Bio-fuel Adoption: Can Best Practices from Brazil be Applied in the United States?

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Author(s): Abrahim Abdulsater, Asem Alluhibi, Bahare Saatchi, Judith Estep

ABSTRACT

Bio-fuel energy can be defined as an alternative source of energy due to being sustainable in both producing energy a t a lower price and avoiding exceeding carbon dioxide emission into the atmosphere. The most common world-wide types of bio-fuel are bio-diesel and ethanol. There are many methods to understand how and why technologies are accepted in a country. This report reviews bio-fuel adoption relative to political, cultural, technical, environmental, and economic perspectives for the two largest bio-fuel producers, Brazil and the United Sates. The research approach is to review the successful bio-fuel adoption in Brazil and ultimately to understand if any of these practices can be applied to U.S. The lessons learned from Brazil could be used by the U.S. to promote more wide-spread use of bio-fuel, with the long term objective of being an "oil-independent" nation in the future.

Note: The authors recognize that there are many issues which have impacted the adoption in both Brazil and the U.S This report identifies the most salient issues relative to the five perspectives. Also recommendations are made for future research if there appears to be opportunities to apply the lessons learned in Brazil, to the adoption of bio-fuel in the U.S.

INTRODUCTION

The need to switch energy strategies from oil to a less risky alternative is the result of a rise in fossil fuel cost, incremental increase of global energy demand, expanding instability of regional policies that supply oil and the augmentation of carbon emission threat. Looking for such alternatives, scholars consider bio-fuel options as a promising substitution for oil [1].

"We can get fuel from fruit, from the shrub by the roadside, or from apples, weeds, sawdust, almost anything! There is enough alcohol in one year's yield of an acre of potatoes to cultivate that field for a hundred years. And it remains for someone to find how this fuel can be produced commercially – better fuel at a better price than we now know."

Henry Ford, 1925

Regarding these alternatives, many developed countries consider expansion of bio-fuel production as a strategy not only to reduce the fossil fuel demand [2] but also as a significant beneficial choice to decision makers for several reasons which include:

1) It can be refilled. Unlike oil that depends on exhaustible resources, bio-fuel is a reproducible agricultural resource.
2) Decreases the carbon emission so it is a promising solution to air pollution.
3) Increases farm income because farmers have an opportunity to produce different types of crops and consequently they may need fewer subsidies.
4) Secures less reliance on importing sources for energy.
5) Requires more labor in comparison with other technology so it is an opportunity for entrepreneurship.
6) Its characteristics are quite similar to gasoline or diesel so it requires less adjustment on engines.
7) It is simple to use and produce for the customer and producers respectively [1].

From this list it can be seen that there are many aspects which would affect adopting alternative fuels. These include the political, cultural, technological, environmental, and economic consequences [3-6]. This research reviews how bio-fuel has (or has not) been adopted in Brazil and the U.S., against this criteria.

According to the history of bio-fuel adoption, Brazil is one of the first countries that adopted renewable energy and could successfully employ bio-fuel energy throughout the entire nation, such that it is known as a leader of alternative energy production [4]. Although the United States has adopted an aggressive strategy to enhance the use of ethanol as a bio-fuel, the nation still debates the efficacy of this fuel alternative among the politicians, the economists, and the environm entalists. The other major, behind the scenes players in these debates are the various interest groups and their lobbyists [5]. This research is about what best practices could be used, based on the successful adoption in Brazil.

BIO-FUEL ADOPTION IN BRAZIL

"Brazil will be the largest supplier of renewable energy in the 21st Century. We will no longer talk about prospecting petroleum; we will talk about planting petroleum." [3]
Luis Inacio Lula da Silva, President, Republic of Brazil, April 7, 2006

In 2006 Brazil ranked 35th among the world's most competitive nations. Relatively speaking, this mediocre rating is not r epresentative of how successful Brazil has been in the development and adoption of alternative fuels, specifically ethanol. Relative to the U.S., Asian countries, and the European nations, who have debated the benefits and adoption methods of alternative fuels, Brazil has been very effective in developing and integrating this fuel source into their culture. They have been so successful that in 2007, over 83% of the vehicles sold in Brazil were Flexible Fuel Vehicles (FFVs) [3]. Brazil's success serves as a global model for the production, distribution, and use of ethanol fuel [4]
Brazil's alternative fuel development began in 1930 and incrementally increased to the level it is today. There were many political, cultural, technological, environmental, and economic (PCTEE) reasons that can be attributed to its success. In general, like most other agricultural nations, Brazil prescribed to the "energy farming" method as a way to improve the quality of life and the economy in a sustainable way [6]. Specifically, the objectives for their alternative fuel program included:

- Energy diversification and security
- Mitigation of air pollution
- Minimize greenhouse effect
- Expansion of agribusiness
- Opportunities for rural workers

Provided are how the PCTEE elements influenced their ability to meet these objectives and achieve the illustrious title of an oil independent country.

Political Impact

The government relied heavily on incentives and subsidies to affect the development and adoption of alternative fuel, with the first policy established in 1931. This policy required the addition of ethanol to imported gasoline in an effort to reduce oil consumption. However, the government's effort and influence intensified in the 70's, with escalating oil prices the need to achieve oil independence was a top priority. The government established Proalcool (Brazilian National Alcohol Program) with the objective of supporting ethanol production. Notably, Proalcool provided the equivalent of U.S. $11B in federal incentives. These incentives were directed at research institutions, private firms, and the general public in an effort to increase ethanol efficiency, production, and adoption. In general, the basis of the incentives was to 1) create and maintain a market for ethanol 2) increase production and 3) foster technological development in the alternative fuel sector. These translated into cheaper credit for private firms, protection against ethanol imports, and tax breaks for the consumers.

For the consumer the incentives were very attractive. Specifically, the price of ethanol was 59% of gasoline; the government regulated gasoline prices so the ability to steeply cut the cost of ethanol in an effort to influence a consumer's purchase was feasible. Also, the taxes on ethanol fueled cars were significantly lower than gasoline powered (vehicles). In fact, the incentives were so attractive that by 1984, **96%** of the cars sold in Brazil were fueled by e thanol [4]. Such a large fleet of vehicles needed an infrastructure to support it – imagine having only a limited number of fueling stations and the impact this would have on planning a trip. Brazil addressed consumer's fueling concerns by ensuring that ethanol was available at every Petrobas station. *Note: 64% of Petrobas shares are owned by the Brazilian government [7]*

However, beginning around 1985 it was becoming more costly to maintain the level of subsidies and incentives, relative to the cost of oil; oil prices fell to U.S. $12-20 per barrel. Fewer incentives, lower oil prices, and a subsequent red uction in ethanol production, but still a high demand for the product due the large number of ethanol cars that flooded the market, set up the perfect storm for an ethanol supply crisis. In 1988 the Proalcool program lost credibility and was terminated. A new fuel was developed MEG – (Methanol, Ethanol, and Gasoline) to handle the existing fleet of passenger vehicles. Finally, in 1999 all ethanol government regulations ended, except for their ability to mandate gasohol blending rates [4]. The government also slowed research and development efforts which logically had an impact on realizing efficiencies with production of ethanol or related technological achievements (e.g. manufacturing of agricultural assets, etc.).

Then at the start of the 21st century oil prices began to steadily increase, once again calling attention to the risks and issues of being dependant on foreign oil imports. The Brazilian government's response was similar to that in the 1930 – regulating the ratio of ethanol to gasoline mix.

The influence of the government, associated policies, and specifically the influence of former President Luis Ignacio Lula da Silva, cannot be underestimated. During his presidency (2003 – 2010), Brazil witnessed significant ethanol production and adoption. "…the biodiesel program demonstrates the Brazilian government's capacity to coordinate policies that redirect resources and transform production and consumption across both the private and public sectors and within a broad set of government ministries and agencies" [8]

Note: There have been significant changes which could re-define the future of bio-fuel in Brazil. The influences are mentioned but, because they are so new, both short and long term impacts have yet to be seen. Speculation on future impacts doesn't necessarily support a lessons learned research approach. Therefore, the recent changes in Brazil may be outside the scope of this report. However, the authors chose to include this information to provide a more comprehensive picture of the bio-fuel landscape. Inferences are drawn on their potential to change the use of bio-fuel. Future research is suggested to understand how they have impacted bio-fuel in Brazil, as they inevitably will.

Fast forward into the future and consider if the newly elected (Jan 2011) President, Dilma Rousseff will maintain similar policies? If not, how could the differences impact the continued use of bio-fuel in Brazil? Some articles suggest that since she was influential for bio-diesel adoption during President Lula's term as the Minister of Mines and Energy, she will continue her pro bio-fuel policies during her term [8]. Only time will tell. Another significant influence on the future of bio-fuel is a proven pre-salt hydrocarbon reserve off the coast of Brazil, discovered in 2007. As reported by the Brazilian National Petroleum Agency, the range of available oil reserves could contain between 50 billion and 80 billion barrels of crude equivalent [9]. Proven reserves have been reported by Brazil as 14B barrels of crude. To put this in perspective this amount is equivalent to 3 years worth of global oil consumption [9]. The impact on the future of bio-fuel could be significant. Similar to when oil prices became competitive with bio-fuel in the 1980's, will Brazil revert to using oil as its primary fuel source? Future research is suggested to see the impact of both President Rousseff's bio-fuel policies and the reaction to the off shore reserve.

Cultural Impact

Brazil is not considered one of the most technologically advanced nations. However, the Brazilians have been ***extremely*** successful at integrating alternative fuel technology, to the extent that they could be considered "oil independent". Certainly the political influence and other factors contributed to this success. However when similar policies are implemented elsewhere, the adoption is not as pronounced. In fact, the gap is so big, it is estimated that it would take decades for the U.S. to achieve the level of adoption seen in Brazil [3]. Why? As suggested by the article, "Beyond a Better Mousetrap: A cultural analysis of the adoption of ethanol in Brazil", Nardon, L; Aten, K. Journal of World Business vol 43 (2008) the answer lies in the Brazilian culture itself. More specifically, such a successful adoption can be attributed to the term *jeitinho, or logics of action of flexible adaptation used to deal with various problems.* A brief historical perspective will help to clarify the term.

Brazil was original inhabited by the Portuguese and they imported a large number of slaves to work in the sugarcane plantations. The combination of backgrounds developed into a unique cultural foundation. Historically, the population is described as "seeking for his soul in the dialectic profusion of his physical and spiritual components, who has to develop a flexible, labile, plastic personality in order to survive, live, and build a country" or a flexibility of body and spirit, allowing deviation from obstacles [3]. As result of the fundamental need to adapt and be flexible, the concept of jeitinho evolved. Flexibility permeates every aspect of Brazilian lifestyle – from disputes on the soccer field to providing an effective response to fuel scarcity [3]. Considering this perspective, it is not surprising that the FFV or ethanol in general, was such a success – it fits perfectly within the fundamental beliefs of their culture. Brazil's response to fuel scarcity follows a logic principle of flexible adaptation. The FFV is the ultimate legitimization of the logic of changing fuels to adapt to external circumstances. The power of deciding fuel mix has moved away from the government and into the final consumer's hands [3].

Technology Impact

In addition to technology impacts on agriculture and harvesting equipment as well as contributing to the efficiencies in sugarcane processing, by and large, one of the *most* significant contributions to the adoption of alternative fuel was the development of FFVs – vehicles that can run on ethanol, gasoline, or any combination of the two. This flexibility allows the consumer to adapt to changing markets/prices. In addition, the vehicle's performance was comparable to a gas-only vehicle and similarly priced. It was unexpected how quickly this technology was accepted. Initial forecasts suggested that by 2006, the adoption rate would be ~60%. However, figure 1 shows the actual market penetration in 2005 Q3 exceeded 60% [3] and by 2007, 83% of the cars sold in Brazil used this technology!

Figure 1. *Market share of FFV's in Brazil Jan 2003 – Oct 2005 [6]*

The FFV was the result of a partnership between Germany-based Bosch and an Italian firm Magneti Marelli. From a technology management perspective, the FFV could not have come at a better time. The development of the vehicle was able to apply lessons learned from previous efforts to integrate alternative fuels and recognized the benefits of providing a car that could run, efficiently, on any fuel. Their solution empowered consumers and provided a long term solution to the ebbs and flows of the oil industry.

Environmental Impact

Sugarcane, for the production of ethanol, can be harvested either manually or mechanically; almost 80% of the sugarcane harvested is done manually. In order to increase the yield by up to 30% and lower transportation costs, the sugarcane is typically burnt prior to harvesting. The effects of the burn could negate the positive environmental impacts of using an alternative fuel - burning results in an increase in atmospheric pollution, accelerated soil degradation, pollution of the aquatic system, and loss of biodiversity. Also, the impact to the most vulnerable citizens should be considered. Depending on the time of year, a significant amount of smoke and suspended particles can remain in the air, posing a serious health threat to the elderly and children. As an example, in municipalities with >50% of the land dedicated to sugarcane production, there is a 15% increase in elderly respiratory illness and a 12% increase in children. The respiratory illness is directly attributable to the suspended particles resulting from a pre-burn [2].

The article suggests a more comprehensive review of policy, rather than just the economic value of alternative fuels, and urges the government to restrict burning times or mandate complete mechanization of sugarcane harvesting. In response to public pressure, there have been some attempts to mitigate the impact of smoke and suspended air particles. Brazilian law 11,241 calls for a gradual increase of mechanization however the law has not been rigorously enforced and push-back is common. The law also states that manual harvesting in areas that can be potentially

mechanized has to be converted by 2020, and phasing out manual harvesting completely, by 2030. Some legislation is written to protect the aquatic areas and soil by restricting harvesting in areas close to rivers/streams, but if enforced, would eliminate between 4% and 28% of cultivation [2]. It remains to be seen if the legislation will have a positive impact on burning. As of 2006, based on the number of fires, expansion of manual cultivation is proceeding faster than mechanization. [2] As well, in Sao Paulo the government has forbidden burning from July until the middle of October, as well as prohibiting burning if the relative humidity falls below 20%, environmental conditions that are conducive to respiratory illness [3].
Similar to adopting an ethanol policy the government is implementing policy to minimize the negative effects on the environmental and health of its citizens.

Economic Impact
In 2004 Brazil was responsible for producing more than one third of the total ethanol produced in the world and was one of the main exporters [6]. In addition to providing a profitable exportable commodity, the impact of the ethanol program resulted in an increase of higher quality jobs for rural populations and successful technology transfers which stimulate wealth among the private sector.
<u>Sugarcane as an Export</u>
Sugarcane has two primary outputs – sugar production (as a food source) and ethanol. Figure 2 shows the distribution of sugarcane products in 2006. There is a significant external market for raw sugar and a modest one for ethanol exports [4].

Figure 2: *Distribution of Sugarcane Production in 2006 [4]*

Specific to ethanol, Brazil can have a fluctuating market. Figure 3 shows for the period 1990 to 1997, the increase in imports can be explained by remnants of the pure ethanol vehicles – as mentioned before during this period it was not cost effective to produce ethanol due to competitive oil prices, yet there remained a supply due to the strong government ethanol policies and the public's acceptance of ethanol-only vehicles. Conversely, there appears to be a consistent export potential – in most years Brazil provided some export of ethanol, except for those years where fuel had to be imported to address the ethanol supply crisis in the early to mid 1990's [6].

Figure 3. *Ethanol Trade in Brazil 1982 –2004* [6]

In addition to the government policies which affect export and import trends, the climate also has an impact. Brazil is subject to the affects of El Nino and La Nina effects. These correspond to lower sugarcane yields and hence higher import trends.
<u>Increase in high quality jobs for rural farmers</u>
Referring to Dave Williams discussion, "Impact Your Community with your Technology", if we define community as the rural farm workers, then the development and adoption of ethanol had a significant impact on the creation of sustainable communities. Some references cite in excess of 800,000 rural jobs have been created as a result of ethanol adoption. In addition, there were 250,000 indirect jobs created [6].
Once again we see the influence of government legislation. A portion of the net sugarcane and ethanol prices are reserved for the assistance in improving services for rural farm workers (e.g. improvements in medical, dental, pharmaceutical, sanitary conditions, etc.)
<u>Stimulating wealth through successful technology transfers</u>
Proalcool addressed the adoption of ethanol in two phases. The first phases focused on adjusting ratio of alcohol to gasoline mix in an effort to curtail oil imports. Phase two introduced the use of ethanol fueled cars. These cars were made by Brazilian manufacturers who purchased the technology from public research centers; investing in research was a primary objective of Proalcool. The technology for the ethanol-based vehicles was developed in the 1970s and sold to the auto-makers who then continued to develop the technology. [6]

BIO-FUEL ADOPTION IN THE UNITED STATES
"…this is our generation's Sputnik moment. Two years ago, I said that we needed to reach a level of research and

development we haven't seen since the height of the Space Race….we'll invest in…clean energy technology – an investment that will strengthen our security, protect our planet, and create countless jobs for our people."

President Obama, State of the Union Address, January 25th,2011

The United States has been paying the price of ongoing industrialization and the incremental demand for energy sources. Increased energy demand can also be seen as a result of the growing and aging population. In addition, the general public and government agencies awareness and concerns about the climate changes and their associated impact to the environment and population have played a big role in the search for alternative energy sources; mainly bio-fuel products.

Ethanol, as shown in table 1 below, is not a totally new concept to the United States, over the past decades the nation has spent a great deal of effort in the area of bio-fuel research. The goal was and still is to limit its dependency on foreign oil, as well as control, and hopefully reverse the course of accelerated emissions of greenhouse gas (GHG). By-products of a national renewable energy sources would include increased employment as well as a lower level of GHG emissions, which both directly and indirectly impact the U.S. population.

In the U.S., ethanol and biodiesel have been the main forms of bio-fuel focused on by researchers; in fact, the U.S. ethanol production in 2010 accounted for 57.5% of the total global production [12]. The sources vary from corn and other feedstock to algae, a promising source, which will not only eliminate the food vs. fuel competition but also minimize the need for

Table 1. A summary of the major U.S. ethanol timeline events [10, 11]

1826	Development of first engine that uses ethanol & turpentine.
1862	Taxation of ethanol by the Union Congress to cover the Civil War expenses.
1896	First automobile for pure ethanol by Ford.
1908	The Ford's Model T as the world first Flex-Fuel-Vehicle (FFV).
1920's	Gasoline became the major motor fuel with ethanol as a booster.
1940's	First U.S. Fuel ethanol plant was built by the U.S. army.
1940's – Late 70's	Low prices of gasoline fuel forced ethanol out of the market.
1989 – 2000	Multiple regulations passed to control the U.S. Motor gasoline.
Late 90's – Present	U.S. FFVs that can perform on a blend of up to E85 entered the market.
2005 – Present	More regulations, subsidies and research funding.

arable land. Other product and byproducts include biobutanol (with similar properties as gasoline), and alternative protein sources for aquaculture and livestock feed [13].

Figure 4. U.S. Renewable Standards and Energy Act of 2007 [14]

Table 2. 2010 World Fuel Ethanol Production [15]

Continent	North & Central America	South America	Europe	Asia	Australia	Oceania	Africa
Millions of Gallons	13,720.99	7,121.76	1,208.58	785.91	66.04	66.04	43.59

Nation	Brazil	European Union	China	Canada
Millions of Gallons	6,921.54	1,176.88	541.55	356.63

Political Impact

As the leader of the modernized world, the United States has an obligation to be among the first nations (if not the first) to think about alternative fuel. Indeed, during the last decades of the 20th century, both federal and states legislative bodies have translated the worries about the nation's energy security and climate global changes into policies. The increasing energy demand, unpredictable crude oil prices, instability of oil-source regions, and the alarming rate of global warming have been among the main reasons why the United States is pursuing an aggressive investment in bio-fuel research and production.

According to a 2010 congressional research service, 22 programs and provisions have been established between the years of 1975 and the year of 2009. As of November of 2011, seven programs have expired; 10 will reach their end of life between December of 2012 and 2019, while the remaining five are not tied to an expiration date. Billions of dollars have been allocated for various programs supported by different governmental departments or agencies such as the Environmental Protection Agency EPA, the U. S. Department of Agriculture DOA, the Department of Energy DOE, the Internal Revenue Service IRS, and the Customs and Borders Protection. To list few examples we mention the 1975 Manufacturing Incentive for Flexible Fuel Vehicles to stimulate the production/sales of FFVs, the 1980 Import Duty for Fuel Ethanol that imposed a tax on imported ethanol to promote and encourage national production. The 2005 Energy Policy Act, and the 2008 Food, Conservation and Energy Act are considered to be the major ones; therefore we will briefly detail them [16].

The 2005 Energy Policy Act was administered by the EPA, and has multiple sections; The §1501 (P.L. 109-58) Renewable Fuel Standard (RFS) which was revisited by the 2007 Energy Independence and Security Act, set up the rules for gasoline & bio-fuel products blending; starting with 4.0 billion gallons in 2006 and reaching 36 billion gallons in 2022 with 21 billion gallons from a non-corn source. Another section, Title XVII, or what is known as the DOE Guarantee Loan, was initiated to fund energy related projects such as bio-fuel researches. The §942 (P.L. 109-58) Cellulosic Ethanol Reserve Auction allocated a total of $1 billion to the DOE spending in support of cellulosic bio-fuel production. The regulations were finalized in October of 2009. Other sections were crafted too under the 2005 Energy Policy Act.

Advanced bio-fuels were also supported by The 2008 Food, Conservation and Energy Act, better known as the 2008 Farm Bill, under the §15321 (P.L. 110-246) Credit for Production of Cellulosic Bio-fuel. This IRS program allows the cellulosic bio-fuel producers to claim a maximum tax credit of $1.01 per gallon. As generous as it sounds, this regulation was tied to others that would lead to the reduction of the final allowable claimed credit.

There are a wide range of beneficiaries which include farmers, rural small business and bio-fuel producers. A complete list of the 22 programs can be found in the September 15, 2010 Congressional Research Service 'Bio-fuels Incentives: A Summary of Federal Programs' by Brent D. Yacobucci [16].

The second form of governmental influence on bio-fuel adoption came at the state level. Multiple states legislators were attracted to the concept of achieving a national self-sustained energy status and used their influence within their own states. Since these policymakers are more familiar with the landscape of their state, the overall interaction of the community and their surroundings, and their various resources as well as their stakeholders, they could be more innovative and creative than the federal government to establish effective policies. The initiatives were classified and categorized under various policy labels which included the development of sustainable feedstock guidelines, establishing minimum renewable fuel standard, researching and developing locally appropriate feed stocks, and conversion technologies. Specifically, a few examples are noted [17]:

- The Pennsylvania's Alternative Fuels Incentive Grant assisted the funding of more than 50 projects valued at $17.8 billion since the start of 2006 and invested a yearly $5.3 million till 2011 in support of locally produced bio-fuel.
- In the '2007 California State Alternative Fuels Plan', the Air Resources Board and Energy Commission realized the large unused biomass resource in the form of agricultural waste, forestry, and urban waste streams. California decided to benefit from them in the energy production arena in order to reach a Low-Carbon Fuel Standard.
- In 2007, the 'North Carolina's Strategic Plan for Bio-fuels Leadership' was published. The plan was drafted to reduce the annual fuel demand by 10% and to replace it with local bio-fuels product by the year 2017.

- In 2008, the Maryland's Agricultural Water Quality Cost-Share program was designed to pay landowners up to $85 per acre to plant their land for winter to minimize the soil erosion and nutrient runoff. The program aimed at two targets; increasing the harvest of feedstock and the carbon segregated in the soil.

A more comprehensive list of the state influenced legislatures can be found in the February 16, 2010 'Developing an Advanced Bio-fuel Industry: State Policy Options for Lean and Uncertain Times' published by the Environmental and Energy Study Institute [17]. The bio-fuel adoption path was never obstacle-free, related to government policies. Even though the giant oil companies, such as ExxonMobil and Chevron, invested in some future bio-fuel technologies, their lobbyists' actions suggested otherwise. In reality, they mostly opposed or delayed passing of any mandates for alternative fuels. Their thinking was that it would detract from short term gains and control of the oil industry [18].

Cultural Impact

The need for the creation of employment opportunities has perhaps the biggest impact on the population. Bio-fuels use has had a great impact on the U.S. population. Specifically, the transfer of land from local owners to investors for large-scale industrial plantations has created income for rural farmers. Also, other have migrated from their local establishments to seek employment in these new plantations and associated agri-businesses [19]. These new job opportunities also affect the surrounding by creating ancillary services (medical, schools and other social services). As a result, employees at these farms have an opportunity at a more prosperous livelihood.

Conversely, bio-fuel production may contribute to increasing the cost of food. The expected increase in corn prices is of particular concern, since more than 70% of the corn grown in the U.S. is used to feed livestock [20]. Diverting corn into bio-fuel production may, as a consequence, increase the price of meat and grain products [20]. The increased use of bio-fuel energy carries many associated impacts, both positive and negative, related to social impacts. These effects need to be critically assessed to bring a more thorough understanding and formulate, the best suited strategies promoting positive development, creating jobs, while limiting the negative impacts such as an increase of food prices.

Technology Impact

The bio-fuel history goes back to the 1880s (refer to table 1) when the first diesel cars were designed to run on peanut oil. Henry Ford produced bio-fuel cars as early as the 1908 T model. Hemp and peanut oil were the main resources of the bio-fuel sold by Standard oil and it did account for 25% of the total fuel sold. Unfortunately, the biodiesel industry collapsed in the 1930s under the massive and aggressive campaign of the petroleum industry. It took the industry, and the world, some 40 years and a couple of oil crises to realize that non-renewable energy sources would at one point be depleted, not to mention the inability to control the foreign oil sources. Recently, due to public awareness and demand for more environmentally friendly products, the auto industry is beginning to support the market with Bio-fuel, flex-fuel and hybrid cars. In fact, all the U.S. passenger cars sold since 2000 are regula ted and designed to run on a mix of gas and bio-fuel [21]. The bio-fuel technology was kick-started in the 1970s to the present day with U.S. Energy Secretary Chu's latest position on bio-fuel research:

".Using consolidated bioprocessing, a research team led by James Liao of the University of California at Los Angeles for the first time produced isobutanol directly from cellulose. The team's work, published online in Applied and Environmental Microbiology, represents across-the-board savings in processing costs and time, plus isobutanol is a higher grade of alcohol than ethanol… [22].

As of today, multiple processes to manufacture ethanol exist or are in their final stages of development. A large number of private and governmental R&D laboratories are working to decrease manufacturing costs and increase efficiency. A typical cycle is represen ted by figure 5 [23].

Figure 5. Biomass-to Bioenergy Supply Chain [23]

The supply ranges from peanut oil, hemp, corn, panicum (switch grass) and all kind of plants and plant derived materials. The processing and conversion could be biochemical, thermo chemical (which may complement each other) or by gasification [24]. Another technological front, which is moving at a rapid rate, is biomass algae. This technology is significant because it relies on non-food biomass. Using this technology would address the depletion of food sources (corn) for ethanol production. Via a continuous harvest process, carbon dioxide (CO2), the major greenhouse gas, emitted by power plants, oil & gas refineries, and cement factories provide high growth rates for the marine microalgae [25]. This bio-fuel production procedure, from photosynthetic microbes, started in the early 1980s and more than U.S. $25M was invested on various programs by the U.S. National Renewable Energy Laboratory (NREL) and was terminated in the late 1990s by judging the program non-economical, non-feasible. But Cellana scientists, supported by the founders, managed to attract investments for another U.S. $20M to refund the research of the Aquatic Species Program (ASP). In a 4 year period (1998-2001) the results were shocking and the conclusion that was based on a large-scale pilot operation proved the NREL wrong. In a very detailed article, the coauthors postulate a target of fossil-free independence by 2020 [26]. This accomplishment was finally recognized by the current administration on May 5, 2009. President Obama & Secretary of Energy announced a U.S. $800M investment in new research on bio-fuel, including the algae as an alternative and renewable source of biomass feedstock. A National Algal Bio-fuels Technology Roadmap Workshop was convened by the department Of Energy (DOE) in December of 2008 [27].

Two more technologies are worth mentioning for the very positive and promising results they display; The Hydrothermal Liquefaction (a thermochemical technique conducted by Professor Yuanhui Zhang at the University of Illinois) that successfully produced bio-crude oil from waste material mimicking the nature's process beneath the earth's crust. Professor Zhang is very optimistic about his process especially if algae are used as the feedstock [28].

The second is the Cellulosic technology [29] – this technology is in its final stages of development. This technique, like the other advanced bio-fuel techniques, will not rely on food material as feedstock instead it will be using abundant agricultural wastes and any other wood-like material to generate about 60 billion gallons/year an approximate 30% of 2030 gasoline consumption once commercialized [29].

In parallel with the achievements of the advanced bio-fuels, the current technologies for the commercial corn ethanol production are improving on all fronts from the corn field to the refinery. Figure 6 shows the improvements in corn production resource needs for the years 2007 vs. 1987 [30].

Figure 6. Improvement in Corn Production Resource Needs, 1978-2007
(Expressed as impacts/resource needs per bushel produced) [30]

Environmental Impact

The National Renewable Energy Laboratory (NREL) was the first body to venture into bio-fuel research, concentrating primarily on cellulose ethanol. Environmental impacts associated with bio-fuels can be associated to the nature of its production. In recent years, there has been a lot of emphasis on the technology and challenges of bio-fuel systems and their relative efficiencies with respect to energy and carbon dioxide emissions. This research has paid less attention to the impact on the environmental issues associated with the development of large scale bio-fuel production [31]. The researchers suggested that the average future GHG emission from corn ethanol and gasoline or diesel fuel could be similar, however, there is uncertainty associated in these estimation [31]. In general, ethanol doesn't provide any quality advantage in local air over gasoline [31].

According to Kojima and Johnson 2005, the liquid bio-fuel production was a little over 1% of the global renewable energy and a little shy of 1% of the global crude oil. This statement suggests that nations started considering issuing policies that will encourage the involvement in alternative fuel research and the impact may be felt within a decade [1]. These policies fueled the concerns of environmentalists which feared a shift toward more corn oriented farming to take advantage of these policies and realize more economic gain. To achieve a better crop, farmers may tend to increase the use of fertilizers and pesticides. The increased use of these chemicals may cause additional damage to the environment. Also, there is a fear that additional farmland will be needed. At what cost? Cellulosic ethanol requires wood-like biomass which would impact forestation and there are already debates about how to use corn crops – for food or ethanol production. The potential of expanding farming/forestation to manufacture ethanol directly affects the amount of GHG presence in the environment [31].

Economic Impact

The United States government invested a significant amount of money in domestic bio-fuels production hoping that they will one day be the primary source of energy. This way, a non-renewable fuels independency will be possible - the diversification of the energy market would be of a positive benefit to the producers and consumers. This investment is a direct response to forecasted shortages and increased prices of fossil fuels. The Agro-biotechnology journal estimates that by 2015 the US corn market is expected to support 15 billion gallons of ethanol which will only be enough for less than a quarter of the overall U.S. population fuel demand. Also, 12.3 billion bushels of corn would be available for the food industry and export market [32]. However, the economic potential associated with bio-fuel is dependent on energy prices and policies regulating the researches and production of renewable energy. Day to day fluctuations of oil prices make it hard to predict ethanol's economic potential in the United States [1].

DISCUSSION

Although Brazil is not as developed a nation as the United States, it still could successfully adopt alternative fuel technology, to the extent that it is known as an "oil-independent" nation. In comparison, the U.S. hopes to be fossil-fuel independent by 2020, yet it is one of the prosperous countries in world. The research attempted to understand this paradox by examining the political, cultural, technical, economic, and environmental impacts surrounding bio-fuel adoption. In general, studying the history of alternative fuels in Brazil and U.S. shows that the countries employed completely different policies at the same period of time. In the 1930s, Brazil established the first policy of alternative fuel while the U.S. consumption of biodiesel collapsed due to a total absence of any marketing campaigns. Instead U.S. investors pursued the petroleum industry.

Regarding the source of bio-fuel, each country uses a different source. Brazilian feedstock relies primarily on sugarcane while the U.S. cultivates corn to produce ethanol. By comparing sugarcane and corn characteristics (Table 3) it is understood how sugarcane characteristics help Brazil to produce ethanol through easier processes and increased yields, versus corn, which is used by the U.S. [33].

Table 3. Sugarcane and Corn Characteristics Comparison [33]

Brazil- Sugarcane	United States- Corn
The sugar (source) in sugarcane can be converted directly into ethanol.	The starch in corn is first converted into sugar. Then the sugar is converted into ethanol.
Sugarcane is planted every six years using cuttings.	Corn is planted every year using seeds.
Sugarcane provides five cutting over six years and then is replanted	Corn is harvested once each year.
Sugarcane yields about 35 tons per acre (entire plant) per harvest acre.	Corn yields about 8.4 tons per acre (entire plant) per harvested acre.
Sugarcane yields about 4.2 tons of sources per acre (10 to 15% of sugarcane yield).	Corn yields 4.2 tons of corn graph per acre (150 bushels) or 2.4 tons of starch.
An acre of sugarcane produces about 560 gallons of ethanol (35 tons yield).	An acre of corn produces about 420 gallons of ethanol (150 bushel yield).
Sugarcane feedstock is cheaper to grow than corn per gallon of ethanol.	Corn feedstock is more expensive to grow than sugarcane per gallon of ethanol.
Sugar-ethanol can be produced cheaper than corn-ethanol.	Corn-ethanol is more expensive to produce than sugarcane-ethanol.
The by-product of ethanol production is bagasse.	The by-product of ethanol production is distillers grains with soluble that is used as livestock feed.
The energy source for ethanol production is bagasse.	The energy source for ethanol production is natural gas coal, coal and diesel.
About 9 million acres are used for ethanol production.	About 180 million acres are used for ethanol production.
Brazil has great potential for expanding sugarcane acreage without limiting the acreage of other crops.	U.S. expansion of corn acreage will come at the expense of reduced soybean and other crop acres.
No subsidies for ethanol	Subsidy reduction from \$.51 per gallon to \$.45.
No import tariff on ethanol	A \$.54 per gallon import tariff.

However, in 2007, U.S. surpassed Brazil in ethanol production. This can be the result of enforcing some environmental restrictions in Brazil – the government has forbidden burning from July until the middle of October, as well as prohibiting burning if the relative humidity falls below 20%. These restrictions focus on environmental conditions that are conducive to respiratory illness [3,330].

One reason that Brazil could adopt alternative fuel relatively easy is Brazil's historic ability to be flexible. This cultural basis is known as Jeitinho. Brazil has a cultural reference of adaptability and willingness to change versus the U.S., where people seem reluctant and resistant to changes. Related to the cultural adaptability, this may not be an area where the U.S. can apply the lessons learned from Brazil.

Based on their previous bio-fuel experience, beginning in the 1930s, Brazil could largely develop the required technological infrastructures to use ethanol throughout the nation. Brazilian car manufacturers produced FFVs that can run on gasoline, ethanol, or any combination of the two. This flexibility allows the consumer to adapt to changing markets/prices. Also in Brazil all gas stations are well equipped for storing and distributing both gasoline and ethanol. In comparison, the United States does not use FFV in the same manner as in Brazil; U.S. FFVs only run on E10, a mix of ethanol and gasoline, nor does the U.S. have an infrastructure to support wide scale production or distribution. It can be inferred that the inaccessibility of bio-fuel is causing less acceptance in U.S. (as compared to Brazil).

Both Brazil and the United States have concerns about the environmental effects of bio-fuel, but in this respect both countries have taken different measures to deal with those concerns. In Brazil, as mentioned earlier, the government has legitimated some regulations for producing bio-fuel, while the U.S. is expanding research on algae as an alternative source for producing bio-fuel; the process of manufacturing alternative fuel from this source is less harmful to the environment.

In Brazil bio-fuel has proved to be economically beneficial, both as an export and national fuel source. The U.S. is struggling with a wide-scale adoption so economic impacts are less certain. One economic impact that is readily seen in the U.S. is on the price of corn – it's a balance between using corn as a food source and using it to manufacture bio-fuel.

CONCLUSIONS

This research focused on bio-fuel adoption for the two largest ethanol producers - Brazil and The United Sates. Both countries were well studied regarding political, cultural, technological, environmental, economic issues. A summary of their response for each perspective is summarized in table 4. Each country had/has a strong political influence which encouraged research in alternative fuels. Similarly, each had supportive policies and regulations such as assigning tax credit and increasing investment.

Table 4. Brazil and U.S. Comparison Regarding Bio-fuel Approach

Aspects	Brazil	USA
Political • Alternative fuel first policy-1931 • Proalcool to support ethanol production • Investing on developing ethanol (efficiency, Production and adoption • Cheaper credit for private firm • Tax breaks for customer	• Switch back to bio-fuel 21st century • Strategy for Alternative fuel vehicle production (96%) • Tax credit 1.01$/gallon • Adoption at the state level • Oil-independent- now • Biodiesel collapsed due to new petroleum industry-1930s	• Support bio-fuel market by car manufacturers- 1 • 800M investment • Oil-independent-2020
Cultural • Ethanol accessibilities gas station • Switch over to oil- oil price reduction in 1985	• Jeitinho- historical flexibility in adopting change • Transferring lands from farmers to investors • Work for investors	• Change rural life into more civilized life
Technological • Flexible Fuel Vehicle (FFV)- 100% of either fuel • Previous experience of alternative fuel	• Sugar cane supply [33] • Use of peanut oil in diesel car-1880	• FFV- combination of gas and bio-fuel • Corn supply [33] • Algae for bio-fuel production
Environmental • Environmental damage due to burning sugarcane • Health threat	• Prohibiting burning actions • Environmental damage due to excess of farming consequences like: • Soil fertilizing • Pesticides	• Vegetable cleaning and burning
Economical • 2004, 33% ethanol production in the World • Profitable export • Two productions: sugar and ethanol • High quality Jobs	• Technology transfer - wealth among private sector • 2010, 57% ethanol production in the World • Increase food price	• Increase hunger

In general, this research identified two areas where the U.S. might better understand the success in Brazil and determine how these technologies could be applied. Prior to the manufacturing process there does not appear to be significant opportunities to

utilize best practices. It can be inferred that the technologies used to harvest and manufacture ethanol from sugarcane are too disparate from those required to manufacture ethanol from corn – it would be like comparing apples to oranges. Also, the cultural foundation of jeitinho can not be useful to the U.S. adoption. However, post production there appear to be opportunities to better understand the success in Brazil and apply to the U.S.
Two areas where the U.S. can learn from Brazil involve technological and environmental (infrastructure) perspectives. It would appear that having a *fully* FFV, that is one that can operate on ***any*** ratio of ethanol to gasoline, was critical in the wide-spread adoption in Brazil. This technology accommodates adjustments to fuel blends as a result of fluctuating prices or facilitates a more gradual transition from gasoline to ethanol. More specifically identifying the obstacles to manufacturing and implementing FFVs in the U.S. is suggested for future research. Also, the U.S. does not have a sufficient infrastructure to support the delivery and consumption of bio-fuel. Parallel to other bio-fuel research, the U.S. should consider the infrastructure success in Brazil and determine necessary steps to have one (infrastructure) in place to meet the objectives previously stated: to be oil-independent by 2020.

FUTURE RESEARCH

Any one of the perspectives considered in this report could be developed further, to more specifically understand the issues. Often one perspective had an effect on another (e.g. mandating 100% mechanized harvesting in Brazil would decrease the number of jobs for rural workers). Therefore, general future research could include a discussion on the inter-relationships between the perspectives, as they pertain to bio-fuel adoption.
The report identified potential areas for additional research, which if further understood, may facilitate a more wide-spread adoption in the U.S.

- **FFV:** Vehicles that can operate on 100% ethanol, 100% gasoline or any combination of the two. This technology allows Brazil to respond to fluctuating pricing policies. Analogous to this type of technology, the U.S. is researching the use of smart meters to be used in energy conservation. If the population is ready for flexibility with their energy use then perhaps they might be amenable to flexibility with their vehicles?
- Assuming the U.S. will meet the 2020 target for oil-independence, what alternative fuel source will be used? There are already significant debates about corn and cellulosic ethanol. However, the report identified algae as a promising substitute. Future research is recommended to more fully understand the potential of this fuel source. Could this be a golden opportunity to solve the bio-fuel answers for the U.S.?

Finally, while not directly related to applying lessons learned but discussed in this report, it will be very interesting to watch the impact of a new President and off-shore oil reserves on the future of bio-fuel in Brazil.

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