as to whether or not to remove it. A 54 cent import tariff and a 2.5 percent tax credit were implemented to help protect United States production instead of just importing cheaper ethanol from Brazil. These tariffs only apply to ethanol coming straight from Brazil. Any ethanol that was processed in the Caribbean or Latin America does not get taxed, serving as a loophole around the United States tariff. Those against the tariff argue that the United States should import Brazilian ethanol over oil from the Middle East, contending that ethanol is more of a long-term solution than oil and people from Brazil are not trying to destroy the United States, unlike some extremist factions Middle East.

However, this argument is absolutely absurd because it still makes the United States more dependent on foreign sources of energy. Importing Brazilian ethanol could be a better solution instead of oil from the Middle East, but it is not a good answer because the goal of the United States should be energy independence. Importing Brazilian ethanol still makes the United States dependent on another country for energy. Some Americans still import some Brazilian ethanol if it is more economical than purchasing American ethanol.

Many economists around the country have analyzed the situation of whether or not to remove the tariff on Brazilian ethanol. One group at Iowa State University looked at this situation and concluded that removing the tariff would result in a 23.9 percent increase on the world price of ethanol relative to the baseline price between 2006 and 2015 as well as a domestic price decrease of 13.6 percent, a 7.2 percent decline in production, and a 3.6 percent increase in consumption. They also concluded that if the 51 cent tax credit from VEETC was removed, the world price of ethanol increases by 16.5 percent (Elobeid and Tokgoz, 2006). Another economist did a similar analysis of the situation and concluded the following:

-Net ethanol imports of the U.S. increase by 192.8 percent. Given that net imports make up only 5.3 percent of domestic consumption in the baseline, the large increase in net



imports in the first scenario translates into a 14.9 percent share of imports in total domestic consumption.

-The lower domestic production of ethanol translates into reduced demand for corn in the U.S. Thus, the corn price declines by 1.6 percent on average relative to the baseline.

-Given the decline in corn used in ethanol production, the production of by-products decreases, by 7.5 percent on average for DDG, and by 1.8 percent each for gluten feed, gluten meal, and corn oil.

-Brazil responds to the higher world ethanol price by increasing its production by 8.8 percent on average relative to the baseline. Total ethanol consumption decreases by 3.2 percent and net exports increase by 61.9 percent.

-The lower supply of Brazilian sugar leads to an increase in the world raw sugar price of 1.7 percent on average. (Ellis, 2006)

This is in addition to the decrease of domestic price, decline in production, and increase in consumption. It is very clear why Brazil wants the United States to remove the tariff. Brazil would make a profit off the ethanol from sugarcane as well as processed sugar. Brazil would export ethanol for a higher price in addition to exporting much more than it already does. There are pros and cons by removing the tariff. The price of corn decreases in addition to the cost of ethanol, helping the consumer. However, the United States would import more ethanol and hurt small farmers in the United States by using Brazilian ethanol instead of homegrown ethanol. Given the final goal of energy independence, the smarter choice is to keep the tariff in place so that the jobs stay in the United States.

## **Harvesting corn**

One of the problems that Brazil faced was the cane farmer's rights and living habitat. In Brazil, many cane farmers nearly kill themselves each day in order to meet demands. In the United States, this is not as much of a problem because the land is much flatter and the climate is not as tropical in the Midwest. Therefore, much of the land is mechanically harvested instead of paying workers to manually collect corn from the fields. The main problem is keeping the

small farmers in business. Because of the recent increase in the price of land and upkeep of food for the livestock, many small farmers who own or rent land cannot afford to keep their farm based on the price of land and the upkeep for feeding livestock. Large farmers make huge gains because they profit from the increased price of land and corn. After profiting from increased prices in food, the large farmers can simply buy off the land from the small farmer, not only creating a larger margin between the large and small farmers, but also putting small farmers out of business. Unless the government steps in with a plan to stop this, the only way for small farmers to survive is by forming unions or cooperatives. Small farmers were able to survive in Brazil by working together for profits instead of competing against each other. This is the only way for them to survive and not to succumb to the large farmers.

As demands for ethanol increase each year, more distilleries must be built each year. These new distilleries must be built near the farms in order to keep the distance to the distillery at a minimum and profits at a maximum. In Brazil, distilleries are built all over the country because sugarcane is grown in many areas. This means that the distance between distilleries and petrol stations is normally short. The United States does not have such a luxury because corn is grown in the Midwest only. Therefore, it is very difficult to transport ethanol on the coasts. Unlike oil, ethanol cannot be transported through pipelines because it will pick up excess water. The ethanol also corrodes pipelines and picks up any solids along the way. Therefore, the only way to transport ethanol from the Midwest to the coasts is by land before it is mixed with gasoline. If the ethanol is mixed with gasoline before it is used, the mixture can become contaminated. Unfortunately, it is very difficult to make a good profit from ethanol on the coasts (SECO, 2008). This is one reason why ethanol from corn is not the future feedstock. Ethanol from sources other than corn could be grown anywhere in the country and processed into ethanol without having to travel over 2000 miles to its destination.

## **Growing technology**

Technology in the field of ethanol production has been growing at a rapid pace since the Energy Policy Act of 2005, which gave a significant amount of money towards research. The ultimate goal is to produce ethanol quickly and efficiently from vegetation, also known as cellulosic biomass. The rate of increase in technology was much faster after the enactment of Pro-Alcohol than before. This will be similar to the United States after the enactment of the Energy Policy Act and The Energy Independence and Security Act because of the amount of money and tax incentives poured into research. Ethanol production is still research in progress.

Turning corn into ethanol is much different than turning sugarcane juice into ethanol. The corn can be either dry milled or wet milled before it goes through fermentation while sugarcane is crushed with the juice extracted straight into fermentation. However, turning corn stover into ethanol is identical to turning sugarcane bagasse into ethanol because they are both lignocellulosic materials. Though the percentages of cellulose, hemicelluloses, and lignin are different, both corn stover and sugarcane bagasse need to be pretreated, hydrolyzed, fermented, and distilled in similar fashions. The ultimate goal is a process to turn lignocellulosic material into ethanol by an economic and efficient process. Brazil has had some success in research of different ways to make ethanol.

There are a few processes that have worked well in converting sugarcane bagasse into ethanol in Brazil. The biggest problem with pretreatment processes is implementing them on a large scale. Methods such as steam pretreatment and pyrolysis can be effective on a large scale. Soaking the bagasse in hydrogen peroxide for lignin removal can also be effective with large amounts of bagasse. However, the most effective way to pretreat bagasse may be a combination of two or three methods in order to separate the cellulose, hemicelluloses, and lignin. Research has shown that complete separation of the cellulosic biomass yields the

highest amount of simple sugars available for fermentation. Research in the hydrolysis area requires lots of experimentation with strong acids, weak acids, and different enzymes. However, past studies have shown that enzymatic hydrolysis is the method of choice for cellulose while acid hydrolysis is the best choice for hemicelluloses. After hydrolysis, the two paths (one for the juice/corn and the other for the bagasse/stover) meet for fermentation and distillation. The fermentation process is still efficient, but it can be made more efficient with research for temperature of the beer, cooling of the beer, sugar concentration in the beer, and other variables.

## **Corn is not the answer**

The primary feedstock used for over 95 percent of ethanol in the United States is corn. Corn is mostly grown in the Midwest in states like Iowa, Ohio, and Illinois. Although corn is the most inefficient feedstock, it is used across the country because it is the most economical for farmers on account of government subsidies for production and consumption of corn-based ethanol. Corn is still one of the most expensive feedstocks to use for ethanol production. The processes used to convert corn into ethanol are not environmentally friendly. Corn is not very profitable, but farmers can make more money off corn than other crops such as wheat and sorghum. Corn is not very efficient and there is not enough of it across the country to supply the country with ethanol. Therefore, corn is not the final answer to the ethanol problem but it is the only solution until a better feedstock becomes readily available.

Corn is not an efficient means to produce ethanol because the energy required to make ethanol from corn is too high when compared to the energy output from a unit of ethanol, whose inputs are shown in Table 6.1. Studies have shown that the energy balance of corn is as low as 1.3 to 1 which means for every unit of energy put into making ethanol, 1.3 units of energy come

out of using ethanol (Scott, 2007). This energy balance is not good when it is compared to sugarcane-based ethanol whose energy balance is between 8-10 to 1 or even gasoline with an energy balance of about 5 to 1. The energy input to make ethanol from corn comes from coal and gasoline that are not environmentally friendly. The main reason for the low energy balance of corn is the chemical structure of corn versus sugarcane juice (excluding the corn stover and sugarcane bagasse). One kilogram of corn will not yield the same amount of simple sugars as a similar amount of sugarcane sap. One study suggests that once the technology is available, cellulosic biomass such as switchgrass could have an energy balance of over 7 to 1 (Schmer et al, 2007). With current technology, it could achieve an energy balance of 3-4 to 1. A more efficient feedstock would make ethanol a more attractive alternative fuel source.

**Table 2. Inputs Per Gallon of 95% Ethanol Produced from Corn<sup>a</sup>**

Inputs	kg	BTU	Dollars
Corn	10.2 <sup>b</sup>	40,221 <sup>b</sup>	\$0.69 <sup>b</sup>
Transport of corn	10.2 <sup>b</sup>	4,727 <sup>c</sup>	0.22 <sup>d</sup>
Water	601 <sup>e</sup>	1,353 <sup>h</sup>	0.08 <sup>d</sup>
Stainless steel	0.023 <sup>e</sup>	1,348 <sup>e</sup>	0.04 <sup>d</sup>
Steel	0.045 <sup>e</sup>	2,106 <sup>e</sup>	0.04 <sup>d</sup>
Cement	0.12 <sup>e</sup>	909 <sup>e</sup>	0.04 <sup>d</sup>
Coal	1.40 <sup>f</sup>	39,076 <sup>f</sup>	0.08 <sup>g</sup>
Electricity	0.91 kWh <sup>f</sup>	9,379 <sup>f</sup>	0.06 <sup>g</sup>
Pollution control costs	—	—	0.23 <sup>d</sup>
<b>TOTAL</b>		<b>99,119</b>	<b>\$1.48</b>

<sup>a</sup> Outputs: 1 gallon of ethanol = 77,000 BTU

<sup>b</sup> Table 1.

<sup>c</sup> Estimated (90 mile roundtrip).

<sup>d</sup> Pimentel and others (1988).

<sup>e</sup> Slesser and Lewis (1979).

<sup>f</sup> Larry Johnson (personal communication, Delta-T, 2001).

<sup>g</sup> USBC (2001).

<sup>h</sup> Pimentel and others (1997).

Table 6.1: Energy required to make a gallon of ethanol. This study shows that the energy input is greater than the energy output from ethanol produced from corn. Although the processes in today's environment require less energy, the inefficiency to produce corn-based ethanol is still shown (Pimentel, 2003).

## Water consumption- a problem

Another contrast between ethanol from sugarcane versus corn is the use of water. Ethanol plants in Brazil use a lot of water, but the use in the United States is even higher. Corn takes a significant amount of water to grow as opposed to sugarcane. Fifteen percent of cornfields are irrigated in addition to natural rainwater (Pimentel, 2003). In Brazil, rainwater is

sufficient to grow the sugarcane even in the desert areas of Brazil. Different ethanol plants in the United States use different amounts of water to produce ethanol. Most plants range anywhere from 3.5 to 6 gallons of water. Wet milling of corn requires additional water use as opposed to sugarcane sap. The best estimate of water use for every gallon of ethanol from corn produced is about four gallons although the Renewable Fuels Association estimates three gallons (Keeney and Muller, 2006). This number has dropped within the last 10 years because of better technology, but still remains much higher than that of Brazil's ethanol plants. As more ethanol becomes produced, more water will be required in order to keep up with the increasing demands. Figure 6.3 illustrates the increasing water needs of US ethanol plants. One suggestion is to build ethanol plants near wastewater facilities because most ethanol plants have water treatment facilities that can process the wastewater so that it can be used for ethanol production (Keeney and Muller, 2006). A process such as this could cut down on the amount of water needed by the ethanol plant.

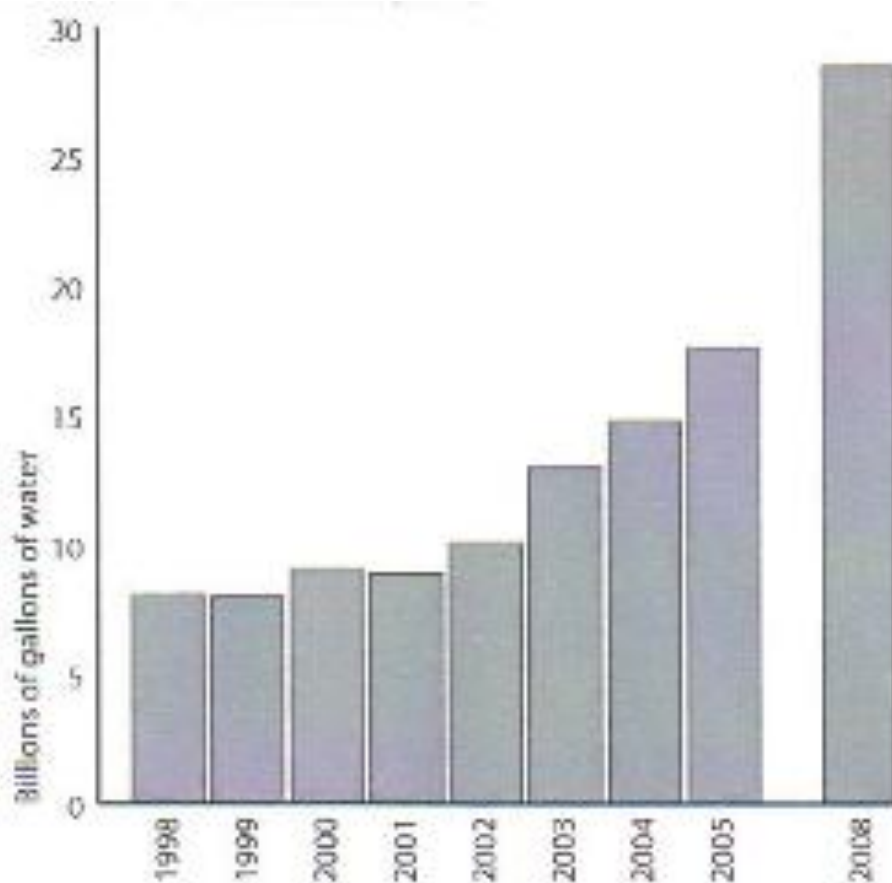


Figure 6.3: Total water use by all ethanol plants in the United States. The number for 2008 (around 30 billion gallons) is a prediction made by the authors from 2006 (Keeney and Muller, 2006).

### **For combustion or consumption?**

Another issue with using corn for ethanol is the fact that it takes up land used to grow other crops. Brazil does not have this problem because it has lots of land that could be expanded to grow other crops. The United States does not have additional unused land that is conducive to growing corn. Because more corn is needed to produce ethanol, crops such as wheat, sorghum, and barley are sacrificed to grow more corn. Farmers are going to grow the crop that yields the most profit, and corn is that crop because of the government subsidies as well as the increasing demand. While the number of acres of corn planted each year is



continuing to rise, the statistics show that other crops are suffering because of the demand for ethanol. The total acreage for sorghum in the United States was over 10 million acres in the 1980's, but is down to less than 6.5 million acres in 2005. Even crops that could also be used to make ethanol are declining such as barley and oats. Barley has declined from over 13 million acres in the mid 1980s to less than 4 million acres in 2005. Oats have declined from over 12 million acres in the 1980s to barely over 4 million in 2005 (Shapouri and Salassi, 2006). The amount of corn grown in the country has gone up every year since 2002 and is expected to be over 90 million acres in 2008.

The biggest argument against ethanol produced from corn is food versus fuel. The two uses for corn are food and ethanol (fuel). Figure 6.4 shows the increasing percentage of the corn harvest used to make ethanol from 1980 onward. By choosing ethanol over food, the corn supply used for food starts to diminish. There has been much debate over the cause of the price increase in corn, but the main source is the rising price of oil. The price of oil not only initiated the push for ethanol (and therefore the use of corn), but the price of corn is also directly related to the price of oil. One study shows that one acre of corn requires 110 gallons of gasoline to harvest, meaning that more expensive gasoline creates more expensive corn (Scott, 2007). Because the United States exports over 65 percent of its corn all over the world, the price of exported corn increases because the planes, boats, and trucks that export the corn are using more expensive gasoline on account of rising oil prices. However, simple economics dictates that a reduced supply (corn used for ethanol instead of food in this case) with a constant demand will increase the price of the product. The final result is that the price of corn increased from \$3.05 per bushel in January 2007 to \$4.83 per bushel in March 2008 (Texas Comptroller of Public Accounts, 2008). When the price of corn starts to increase, any process or animal that uses corn will also increase. Dairy and meat products increase as a result of the price of corn increasing because cows eat corn. The price of feeding a hog increased 85

percent in 2007 (Scott, 2007). This hurts the small farmer who is trying to rent or buy some land because prices are increasing. With the number of chronically hungry people increasing every day, the debate over food versus fuel should certainly continue until there is a better way to produce ethanol.

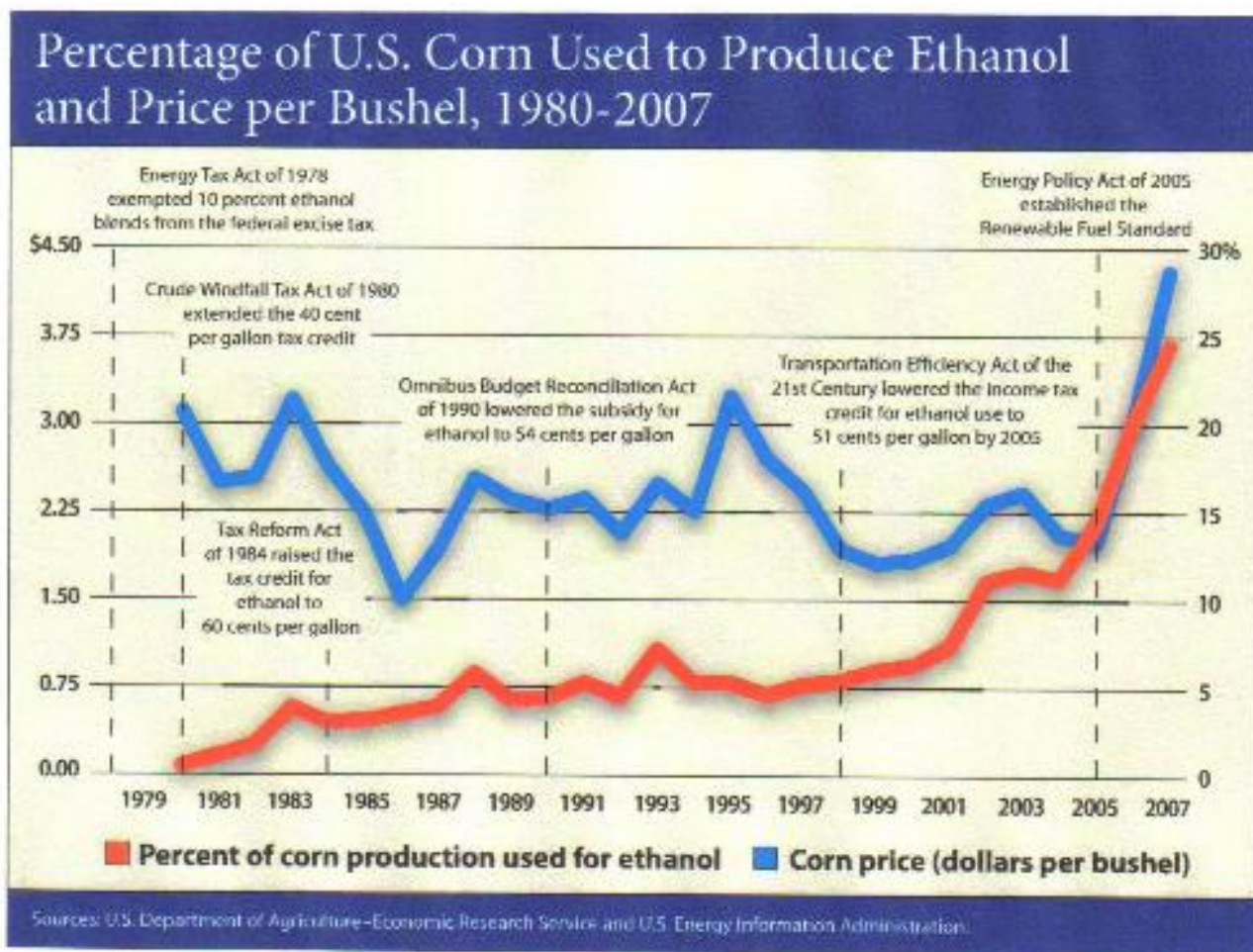


Figure 6.4: Price of corn and percentage of corn used for ethanol from 1980-2007. Both numbers fluctuate until 2005 when both start to dramatically increase (Texas Comptroller of Public Accounts, 2008).

### An E85 world in the US?

Although current technology does not allow the United States to fully give up oil, many wonder what the country would be like if all gasoline was replaced with E85 ethanol from corn.

The following is a quick and easy simulation to see how many acres of corn would be needed to fully supply the country with E85 gasoline from ethanol disregarding 15 percent gasoline still needed to accompany the 85 percent ethanol. According to the Energy Information Administration (2008), consumers in the United States consumed about 377.5 million gallons of motor gasoline per day that accounts to 137.8 billion gallons total in 2007. This does not include diesel, kerosene, or other products produced from oil. Given that E85 is about 70 percent efficient as normal gasoline, the E85 equivalent number to that amount of gasoline is 192.9 billion gallons of E85. Because this fuel is 85 percent ethanol, the amount of ethanol in this fuel is 164 billion gallons. Assuming that the ethanol content is not 85 percent year round because ethanol cannot start an engine in the cold weather, this number can be decreased to roughly 150 billion gallons. Studies suggest that one acre of land can create anywhere from 2.5-2.8 gallons of ethanol, meaning that the lowest number of acres to meet the requirement is 55.5 billion acres. Given that the area of the United States is roughly 2.5 billion acres and assuming all the corn goes directly to ethanol production, that kind of ethanol demand requires an area of land 22 times the United States to fully stock the country with enough E85 for motor vehicles. This does not even touch on the amount of water (4 gallons per 1 gallon ethanol), the amount of ethanol plants needed, or the amount of labor and money required to keep up such a demand. Needless to say, this simulation is not accurate but does give a general idea of the amount of land and labor required to keep the country running on ethanol.

Although ethanol from corn is not the final solution, it is an important stepping-stone towards a better future. Although the processes that make corn into ethanol are almost fully developed, other feedstocks that could be more beneficial than corn await research. If research progresses like it has in Brazil, the United States will be just fine. It would be very unwise to fully abandon the ethanol program because it does have immediate benefits. It does supply well paying jobs here in the United States instead of importing foreign energy. One report

suggests that in 2007 alone, the ethanol industry created or made plans to create 240,000 jobs and add 47.6 billion dollars to the GDP (SECO, 2008). The ethanol program clearly shows that the United States is geared towards energy independence. Once the correct technologies become available, ethanol will be easier and more efficient to produce. As shown in Figure 6.5, switchgrass could potentially create 3 times the ethanol in the same amount of area using less energy that is incredibly important to the United States, which does not have any free area to use for farmland like Brazil. Should switchgrass become available with efficient technology, two out of every three acres of corn used for ethanol could go towards food production while the third out of the three acres could be converted to switchgrass and still meet the ethanol demand. There are some concerns of switchgrass being used instead of corn, particularly environmental because it does degrade the soil and hinder other ecological processes (James et al, 1997). However, the efficiency of switchgrass makes it a very popular choice over corn.

Ethanol is not the solution to the energy crisis faced in today's society, but it is a key component in the equation. The solution will most likely include many different components such as hydrogen fuel cells, solar power, nuclear power, and wind power in addition to ethanol. Although renewable resources represent only about six percent of all energy, new ideas are being researched every day. As with Brazil, the road to energy independence is not easy, but the United States is on the right path.

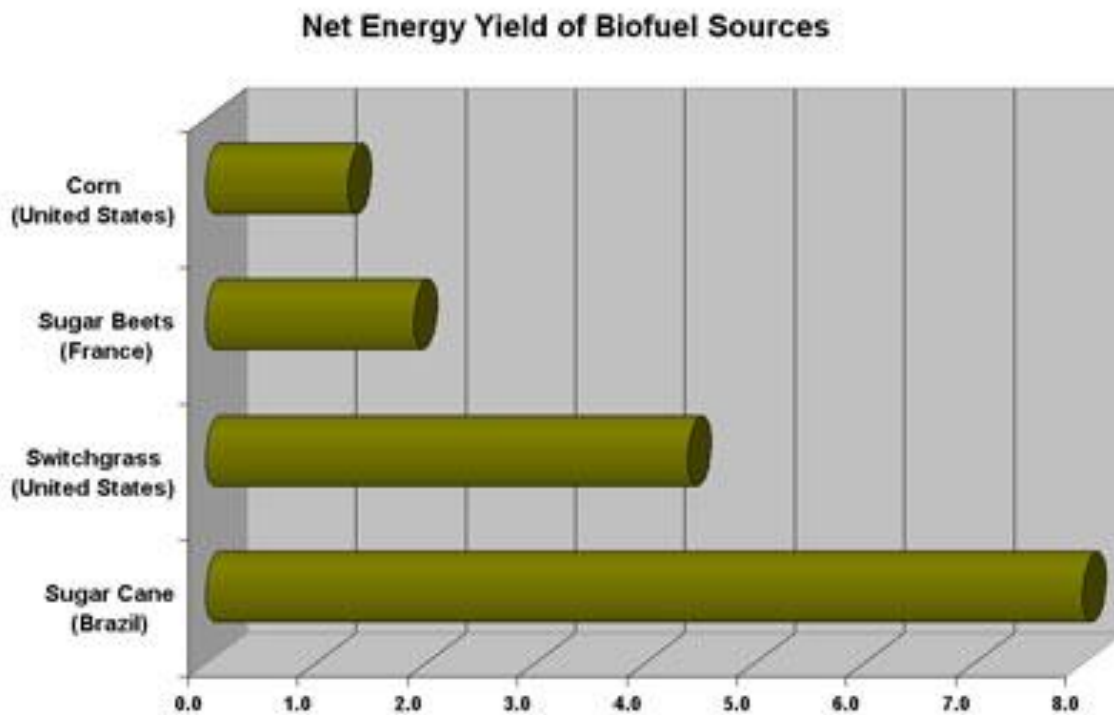
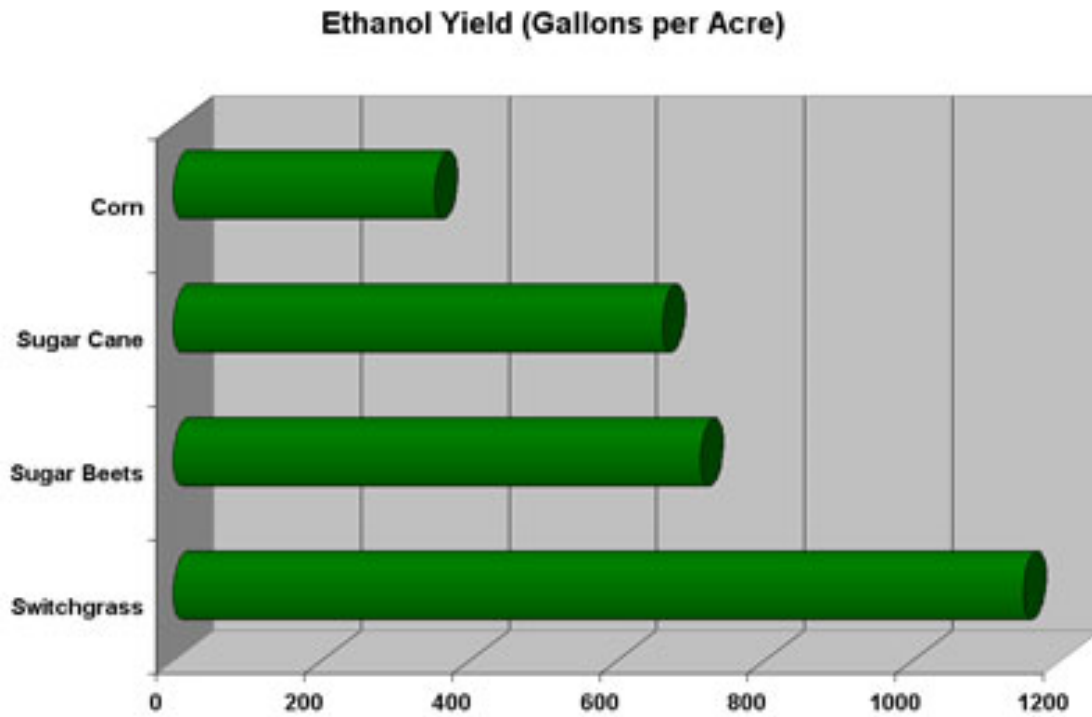


Figure 6: Net energy yield and ethanol yield per unit land for four different feedstocks (Butler, 2006).

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