Historical Case Studies of Energy Technology Innovation

CASE STUDY 13: ETHANOL (BRAZIL).

BRAZILIAN ETHANOL: UNPACKING A SUCCESS STORY OF ENERGY TECHNOLOGY INNOVATION

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AUTHORS' SUMMARY

Brazil's First Ethanol Program (ProAlcool), launched in 1975, was a direct response to the dramatic rise in imported petroleum prices in 1973. The military government of the time saw this as a challenge to Brazil's financial stability and energy security, since the country imported 80% of the fuel used by its transport sector. Moreover, Brazil had extensive sugar plantations that were facing increased challenges to their exports from European Union trading preferences with African, Caribbean, and Pacific countries and the emergence of corn syrup and other close substitutes for sugar.

ProAlcool was initially a classic import substitution policy. Subsidies were used to expand ethanol production, then in its infancy, and to induce vehicle users to shift to dedicated engines for ethanol that could handle a gasoline blend with more than 5-10% ethanol. When gasoline prices fell a few years later, those who had shifted were left paying the higher costs of ethanol, while the original problem of oil imports remained.

In this changed context, the government decided to invest in the research needed for Brazil to become a more efficient ethanol producer and thus be in a position to eventually eliminate subsidies. At the core of this process was a research partnership that brought together the Brazilian Agricultural Research Corporation and Copersucar, a cooperative of sugar mill and ethanol plant owners. Between 1975 and 2002, ethanol production increased from 0.6 to 12.6 million cubic meters and the price paid to alcohol producers dipped below that of Rotterdam gasoline prices (Goldemberg et al., 2004). By early in the new millennium, increasing yields and reduced processing costs (van den Wall Bake et al., 2009) had eliminated the need for subsidies. The decision to develop flex-fuel engines, in collaboration with foreign-owned automobile producers, strengthened the domestic auto industry and led to a dramatic

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shift in consumption habits and practices, thus further building the market. Introduced in 2003, flex-fuel vehicles accounted for 81% of the light vehicle registrations by 2008 (ANFAVEA, 2008).

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1 INTRODUCTION

The Brazilian ethanol industry is often held up as an exemplar of successful energy technology innovation and renewable energy policy. Owing to its long growing season and abundance of fertile land, Brazil is naturally suited to agricultural energy production. However, many tropical nations are similarly endowed. What has set Brazil apart as an ethanol producer is a long-term, consistent policy, drawing on multiples sectors of society, in support of ethanol production. As the world considers biofuels as a partial solution to a host of energy challenges, and as other nations consider trying to replicate the Brazilian experience, it is important to analyze or 'unpack' the factors behind this innovation history.

The co-incidence of the oil price hikes and export challenges faced by Brazil's sugar producers triggered the development of Brazil's ethanol program, ProAlcool, in 1975. This case study analyzes the rationale for the Brazilian decision to develop ethanol production from sugarcane in the 1970s based on both distinctive historical experiences as well as established actors. When the price of gasoline fell in the 1980s the market for ethanol collapsed, but Brazil did not abandon its ethanol pathway. Through a process of policy learning within government, and the development of knowledge networking with and within in the private sector, the initial supply-side emphasis was widened to include the demand for ethanol in the transportation sector. Over the next twenty five years this evolving strategy has resulted in a continued market expansion of Brazil's ethanol sector and has laid the foundation for the emergence of an innovative biofuels industry.

This case study considers these various sides to the innovation history of Brazilian ethanol. First, we provide a chronology of the main periods in the development of Brazilian ethanol, paying particular attention to the actors and institutions behind ethanol policy as well as to the vehicle technologies that have allowed ethanol to become widely adopted as a transportation fuel in Brazil. Second, we analyze the advances in agricultural and industrial systems that improved the productivity of Brazil's ethanol economy to high levels and have been associated with the declining production cost profile of ethanol. Third, we unpack the economic dimensions of the ethanol program to provide a more critical picture of its economic success and overall cost than is frequently advanced in the literature.

2 HISTORY OF BRAZILIAN ETHANOL

2.1 Pre-1975: Historical contingencies

The Brazilian ethanol program was built in the 1970s on three historical foundations: (1) the location and concentration of the Brazilian sugar industry; (2) a long history of ethanol production during periods of crises and as a way of countering sugar price volatilities; (3) the political economy of Brazil in which industrial and energy policies have been shaped strongly by recurring military governments. Throughout these historical developments important institutions and actor networks were formed that constituted the nexus of the ProAlcool Program introduced in the 1970s.

Sugar has been a defining agricultural commodity for Brazil ever since the establishment of the first Portuguese colony in 1531. Initially located in the northeast, the sugar industry has been concentrated in the southwest of Brazil in the state of São Paulo ever since World War I. Brazil's sugar industry has traditionally been highly concentrated: in a geographical region as well as in large plantations and sugar producers. In the 2008/2009 growing season, for example, the 45 largest sugar cane producers in the state of São Paulo accounted for 50% of total production, and the 100 largest producers for over 82% (UNICA, 2012). This concentration provided for localized learning and spillover effects in adoption of institutional and technological innovations, further enhanced by the ease of access to knowledge, technology and capital enjoyed by very large-scale sugar producers. In 1959, a small number of sugar growers and ethanol producers from São Paulo founded a cooperative, Copersucar, set up to commercialize the sugar and ethanol production of its associates. Its members were also cognizant, however, of the need to develop new sugar varieties and thus improve productivity which, at about 42 tonnes per hectare, was well below the yields of 80 tonnes per hectare produced by their competitors abroad (Wilkinson and Sorj, 1992). The Copersucar Technology Center (CTC) became a powerful actor and an important center of research in the sugar and ethanol industry.

For much of its early history, ethanol production was used primarily as a means of stabilizing sugar prices or responding to energy crises during wars. The Institute for Sugar and Alcohol (IAA), formed in 1933, was a regulatory agency that regulated prices and set quotas for both sugar and ethanol production, and after 1965, also levied export fees to finance the modernization of Brazil's sugar industry. Ethanol had an important role to play as a fuel, especially during the First and Second World Wars when imported gasoline was scarce. Production levels of 650 million liters from 1941 were only reached again in 1976 (EPE, 2006; Goldemberg, 2009). However, the distilleries controlled by the IAA functioned mainly to remove excess sugar from the market in order to stabilize sugar prices at supported levels (Barzelay, 1986). As a result, the industry was well positioned to rapidly expand ethanol production under the ProAlcool Program.

The historical context of Brazil's political economy also deserves special attention. Two historical milestones in Brazil's ethanol experience were initiated by authoritarian or military governments. The very first mandatory ethanol gasoline blend (5%, or E5) was instituted by the first Vargas government in 1931 (Vargas having come to power in a coup d'état in 1930) and the 1975 ProAlcool Program was instituted by President Ernesto Geisel, under a military government. Geisel was deeply familiar with energy issues, having formerly been President of Petrobras, the state owned oil company, created under the second Vargas government in 1945. The political and institutional stage was thus set for launching an ambitious ethanol program in the 1970s as a twin response to the oil price hikes as well as collapsing sugar export markets and prices.

2.2 Phase 1, 1975-1979: Saving the sugar industry

Although sugar and alcohol production has a long history in Brazil, the modern ethanol program began when the National Alcohol Program, ProAlcool, was established in 1975. At the time, Brazil was heavily dependent on imported petroleum, and the quadrupling of oil prices in 1973-74 contributed to a foreign debt crisis and brought an end to several years of rapid economic growth that had come to be known as the "Brazilian miracle."

At the same time that oil price shocks were damaging the Brazilian economy, radical changes in world sugar markets were exacerbating the country's economic problems. Brazil had responded to high world sugar prices in the early 1970s by expanding production capacity. In 1975, sugar prices collapsed. In February of that year, a trade and aid agreement between the European Community and 71 African, Caribbean and Pacific countries gave the latter preferential access to the European market for sugar, reducing opportunities for Brazilian sugar exports. In the United States, the other major market for sugar, the food processing industry was then beginning its conversion to corn syrup, a close substitute for sugar in soft drinks. This confluence of factors left Brazil with excess mill capacity and a reduced ability to earn foreign currency.

In response, President Geisel created the Programa Nacional de Álcool, known as ProAlcool. This program was intended to both reduce Brazil's dependence on imported oil and make use of idle capacity in the sugar industry by converting sugar to ethanol. The IAA, Copersucar, and Petrobras were the principal institutions and actors involved in the creation of the ProAlcool program (Bertelli, 2011; BNDES and CGEE, 2008).

ProAlcool was a classic import substitution policy that focused on increasing the sugarcane output of producers at the same time as it maintained low ethanol prices for consumers. Because of Brazil's long history of producing ethanol from sugar, the first phase of the ProAlcool program required few major technical or institutional innovations. Ethanol was initially simply blended with gasoline at rates of 5-10% (E5-E10) which can be used in unmodified gasoline engines and does not require significant modifications at gasoline distribution stations. Ethanol produced and sold in Brazil comes in two qualities: hydrous or containing water (typically some 5%) and anhydrous or not containing water (with the water removed chemically after distillation). The introduction of anhydrous ethanol allowed the ethanol/gasoline blend to increase to 20-25% (E20-E25 being currently the market norm in Brazil with pure gasoline not sold at all).

The government incentivized ethanol production with low interest loans to expand mills and distilleries, guaranteed prices set at the average cost of production, and created demand through blending mandates. At the same time, research into new varieties of sugarcane was carried out by the quasi-governmental agricultural research agency, EMBRAPA, the IAA's research arm, Planalsucar, the Copersucar Technology Center (CTC), and the Campinas Institute of Agronomy (IAC). Petrobras was granted a monopoly on ethanol distribution. Given Petrobras' experience as a gasoline retailer, this helped to speed up the introduction of ethanol and also assured Petrobras' strong integration into the ethanol actor network. During this phase of the ethanol program, sugar cane production increased by 50% and ethanol production quintupled to 2.8 billion liters. At the same time, domestic research on (hydrated) ethanol only engines was stepped up, with the Brazilian government pushing and subsidizing (the initially reluctant) auto companies to develop engines capable of running on 100% ethanol. This innovation effort culminated in 1979 with the commercial introduction of the first pure-ethanol vehicle, a Brazilian Fiat 147.

2.3 Phase 2, 1979-1985: Continued expansion and innovation

By 1979, the period of easy growth was over. Excess sugar supply capacity had been utilized, and enough ethanol was being produced to provide the nation with an 80/20 gasoline-ethanol mix which was as much ethanol as the conventional gasoline-powered vehicles could accept. In order to support continued growth, the nation's vehicle fleet would need to shift toward ethanol-only vehicles, and a new fuel pump infrastructure would need to be built for them. During the first half of 1979, with earlier production targets having been met, ethanol policy was at a standstill.

In the summer of 1979, OPEC announced a 37% oil price increase which led to the second oil price shock, and the second phase of the ethanol program began. The government announced that ethanol pump prices would be fixed at 59% of the price of gasoline, and that ethanol-only vehicles would be subject to lower sales taxes and licensing fees than conventional vehicles. As shown in Figure 2 below, ethanol-only vehicles were an immediate success, accounting for more than a third of new vehicle sales in 1980, and virtually all of new vehicle sales by 1985 (Furtado et al., 2011).

Petrobras built a distribution and pump infrastructure for pure, as opposed to blended, ethanol. Foreign and domestic automakers, under pressure from the government, started manufacturing ethanol-only vehicles. By 1985, virtually all new vehicles sold in Brazil ran on pure ethanol. During this phase of the program, ethanol production quadrupled to 12.8 billion liters (see **Error! Reference source not found.**). In 1980, domestic ethanol costs were three times higher than international spot market prices or import costs for gasoline (Goldemberg, 2009:94). Yet dedicated efforts to improve the economics of domestic ethanol production were not deemed necessary, as conventional wisdom at that time assumed ever escalating oil prices which would ensure domestic ethanol would soon become cost competitive with imported crude oil and gasoline.

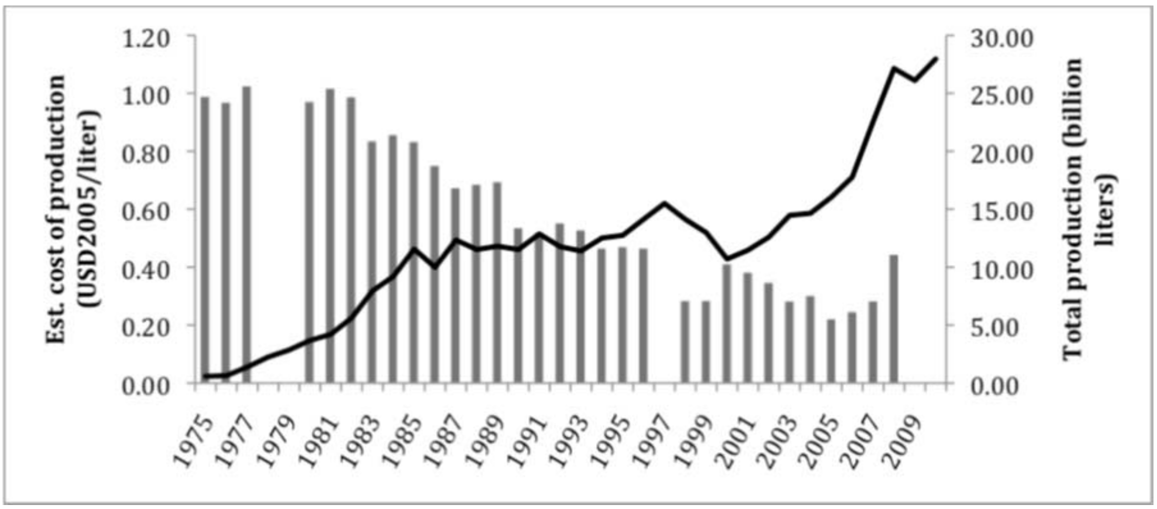

Figure 1. Increasing Ethanol Production (Billion Liters) At Decreasing Cost (US$2005/Liter). Notes: Brazilian ethanol costs are highly sensitive to the exchange rate in the base year chosen (2005), although the cost dynamics over time invariably show a significant reduction during the period 1975-2000, and a stationary, albeit fluctuating trend thereafter (see text for discussion). Sources: Production data (1975-2010) from EPE, 2011; Production cost data (1975-2004) from van den Wall Bake et al., 2009, and (2005-2008) from Valdes, 2011.

2.4 Phase 3, 1985-2003: Uncertainty and Crisis

As the military dictatorship gave way to civilian government in 1985, Brazil entered a period of economic difficulties, including a debt crisis, an IMF-imposed austerity program, and hyperinflation. Struggling to control prices throughout the economy, the government reduced guaranteed prices for ethanol to below the cost of production (Goldemberg et al., 2004), and ethanol output fell for the first time since the program began. When oil prices tumbled in 1986-1987, making ethanol increasingly uneconomic, the government banned the construction of new distilleries (Sperling, 1988).

At the same time, world sugar prices recovered, and by 1990 producers were increasing sugar exports even as ethanol output stagnated. Ethanol shortages caused high prices and long waits for drivers of

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ethanol-only vehicles, and Brazil was forced to import ethanol from overseas. Pure ethanol vehicle owners were put at considerable economic disadvantage, compounded by emerging technical performance issues with pure ethanol engines, including the inability to start in cold temperatures and the requirement of more frequent refueling. Consumers lost confidence in the future ethanol supply, and the purchase of ethanol-only vehicles collapsed (see Figure 2).

Although ethanol production stayed within the 10-15 billion liter range from 1985 until 2003, reduced subsidies caused the industry to consolidate and increase production efficiency markedly during this period. Goldemberg (2009: 94) reports a doubling of yields from some 3000 to 6000 liters ethanol per hectare. Production costs declined significantly through a concerted effort throughout the entire value chain involving research, yield increases, economies of scale in ever larger distilleries as well as the utilization of bagasse (a byproduct) for electricity generation. Prices were deregulated for anhydrated ethanol used for blending in 1997 and for hydrated ethanol in 1999. Deregulation left blending mandates and relatively high taxes and price controls on gasoline as the major tools with which the government intervened in the ethanol market (Goldemberg et al., 2004).

2.5 Phase 4, 2003-Present: Flex fuel vehicles

Following this period of relative stagnation, standard gasoline engines were reestablished as the norm (see Figure 2). The ethanol program was revived in 2003 with the introduction of flex-fuel vehicles (FFVs). The first (full) flex-fuel car commercially introduced in Brazil was the Volkswagen Gol(f) 1.6 Total Flex. Encouraged by the Brazilian government, this innovation was introduced by the Brazilian subsidiaries of major international car companies such as General Motors and Fiat as well as Volkswagen, drawing both on indigenous R&D as well as international knowledge and technology spillovers (the Model T Ford produced between 1908-1927 had flex-fuel features).

Flex-fuel vehicles (FFVs) were priced competitively with traditional gasoline automobiles (predominantly via government incentives) and allowed consumers to choose the desired blend ratio. FFVs can take pure gasoline, pure ethanol, or any mix. On-board sensors determine the fuel mix and adjust operation accordingly. A significant cost cutting innovation was the introduction of post combustion (tailpipe) sensors for establishing the gasoline/ethanol blend of the fuel, as opposed to the previous dominant (and expensive) design of pre-combustion (tank/fuel supply) sensors.

The government incentivized the purchase of FFVs with the same policies that earlier had been used to increase sales of ethanol-only vehicles, including favorable tax treatment at the point of purchase, and reduced annual licensing fees. Presently, over 90% of new passenger vehicle sales in Brazil are flex-fuel vehicles (see Figure 2) allowing consumers to make decisions, based on price and other factors, about which fuel to use at any given time. FFVs thus resolved the issue that led to a collapse in consumer confidence when oil prices collapsed in the late 1980s and early ‘90s. Consumers now have the ability to choose the most economical fuel at any given time, and therefore are no longer vulnerable as they once were to price spikes or fuel shortages. The rapid proliferation of FFVs in Brazil shown in Figure 2 is the most critical development in the recent success of the Brazilian ethanol program. Importantly, the vehicles were made available at a time of record-high petroleum prices, meaning ethanol was frequently the cheaper option of the two fuels.

Because ethanol has a lower energy content than gasoline, ethanol pump prices have to be lower compared to gasoline in order to be competitive. For much of the last decade, the price ratio of ethanol to gasoline has hovered around 60% (Valdes, 2011). This price ratio is a result of, on the one hand, increased efficiencies in the ethanol value chain, and on the other, gasoline price controls and relatively high gasoline taxes (read: preferential fuel tax treatment of ethanol). In other words, although ethanol prices are no longer regulated or kept artificially low, ethanol is competitive at the pump largely due to a preferential tax regime. A defining characteristic of Brazil's fuel taxation is that it is regionally differentiated (i.e. determined at state levels). The price spread between gasoline (E25 mixture) and pure ethanol varies across states, and generally has been largest in the center of the sugar industry, the state of São Paulo, and lowest in the Amazonian periphery (UNICA, 2012).

Market conditions in 2011 demonstrated the resilience of the transportation fuels sector in Brazil. High world sugar prices that year led producers to divert feedstock into sugar production. At the same time, heavy rains led to poor sugarcane harvests. Because of the flexibility inherent in the FFV fleet, consumers did not suffer shortages or price spikes. Meanwhile, incipient ethanol shortages were managed through decreased blending ratios and corn ethanol imports from the U.S. (Almeida and Dreibus, 2011).

Whereas ethanol imports in the 1990s signaled a crisis in Brazil's ethanol program, imports in 2011 are perhaps a sign of the program's success. Ethanol has become an important transportation fuel in many countries, in no small part because Brazil has demonstrated its viability. Furthermore, the international market for ethanol is becoming less restricted, as evidenced by the recent elimination of import tariffs in Brazil and the US. As the international market for ethanol grows, Brazil is well-positioned to be a major supplier to the world, although recent ethanol price escalation trends in Brazil and an ever appreciating currency undermine export potentials and competitiveness particularly with respect to subsidized production like US corn ethanol.

From 1975 to the present, Brazil has maintained policies that have nurtured the ethanol industry by both subsidizing supply and creating demand. Whether Brazilian ethanol can compete favorably on price with gasoline depends in large part on exchange rates, among other factors. But economies of scale and technological improvements have brought costs down enough that ethanol is and will likely remain an important transportation fuel, not only in Brazil but also in the US and Europe, for the foreseeable future.

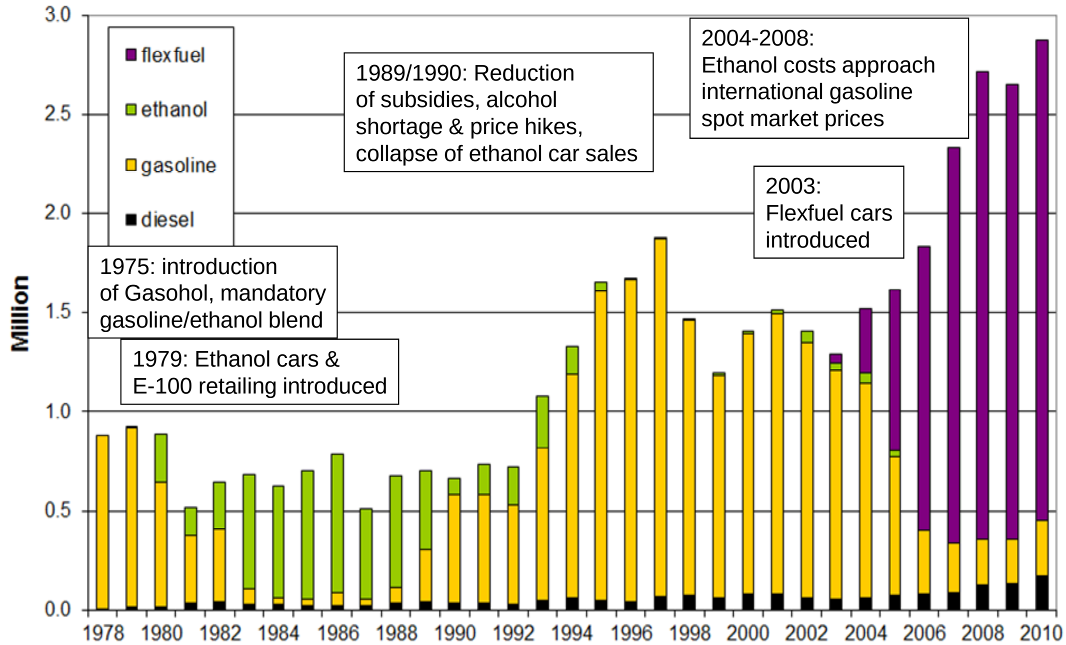

FIGURE 2. LIGHT VEHICLE REGISTRATION IN BRAZIL (MILLIONS PER YEAR) PER VEHICLE FUEL TYPE. NOTES: POLICY MILESTONES ALSO INCLUDED. SOURCE: ANFAVEA, 2008; 2012).

3 LEARNING & COST REDUCTIONS

Production costs of ethanol from sugarcane in Brazil have declined by 70% over the last thirty-five years (van den Wall Bake et al., 2009). In the first phase of the ProAlcool program, the largest impacts on cost originated throughout the ethanol production process – from agricultural development, production, and distribution. The majority of cost reductions stemmed from increasing agricultural yields and decreasing industrial costs, and also the use of bagasse (the sugarcane left over after extraction of sugar juice) for industrial heat and electricity generation.

Cost reductions are thus the result of multiple interacting factors, including R&D based innovation (e.g., in yield increases), economies of scale (e.g., in distillation plants), as well as the demand-pull induced ‘learning by doing’ effects. The innovation history of Brazilian ethanol demonstrates the importance of multiple factors influencing cost and technological innovation whose success lies precisely in their combined effect. Though the initial demand-pull policy efforts were necessary to establish the foundation of a market, the heart of ethanol’s success in Brazil were the significant cost reductions that arose from technology innovations at the agriculture stage, distillation/refining stage, and FFV automobile engines. Post 2000 price trends in Brazilian ethanol indicate no further significant cost improvements.

3.1 Increasing Agricultural Yields

Agricultural production of sugar cane has been an important part of the Brazilian economy for centuries. Producers constantly search for methods to increase yields or reduce input costs, but it was not until the initiation of ProAlcool that substantive agronomical research was dedicated to increasing sugarcane yields.

The result was improvements at every stage of agricultural production (see Table 1). New varieties of cane have been developed, many of which were designed via genetic hybrid technology and ideally suited for certain regions or growing conditions. Planting of cane, which utilizes a ratoon system that allows for more than one harvest from a single planting, has been increasingly mechanized throughout the past thirty-five years. Similarly, cane harvesting, long a labor-intensive and dangerous process when done by hand, is slowly transitioning to mechanical harvesting. Fertilizer application, soil preparation, and residue management have been optimized, as has transportation from farm to distillery, minimizing loss of 'total reducible sugars'. Combined, these efforts have resulted in yield increases of up to 60%.

Yield improvements have been bolstered by the development of more sophisticated accounting and systems management tools now employed by cane producers to optimize the timing of operations.

Table 1. Comparison Of Cost Structure Of Brazilian Sugarcane In 1976 And 2005. Notes: cost structure shown in US$2005 per tonne cane (TC) and in percent. Source: van den Wall Bake et al., 2009.

	Costs [US$(2005)/TC]		Cost reduction (%)
	1976	2005	1976-2005
Land rent	7.33 (20%)	2.60 (21%)	64%
Soil Preparation	9.78 (27%)	2.33 (19%)	76%
Stock Maintenance	7.47 (21%)	3.31 (27%)	58%
Harvest – Loading	5.97 (17%)	2.47 (20%)	59%
Transport	5.22 (15%)	1.66 (13%)	68%
Total	**35.77 (100%)**	**13.09 (100%)**	**65%**

3.2 Decreasing Industrial Costs

The primary objective of the industrial milling process is to extract the maximum amount of sugar from the harvested cane. This process involves extensive mechanical and chemical processes that result in an 80-90% yield efficiency. After treatment, the extracted sugar juice is fermented and subsequently distilled into alcohol. Remaining water is removed via a chemical process in the case of anhydrous alcohol.

The production of bioethanol is hardly different from the production of any alcohol spirit. The general technology for converting sugary liquids to alcohol has existed for centuries: yeast consumes the sugar, converting to alcohol concentrations of approximately 8% by volume. This 'wine' is then distilled.

Despite the maturity of the technical process, collaborative R&D continued to improve the milling process and introduced new innovations, including 'open' fermentation, or the extraction of ethanol from the hydrolysis and fermentation of lignocelluloses materials from sugarcane residues. Increasing scale and efficiency and system optimization have been the most important factors in driving down industrial processing costs (see Figure 3). The extent of economies of scale present in ethanol distillation plants is remarkable: van den Wall Bake et al. (2009) report typical investment costs of 22-26 million US$ for a new plant built in the 1970s of an average capacity of 120 m3/day compared to 55 million US$ for a plant of some 1000 m3/day built after 2000, i.e. an increase in production capacity over a factor of eight only requires an increase in total investments of less than a factor of 2.5 (Grubler et al., 2012).

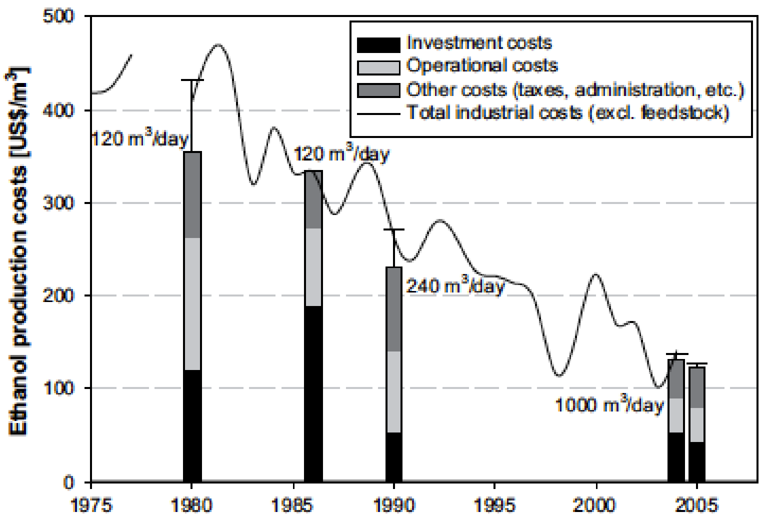

FIGURE 3. ETHANOL PRODUCTION COSTS (EXCLUDING SUGAR FEEDSTOCK COSTS) IN US$ PER M^3, TOTAL AND PER COMPONENT. NOTES: THE AVERAGE SIZE OF NEW ETHANOL DISTILLERIES IN M^3 CAPACITY PER DAY IS ALSO SHOWN. SOURCE: VAN DEN WALL BAKE ET AL., 2009.

3.3 Bagasse

Sugarcane bagasse is the cellulosic material leftover from the milling and distillation process. Bagasse has long been used in distilleries as combustion material to generate both heat and power for use in the ethanol production process. It has resulted in significant increases in process efficiency and often generates surplus power that is fed into the electricity grid, creating additional revenue (or by-products credit).

4 SUBSIDIES & THE COST OF THE ETHANOL PROGRAM

The dominant economic narrative of the Brazilian ethanol program is that after a dedicated three decades long effort it was finally possible to drive down ethanol costs to become cost competitive with fossil fuel alternatives. This version of the innovation history of Brazilian ethanol was supported by an influential paper by Jose Goldemberg published in Science (Goldemberg, 2007) which compared Brazilian ethanol prices with Rotterdam gasoline spot market prices over the period 1980 to 2005 using constant US$2004.

The analysis used a US$ reference point as the ethanol program evolved over an extremely turbulent period of economic history in Brazil, characterized by prolonged periods of hyperinflation and exchange rate volatility. However, this makes the analysis highly sensitive to the choice of reference year. The US$ - Real exchange rate varied between 0.9 to 3 Real per US$ (IMF, 2012) over the period 1995 to 2011. The three years with the highest exchange rate (around 3 Real/US$) were in 2002-2004 (compared to a yearly average exchange rate of 1.7 Real/US$ in 2011). The use of 2004 as base year and for the exchange rate thus can be misleading as it proportionally scales all domestic ethanol prices to the lowest US$ denomination observed historically.

Figure 4 compares Goldemberg's original 2007 data with more recent Brazilian price trends and the Rotterdam spot market price, expressed in both US$2004 (left-panel) as well as Brazilian Real2010 (right-panel). The original price data in Goldemberg (2007) were expressed on a volume basis. Given the lower heating value of ethanol compared to gasoline (21.2 versus 32.2 MJ/liter), the original price data have been adjusted and expressed on a better comparable per unit energy content (GJ) basis.

As Figure 4 shows, the relative economics of Brazilian ethanol and the inferred levels of subsidies are critically dependent on the exchange rate used in the comparison. Using a 2004 base year and exchange rate basically confirms Goldemberg's original conclusion: since 2004, Brazilian ethanol is cheaper than imported gasoline. This suggests an economic success story. Conversely, using a 2010 base year and exchange rate and denominating in (constant) Brazilian Real2010 yields a quite different picture: only in three out of a total of 36 years spanned by the time series (2004, 2007 and 2008) is ethanol at par with imported gasoline prices. It is significantly more costly in 33 out of 36 years, including also the post-2008 period.

Both economic comparison metrics agree that prior to 2004 Brazilian ethanol prices were significantly above those of imported gasoline. The difference between domestic ethanol and international gasoline prices (times ethanol sales volumes) yields a proxy, even if imperfect indicator of the total subsidy implicit in the program (see Figure 4).

Subsidization of the ethanol industry has taken many forms since 1975. Supply incentives included low and negative interest rate loans to mills, and regulated demand at fixed prices. Consumer incentives included capped low prices for ethanol, and reduced taxes and licensing fees on ethanol-only, and later flex-fuel vehicles.

Gasoline consumers paid the largest of these subsidies. Gasoline prices were kept at a fixed interval above ethanol until ethanol prices were deregulated in 1997 (for anhydrated) and 1999 (for hydrated) ethanol. Petrobras, which had a monopoly on both ethanol and gasoline distribution, effected the transfer of funds from gasoline consumers to ethanol producers through pricing. It collected the subsidy when selling gasoline to distributors, and delivered it to ethanol producers when buying ethanol at fixed prices (Moreira and Goldemberg, 1999). This intra-sectorial subsidy ended with price deregulation, though the government continues to support ethanol by taxing it favorably relative to gasoline.

This subsidy has been a significant, if not the dominant, portion of total subsidies to ethanol producers. It can be estimated by considering prices from the position of the refiner/blender. Whatever amount of ethanol was injected into the system downstream of the blender, an energetically equivalent amount of gasoline could have been injected at lower (or greater) cost. The difference between what was spent on ethanol and what, hypothetically, would have been spent on an energetically equivalent amount of gasoline, is an estimate of the subsidy.

Using 2004 base year and exchange rates and the US$ as denominator yields a cumulative net subsidy of 35 billion US$2004 (cumulative subsidy of 45 billion US$2004 1975-2000 minus negative subsidies or macro-economic savings of 10 billion US$ in the 2001-2011 period). Using 2010 base year, exchange rates and the Brazilian Real as denominator yields a cumulative net subsidy of 240 billion Real2010 over the period 1975-2011, or of some 136 billion US$2010 (with the 2010 exchange rate being 1.76 R/US$).

The large range of estimated subsidy between 35 to 136 billion US$ both illustrates the ambiguity of economic comparisons under widely varying exchange rates as well as the significant levels of resource mobilization necessary by such an ambitious national scale long-term program of energy technology innovation. Cumulative subsidies prior to 2000, often referred to as the ‘learning investment’ necessary to drive down long-term costs and prices, range between 45 to 114 billion US$.

These price differential-derived subsidies are only a crude and macro-level perspective and in all likelihood represent a conservative, lower bound estimate. To illustrate this point, consider the situation for the year 2008, which both indicators agree was the year with the most favorable price ratio between domestic ethanol to imported gasoline. The price difference between domestic ethanol and gasoline spot market prices ranged between 8.6 US$2004/GJ to 2.3 Real2010/GJ in favor of ethanol. In the last week of October 2008, for example, average retail prices differed between 1.513 and 2.511 Real per liter for E100 and E25 respectively (ANP, 2008). Considering the different heat values this translates into prices of 71.4 and 85.3 Real/GJ for E100 and E25 respectively, i.e. a price spread of 13.9 Real/GJ, mostly accounted for by the preferential (lower) tax treatment of ethanol. Multiplying by total ethanol sales of 460 PJ in 2008 (EPE, 2011) and assuming that the entire price spread on an energy content basis is attributable to tax rate differences, gives an estimated foregone tax revenue of some 6.4 billion Real in 2008 (3.5 billion US$ in 2008), the year where domestic ethanol had a decisive (wholesale) price advantage over imported gasoline.

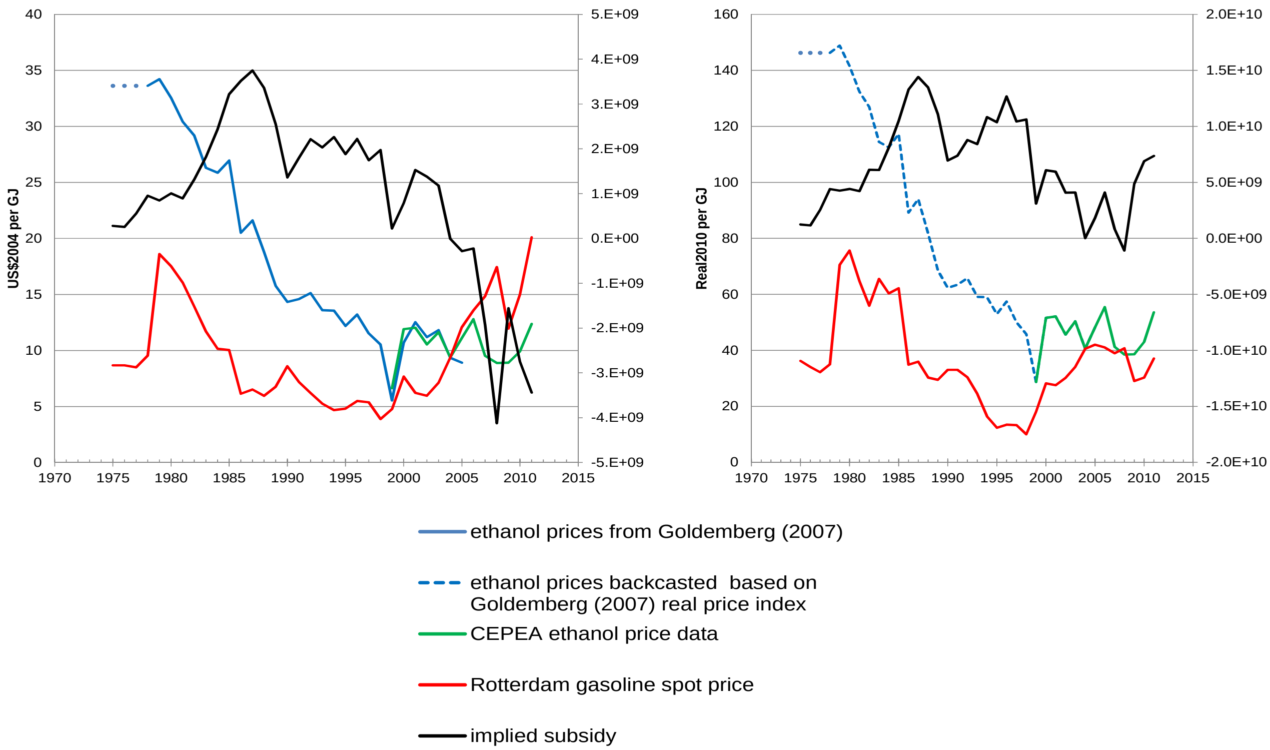

Figure 4. Brazilian ethanol prices vs. Rotterdam gasoline spot market prices, with inferred subsidy. Notes: left-panel shows prices in US$2004 per GJ; right-panel shows prices in Real2010 per GJ. Inferred subsidy (billion US$2004 and Real2010) shown on right y-axis estimated as price differential times ethanol sales volume, with positive values indicating ethanol subsidy and negative values indicating macro-economic gains, right axes). Sources: Goldemberg, 2007 for ethanol prices to 2005 adjusted from volume to energy content basis; CEPEA, 2012 for ethanol prices from 2000-2011; IEA, 2012 for nominal gasoline prices converted to constant US$ using the US GDP deflator.

5 CONCLUSION & LESSONS LEARNT

In 2010 Brazil produced roughly 28 billion liters of ethanol (EPE, 2011). This is about 50 times as much as was produced when the ProAlcool program was created in 1975, and about 30% of the world total (EPE, 2011; RFA, 2012) Furthermore, ethanol accounts for roughly 20% of the highway transportation fuel mix in Brazil, with gasoline comprising 28%, and diesel fuel (predominantly used in trucks) making up the balance (EPE, 2011).

Industry projections indicate continued expansion as Brazil strives to satisfy not only its internal market, but overseas demand as well. The US Environmental Protection Agency, for instance, has classified Brazilian ethanol as an “advanced biofuel,” that satisfies renewable fuel requirements. This drives up demand for Brazilian ethanol, and has led to a curious situation: tankers loaded with Brazilian ethanol destined for the US now cross paths on the high seas with tankers loaded with US corn ethanol destined for Brazil. The two fuels are chemically equivalent, but Brazilian ethanol is perceived as having environmental benefits that increase its value and that will continue to drive the industry’s expansion.

There are many lessons to be taken from the story of Brazilian ethanol. Investments in the form of direct and indirect subsidies were very substantial relative to the size of the Brazilian economy. Perhaps just as significant as the subsidies themselves is the fact that they were partially wound down, especially following the collapse of oil prices in 1986-87. The partial withdrawal of subsidies forced the industry to consolidate and to innovate, modernize and improve ethanol economics. Also important was the coordinated engagement of multiple sectors and stakeholders of Brazilian society, including not only the growers and processors that supplied ethanol but also the auto industry that developed the vehicles to burn it.

Perhaps the foremost lesson of all from the Brazilian ethanol experience is the importance of a consistent, long-term policy framework. The Brazilian ethanol project began in earnest in 1975. In the nearly four decades since, oil prices have soared and collapsed, Brazil's political and economic systems have come apart and been remade, and the ethanol program itself has faced several periods of crisis. Yet policies to support the Brazilian ethanol industry, and the research and investment that underlie its performance, have never been abandoned. It is this decades-long continuity in policy that has made the innovation history of Brazilian ethanol unique.

6 FURTHER READING

For further, more detailed treatments of the Brazilian ethanol story, see: Wall Bake et al. 2009; Valdes 2011.

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