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Transportation Biofuels in the US A Preliminary Innovation Systems Analysis

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1 Introduction

The recently heightened attention to US petroleum consumption and the associated environmental and economic impacts has resulted in a resurgent interest in biofuels as an alternative source of energy for transportation. The production and use of biofuels for transportation is not a new idea and in fact has been around as long as we have had cars. The difference today is a combination of factors – economic, environmental, technical, and political – that have combined to create an atmosphere in which biofuels are viewed as having the potential to replace a significant percentage of our transportation energy needs. This paper is an attempt to understand the most significant factors that have contributed to this situation and to use that understanding to provide insight about the impact of future policies and business decisions on the market.

The transportation biofuels market in the US has grown substantially in the last few years with sales reaching almost 4 billion gallons in 2005, up from 2 billion in 2002. Sales are expected to exceed 5 billion in 2007 (see Figure 1) with an additional 6.2 billion gallons capacity under construction over the next several years.[1]

The recent growth in the market in the US is driven almost entirely by the use of ethanol as a blending agent for gasoline to increase octane and as an "oxygenate" for cleaner combustion. Ethanol can be blended into gasoline up to concentrations of 10%[2] without any modification of the vehicle or retail infrastructure required. The use of ethanol in concentrations greater than this, which would currently require either a dedicated alcohol or "flex-fuel" vehicles (FFV)[3] and capable retail fuel dispensers, has been minimal[4]. In this sense, the current demand for biofuels as a true 'alternative fuel' is nearly non-existent. It will be one of the key points within this paper to make the distinction between biofuels as a blend vs. biofuels as an alternative fuel.

Despite significant efforts by the federal and state governments, the use of dedicated alternative fueled vehicles and fuels (including biofuels) has been limited at best. From the US Department of Energy's Multi Year Plan [1]:

> EPAct [1992] grew out the efforts of the previous Bush Administration to establish a national energy policy. It has been a failure in terms of its intent to encourage the use of alternative fuels in the transportation sector. EPACT focused too much on purchases of alternative fueled vehicles, without paying enough attention to its real goal of seeing alternative fuels enter the marketplace. Flexible fuel vehicles such as the kind that can use ethanol or gasoline have indeed found their way into the marketplace, but few fleets and car owners are actually using the fuel. The NEP report acknowledged this failure and suggested that "[r]eforms to the federal

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[1] http://www1.eere.energy.gov/biomass/biomass_basics_faqs.html (values may include 2007 expansion)

[2] Although many blenders currently use only around 5.7% ethanol (E5.7) to meet oxygen content and octane specifications

[3] It is debated whether existing conventional (non-FFV) might be able to accommodate increased concentrations up to 15-20% by volume.

[4] Estimates from EIA for 2004 where 22 Million Gallons of E85 or less than 1% of ethanol sold that year.

> alternative fuels program could promote alternative fuels use instead of mandating purchase of vehicles that ultimately run on petroleum fuels."

Other reasons given for the limited success of alternative fuels in the US transportation market include [2]: 1) Higher first cost for vehicle; 2) Onboard fuel storage issues (esp. w/ gaseous fuels); 3) High fueling cost (compared w/ gasoline); 4) Safety and liability concerns including insurance; 5) Limited retail infrastructure and 6) The competition (gasoline ICE's) did not stand still. This last point bears further emphasis, especially as it relates to the factors that contribute to the support for new technologies and their competition with conventional technology. Throughout the 80's and 90's, alternative fuels were promoted not only as a way of reducing petroleum dependency but as way of cost effectively reducing criteria air pollutant emissions[5]. During this same period, through the advent of reformulated gasoline and the significant reduction of emissions from the vehicle through the use of improved catalytic converters, fuel injection, evaporative emissions control, onboard diagnostics, and other emissions control equipment, the automobile and energy industry virtually eliminated the advantage that alternative fuels had in this area[6].

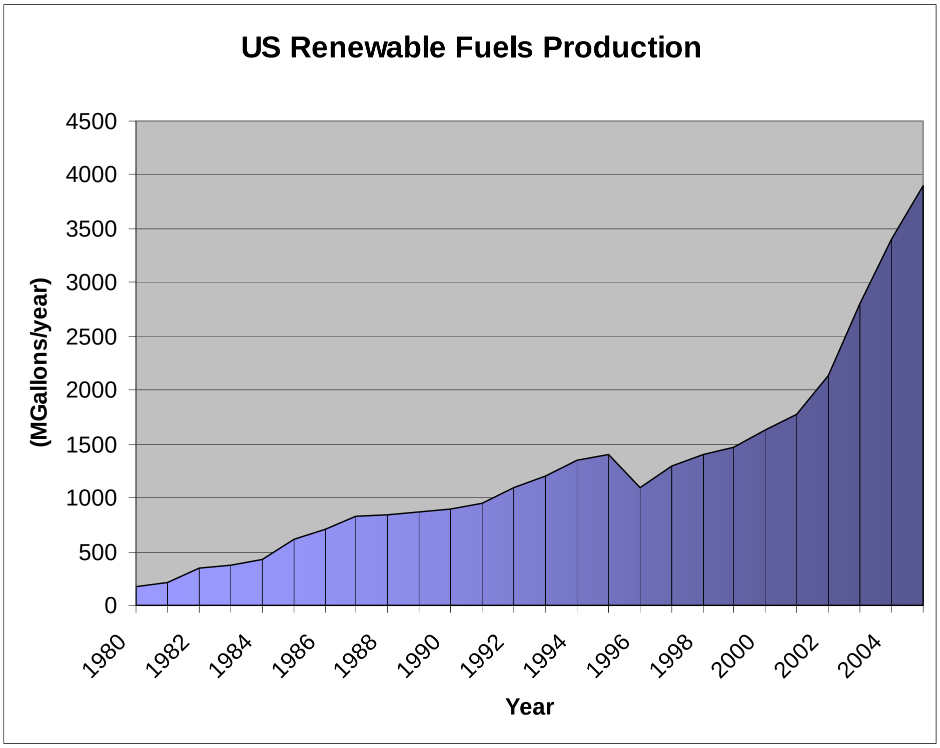

Figure 1: US Renewable Fuels Production (based on data from EIA)

The previous failure of alternative fuels to gain a significant foothold in the market and the relative success of ethanol as a blending agent in gasoline highlights some of the

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[5] "Criteria emissions" here refer to the noxious gases including (but not limited to) Nitrous oxides, hydrocarbons, carbon monoxide, etc. and were not considered to include carbon dioxide.

[6] One key exception was the use of natural gas in heavy duty transit applications.

challenges and opportunities associated with introducing new fuels into the transportation marketplace, the significance of which will be discussed within this report.

The report is structured as follows. It begins by conducting a brief review of the technology specific innovation systems literature as it applies to biofuels with a focus on the major actors, institutions and networks. It then begins the discussion by focusing on the various inducement and blocking mechanisms that are likely to have the greatest influence on the biofuel innovation system within the US. Throughout this discussion we have included areas of focus where we feel additional detail is warranted about a particular aspect of the system (identified by 'Focus' boxes). After the TSIS biofuel discussion, we undertake a simple scenario analysis of the US DOE's "30 by 30" plan and discuss the significance relative to the TSIS framework. Finally we end with the key observations from the report and identify the primary areas of interest for future work.

2 TSIS Framework Applied to Biofuels

The field of Innovations Systems (IS) research attempts to describe the major factors that contribute to the success or demise of a particular product, technology, process or idea. More recently, the idea of Technology Specific Innovation Systems (TSIS or just "Technological System") has emerged which take a particular technology or technological process as the focus [3, 4]. From Hekkert [4]:

"A technological system is a combination of interrelated sectors and firms, a set of institutions and regulations characterizing the rules of behavior and the knowledge infrastructure connected to it."

The system itself is said to be made up of a number of elements, including actors (or agents), networks, and institutions. A more complete discussion of these elements for biofuels is discussed in section 2.1.

TSIS analysis is inherently reflective in nature, requiring a deep study of the historical evolution of technological systems. It can also be used to look towards the future for a particular technology and can be particularly powerful when combined with other tools such as diffusion and scenario analysis. The value of this type of analysis is that it provides the analyst a methodological framework for describing the evolution of technology markets that extends well beyond the more traditional tools of simple techno-economic or policy analysis. By identifying powerful reinforcing or blocking mechanisms, TSIS can be used to help guide the development of effective policy and business strategy and has been used to study, for example, the diffusion of renewable technologies such as wind and solar power in Germany [5] and the rise and fall (and possible rise again) of biomass gasification for power production in the Netherlands [6]. What follows is a discussion of these elements using the framework laid out initially by Jacobsson [3, 7] but modified slightly to accommodate the primary characteristics of interest for the biofuels technical system.

2.1 TSIS Elements

TSIS consists of a number of elements including actors, networks and institutions (shown in Table 1). Actors are firms or other organizations that are sufficiently important technically, financially, or politically to have a strong influence on the innovation and diffusion process. Major actors in the biofuels arena include farmers, agro-business (e.g. ADM, Conagra), researchers (e.g. at National labs, universities), government representatives (e.g. at USDA, UCDOE, California Energy Commission), and energy analysts. These actors can significantly influence the pace and direction of innovation internally (and individually) through product research, development, and diffusion, and collectively by creating or joining professional organizations (e.g. Standard Development Organization's) and associations (e.g. Renewable Fuels Association), and lobbying governments for resources and favorable policy treatment (see also [8]). Different policy regimes (e.g. State vs. Federal) may involve substantially different actors, which can result in regional differences in the direction of TSIS.

Networks are channels for the transfer of both market and technical knowledge. Networks can help to identify promising areas for market development as well as help guide research and resolve technical problems. Networks in the biofuel arena include (for example): research and market focused workshops, user-supplier networks, association and collaboration meetings, congressional testimony process, and the media.

Institutions such as education and research institutions, government agencies and bodies, standing codes and legislation, and capital markets all act to create, diffuse, and store knowledge and set rules and expectations. Institutions are distinct from the actors that exist within them because institutions have the ability to endure beyond the career of any individual. Institutions relevant to biofuels include long-standing biofuels research institutions, state and federal legislatures, venture capital markets, etc.

Primary Actors	**Institutions**	**Networks**
Industry (OEM's, Suppliers, Energy Co.'s	Government agencies	Conferences/Workshops
Codes officials/AHJ's	Research Institutions	Journals
Policy makers	Associations	Supplier networks
Govt. agency representatives	SDOs	Media
Investors	Capital networks	
Researchers	Legislative bodies	
Consumers		

Table 1: Actors, Institutions and Networks

2.2 TSIS Functional Forms for Biofuels

A basic form of TSIS is to describe a number of functions that are served by the system to enable new technologies to develop into commercial products. The purpose of defining the innovation system in this way is to establish an empirical form which we can use to evaluate how particular actors, institutions, and networks affect the development and diffusion of new technologies through time.

This analysis will use a modified form of the framework developed by Jacobsson [2]. The functions we will include in our analysis are:

F1. Creation and diffusion of new knowledge
F2. Supply of resources (capital and competencies)
F3. Guidance of the direction of research (incl. choice of design approach)
F4. Creation of positive external economies
F5. Formation of markets

The first function (F1) "creation and diffusion of new knowledge" relates to the process by which knowledge is generated either through new research or synthesis of existing research and the diffusion of that knowledge through publications, workshops, conferences, testimony, etc. This includes information diffusion about the technology and its potential not only within the research community but also to potential investors, policy makers, skilled trades, etc.

The second function (F2) "Supply of resources" includes the provision of resources which includes both capital and human resources. This includes funding for biofuels research, development, demonstration, and deployment (RD3), government incentives, construction of new facilities and associated infrastructure, and human competencies applied to the system. For biofuels research, development and demonstration, the expansion of both government and industry budgets has increased substantially over the last 5-6 years. For example funding for DOE's biofuel initiative in 2007 is $150 million, a 59% increase over 2006 and DOE recently announced funding of $385 million over four years for six new biorefineries[7]. Government funds, however, pale in comparison to recently increased industry spending on biofuels. Recent industry investment in new biofuels production capacity is soaring, with an estimated investment in new capital from 2000 to 2006 of nearly $10Billion for ethanol production and $1.8 billion for biodiesel production [9].

The third function (F3) "Guidance of the direction of search" refers to guidance about the choice of design as well as the growth potential for a particular market. This function can often manifest itself in the various "roadmaps" that are put out by major actors in the system (for example: [1, 10, 11]) and can affect the future allocation of resources (F2), especially those provided by government agencies[8]. Good guidance will be very important for biofuels as there are a significant number of competing process designs and end-products and it is not at all clear at this point which dominant designs will emerge and when (see

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[7] http://www.energy.gov/news/3255.htm and http://www.energy.gov/news/4827.htm

[8] This is true of the Government agencies that author the roadmaps as well as the firms and research organizations that contribute and/or base their strategies on them.

Focus 3: Biofuels ≠ Ethanol & Biodiesel).

The fourth function (F4) “Creation of positive external economies” relates to the benefits associated with additional firms entering the market and the associated supporting organizations that build up around this activity. For biofuels this could include increased availability of technical service suppliers as well as the economies of scale associated with supporting markets (F5) including distribution and dispensing infrastructure, feedstock markets (including for power production) and related technologies. These are also referred to as ‘network externalities’ within the economics literature.

The fifth function (F5) “Formation of markets” is often broken into several phases including an early or ‘formative’ phase and a later or ‘market expansion’ phase. The formative phase is characterized by low volume of sales and often only into ‘niche markets’. Niche markets are those that are generally capable of absorbing a higher initial cost and help to bring the technology down the cost curve. Niche markets can also be valuable in that they increase the legitimacy of the technology by demonstrating real world costs, quality, and reliability. The market expansion phase is characterized by a rapid growth in sales to a steadily increasing number of customers. For traditional technology diffusion, the market (or customers) are sometimes broken into categories such as ‘innovators’, ‘early adopters’, ‘early majority, fast followers’, ‘late majority’ and ‘laggards’ ([12], others). One key question for biofuels is “who is the customer (see Focus 1)? This depends largely on what part of the biofuel supply chain we are interested in. If the biofuel production technology itself is the focal point, then the customer is most likely the major biofuel producers. The likely-hood of different biofuel producers adopting a new biofuel technology (such as cellulosic production technology) will be driven by that producers risk tolerance, access to feedstock markets, and associated policy factors.

While the term ‘function’ suggests an activity that can be acted upon by various mechanisms (described below), it should not be confused with ‘functionalism’ which suggest that these systems can be modeled objectively. From Hekkert [4]:

> The positivist view with which functionalism is associated holds that social systems can be studied objectively, or value-free. The social world is regarded as a mechanistic system, which can be understood by discovering its elements and the laws by which they are directed. Since the social system, in this concept, does not essentially differ from the physical system, it should be studied by using the same methods as is done in studying the physical system. Given these associations we stress that our project rejects these ambitions and that we fully recognize the contingent and reflexive nature of social reality that prevents such an analysis.
>
> Notwithstanding its cumbersome history, we think that the notion of “function” is useful, provided we stress its heuristic value instead of its positivistic value: it helps to identify, understand, and compare the crucial activities in technology specific innovation systems and it creates insight in the dynamics and possible

> patterns of technological change and related innovation processes. By doing so, it offers policy makers and other actors involved in innovation processes important insights that may guide and support their actions.

Each of the functions discussed above can be affected by various inducement or blocking mechanisms which act to either accelerate or impede the development of the new technology or technologic system. For the purposes of this analysis, we will use a modified form of inducement and blocking mechanisms from Jacobsson [3] as follows (also shown diagrammatically in Figure 2):

Inducement mechanisms

I1. Government policy
I2. Firm entry/activity
I3. Feedback from market formation

Blocking mechanisms

B1. Government policy
B2. Market uncertainty
B3. Lack of legitimacy

Inducement mechanisms act to accelerate the introduction of a technology by strengthening one or more of the functions previously described and create reinforcing or virtuous cycles. For example - government policy (I1) by providing R&D funding (F2) which would cause additional firm activity or new firm entry (I2), which in turn would create new knowledge (F1). These new firms (or activities) (I2) could then further lobby government (I1) for additional government funding (F2).

Blocking mechanisms can act on certain functions to slow and block new technologies from entering the market. For example - lack of confidence in the performance of a particular technology (B3) can stall additional investment (F2) which can create market uncertainty (B2) about that same technology. A further discussion of each of these mechanisms specifically relating to biofuels in general and to cellulosic biofuels in particular is taken up in section 3.

Inducement Mechanisms	**Functions**	**Blocking Mechanisms**
Government policy (I1)	Creation/Diffusion of New Knowledge (F1)	Government policy (B1)
Firm Entry/Activity (I2)	Supply of Resources (F2)	Market Uncertainty (B2)
Feedback from market formation (I3)	Guidance of search (F3)	Lack of Legitimacy (B3)
	Positive external economies (F4)	
	Formation of markets (F5)	

Figure 2: Functions, inducement and blocking mechanisms for TSIS

As we discuss the history and current state of the biofuels technological system in this report, we will indicate which function (F), inducement (I) or blocking (B) mechanisms are being discussed by using the prefix and number of associated with the descriptions above.

Focus 1: Who is the customer?

In order to understand the characteristics of market growth for biofuels and biofuel technologies, it is important to understand who the customer is and how they will interact with the product.

The ultimate customer for biofuel end product is, of course, the driving public. However, depending on the type of biofuel and the way it is sold, the driving public may have only a limited role in the development of the market. As previously mentioned, the majority of biofuel sold today is ethanol which is sold as a blending agent for gasoline up to levels of 10% by volume (E10). In most markets that have ethanol blends, the customer is not given a "choice" between gasoline that contains ethanol and gasoline that does not. If they want the fuel, they buy what is available. When we do give people a choice, as in the case when E85 is sold along side gasoline for use in flex fuel vehicles, the ultimate decision for the purchase of the product is the consumer (see also Focus 4). In this case, the consumer will make a decision about whether to purchase that fuel based on a variety of factors including price (relative to gasoline), availability, and performance (esp. how it affects power, durability, and range of the vehicle). The consumer may also feel compelled to purchase the fuel for social reasons including a desire to minimize environmental impact, support local farmers, etc.

The history of alternative fuels use tells us quite clearly that, absent policy that requires it, the alternative fuel of interest has to provide substantial private advantages over the existing fuel (gasoline) if it is to be adopted [2, 13-15]. This creates a challenge for biofuels such as ethanol, which, when used in an FFV provides very few, if any, private advantages over gasoline. The exceptions are possibly price, depending on the relative price between ethanol and gasoline, and slight improvements in maximum output power (ref EPA). The driver will experience a reduction in range due to the lower energy content of ethanol and an associated reduction in volumetric fuel economy (miles per gallon ETOH)[9]. This is not to suggest that E85 markets will not develop, just that we should be aware of what drives consumers to adopt certain types of vehicles and fuels. In addition, if the factors that are contributing to the relative differences between ethanol and gasoline are changed (such as the removal or reduction of price subsidies), we should understand the impact it may have on the market.

As we work our way up the supply chain we find that the next customer for biofuel product is (for example) the fuel retailer, the local distributor, the refiner (possibly) and the biofuel producer (who buys the biofuel feedstocks from another separate feedstock supply chain). The biofuel producer is also the customer for existing and new biofuel production technologies. Their choice of whether to use existing biofuel technologies such as dry and wet mill fermentation of sugars and starches (for ethanol) or oil transesterfication (for biodiesel), or more advanced technologies such as enzymatic fermentation, acid hydrolysis, or thermochemical conversion of cellulosic feedstocks (e.g. switchgrass, corn stover, poplar, etc.) will be determined by factors such as cost, technological maturity or legitimacy (B2), knowledge base for the new technology (F1, F3), government policy that might encourage (I1) or discourage (B5) the use of the new technology (e.g. cellulosic ethanol distinguished from corn ethanol in carbon policy, for example), and market formation (I3) both for the product and the feedstock.

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[9] They might actually experience a slight improvement in gasoline equivalent fuel economy (mpgge)

An example of a virtuous cycle that is likely to develop for cellulosic biofuels is the recent funding of six new production facilities for cellulosic ethanol production (see http://www.energy.gov/news/4827.htm). These projects were incentivized by government co-funding for the facilities (I1 > F2) and have already created new firm activity (I2). The demonstration of these technologies will contribute the creation of new knowledge about cost, reliability, and other performance characteristics of the technology (F1) and (if successful) will act to reduce the uncertainty (B2) of the technology. These firms will also then be in a position to lobby the government for additional policy support (I1) for this type of technology. Whether or not this activity is sufficient to launch a successful commercialization of this technology remains to be seen.

3 Biofuels in US – Politics, policies and impact on diffusion

This section will discuss the history of the US biofuels market including the early policies and activities that influenced the pace and direction of the market diffusion with a particular focus on the inducement and blocking mechanism's that have contributed to the current market condition.

3.1 Inducement Mechanisms - A History of Policy Support

I1. Government policy

The market for biofuels in the US has always been strongly influenced by US energy and agricultural policy [9]. The Renewable Fuels Association, an advocacy group for the promotion of biofuels, states: "renewable fuels are produced only in countries where programs have been created to assist their production"[10]. The USDA agrees in a 1997 report – ""[t]he most influential actors in the ethanol industry are Federal and State Governments".[11]

While biofuels have existed in the US since before Henry Ford demonstrated that the Model T could run on ethanol in 1908, the modern biofuels effort was really initiated during the 1970's, born from the oil shocks as well as a desire to reduce air pollution by mandating lead-free and cleaner burning formulations of gasoline. These two drivers, along with a desire to support the domestic agricultural system, set the early stage for the modern US biofuels market.

The 1973 oil embargo spurred a number of policy actions by the US government in order to promote the domestic renewable energy sector. The Energy Tax Act of 1978 which also promoted wind, solar and geothermal energy, was the first to define gasohol as a blend of gasoline with at least 10 percent alcohol by volume, excluding alcohol made from petroleum, natural gas, or coal. This act removed the excise tax on gasoline of \$0.04 for gasohol[12] and initiated a market for biologically derived alcohols for the transportation sector.

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[10] Renewable Fuels Association, "The Importance of Preserving the Secondary Tariff on Ethanol," 30 June 2005.

[11] Crooks, Anthony. Cooperatives and New Uses for Agricultural Products: An Assessment of the Fuel Ethanol Industry, Rural Business-Cooperative Service, U.S. Department of Agriculture, 1997. Research report 148

[12] As this was applied to the 90/10 blend, it was an effective tax credit of \$0.40 per gallon of alcohol.

This exemption has continued in various forms from 1973 to present time with the most recent version defined by the JOBS Creation Act of 2004 which created the Volumetric Ethanol Excise Tax Exemption of $0.51/gallon. See Table 2 for history of this exemption over time [9].

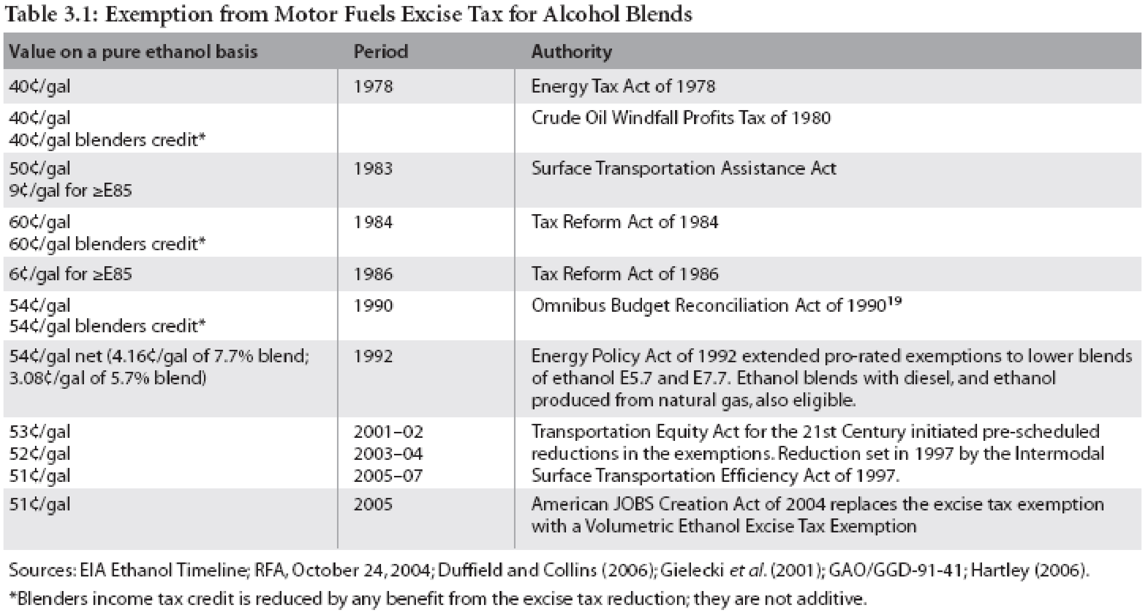

Table 3.1: Exemption from Motor Fuels Excise Tax for Alcohol Blends

Value on a pure ethanol basis	Period	Authority
40¢/gal	1978	Energy Tax Act of 1978
40¢/gal 40¢/gal blenders credit*		Crude Oil Windfall Profits Tax of 1980
50¢/gal 9¢/gal for ≥E85	1983	Surface Transportation Assistance Act
60¢/gal 60¢/gal blenders credit*	1984	Tax Reform Act of 1984
6¢/gal for ≥E85	1986	Tax Reform Act of 1986
54¢/gal 54¢/gal blenders credit*	1990	Omnibus Budget Reconciliation Act of 1990[19]
54¢/gal net (4.16¢/gal of 7.7% blend; 3.08¢/gal of 5.7% blend)	1992	Energy Policy Act of 1992 extended pro-rated exemptions to lower blends of ethanol E5.7 and E7.7. Ethanol blends with diesel, and ethanol produced from natural gas, also eligible.
53¢/gal 52¢/gal 51¢/gal	2001–02 2003–04 2005–07	Transportation Equity Act for the 21st Century initiated pre-scheduled reductions in the exemptions. Reduction set in 1997 by the Intermodal Surface Transportation Efficiency Act of 1997.
51¢/gal	2005	American JOBS Creation Act of 2004 replaces the excise tax exemption with a Volumetric Ethanol Excise Tax Exemption

Sources: EIA Ethanol Timeline; RFA, October 24, 2004; Duffield and Collins (2006); Gielecki *et al.* (2001); GAO/GGD-91-41; Hartley (2006).

*Blenders income tax credit is reduced by any benefit from the excise tax reduction; they are not additive.

Table 2: Excise Tax Exemption History [9]

Other historical policy incentives that have contributed significantly to the success of biofuels in the US include funding for RD2, plant construction subsidies, additional credits and subsidies from states, and import tariffs. A compilation and discussion of these historical and current subsidies can be found in Koplow's excellent summary "Biofuels – At what cost?" [9]. Koplow estimates that the total per gallon subsidy of ethanol has been as high as $3.14/gallon (average between 1982-1986) and is currently around $1.06 - $1.45/gallon (2006 estimate).

Government policy is often used during the formative phase of market development (F5) to create a protected space for new technologies [7]. In the case of biofuels, the presence of subsidies for domestic production and a tariff on imports is one clear example of a protected space created through policy.

A major policy that has contributed to the recent growth of the ethanol market was the EPACT 2005 phase-out and lack of liability protection for MTBE which left ethanol as the only major substitute to meet fuel octane requirements. This along with the Renewable Fuels Standard or RFS (see section 7.2) which requires the purchase of increasing amounts of renewable fuels from 4 billion gallons in 2006 increasing to 7.5 billion gallons by 2012 ensured the rapid growth in the biofuels market[13].

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[13] Although most industry analysts believe that the 2012 production will far exceed the RFS making the standard irrelevant.

Other policies that will have a major impact on biofuels going forward include the upcoming federal farm bill which is anticipated to have significant incentives for biofuels and climate policy that includes transportation fuels. Of particular interest in future policy is the distinction between those that incentivise biofuels directly or those that affect the market for biofuels indirectly by regulating the inputs and impacts of biofuels production (see Focus 2: Carbon policy and biofuels).

Focus 2: Carbon policy and biofuels

One particular government policy that could have a significant influence on the future biofuels market is climate or GHG/carbon[14] policy (reference herein just as 'climate policy'). During the US 109th congress, approximately 106 bills, amendments, and resolutions addressing climate change and greenhouse gas emissions were introduced[15]. Depending on how climate policy is designed and whether it explicitly addresses transportation fuels, could have a significant impact on the market for biofuels as well as on how those fuels are produced.

The primary characteristic of climate policy of interest for biofuels is how much of the supply chain is affected by the policy and how. A policy that affects all aspects of feedstock production, distribution, conversion, delivery and end-use (including all the inputs into each) would likely push the biofuels market toward lower life-cycle GHG feedstocks and processes such as cellulose conversion (see Focus 6: Biofuels - The Great Energy and Environmental Debate) . This could be done either by regulating those entities individually through a cross-sector "cap and trade" type program, GHG taxes, or GHG intensity standards (including life-cycle GHG intensity regulations such as California's proposed "low carbon fuel standard"). Each of these can be designed differently to affect how much of the life cycle GHGs are affected and who is actually regulated.

For example, a sector-wide cap and trade program (or carbon tax) which includes agriculture, fuel production and distribution would likely create a system where the cost of GHG's would be transferred from one entity to another by way of input prices. For example, an ammonia plant that had to account or pay for its GHG emissions would pass some of those GHG costs along to the farmer, who would pass them along to the biofuel plant, etc.[16] Each actor in the chain which emitted GHGs emissions would then be incentivized to reduce their emissions in order to reduce the price of their product. A GHG intensity type regulation would likely work similarly with the primary difference being that the goal is to reduce the overall GHGs per unit of output (as opposed to GHG's overall). A final distinction is who is the regulated entity and whether they will be required to account for upstream GHG's associated with inputs into their process.

Besides offering R&D and direct market support through incentives and subsidies, the government can also promote diffusion by acting as a large user of new technologies or products. In the case of biofuels, the government can act to promote certain types of production processes and technologies by procuring fuels that use those technologies.

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[14] The term 'carbon' used in this Focus discussion is intended to imply carbon equivalent emissions

[15] See http://www.pewclimate.org/what_s_being_done/in_the_congress/109th.cfm for listing.

[16] The carbon cost would effectively act as a tax and the extent to which each entity would be able to pass along those costs would be determined by the associated producer and consumer elasticities (among other factors).

Focus 3: Biofuels ≠ Ethanol & Biodiesel

An area that appears to cause some level of confusion within the biofuel technological system is the lack of distinction between the term "biofuels" and the two most commonly known end-products, ethanol and fatty acid derived biodiesel. The two terms are often used interchangeably even though the latter (ethanol and biodiesel) are only a subset of the former (biofuels)[17]. In fact there are a large number of potentially suitable transportation fuels that can be made from biomass feedstocks including butanol, iso-octane, and even synthetic diesel fuel that is virtually indistinguishable from regular diesel (although having near-zero sulfur content). Some of these non-ethanol and non fatty-acid biodiesel fuels can have certain advantages including their ability to be compatible[18] with the existing transportation fuel distribution, dispensing and combustion (vehicle) systems.

Because biofuels in the US have been historically dominated by corn ethanol, and to a lesser extent, biodiesel, many of the actors in the system have come to equate the term 'biofuel' with these two end-products. As a result of this preconception, the development of policies (B1, I1), R&D funding strategies (F2, F3), and investment (F2) can all be influenced in a direction to favor these two end products. The pre-existing markets (F5) and knowledge base (F1) for these early fuels give them an additional advantage over other alternatives as many of the technological systems are sufficiently well established to allow for scale economies and technological learning. Actors who benefit from this preconception (e.g. corn ethanol and soy biodiesel producers) will have a strong reason to support it. Those who do not benefit or support such a preconception will have to work hard to educate (F1) the main actors as to the benefits of the other alternatives. Because of a lack of existing product and programs, these actors will also face a higher level of difficulty to obtain the legitimacy (B2) necessary to influence the system. This is a classic case of a virtuous (or vicious) cycle that contributes to the 'lock-in' of the existing technological system (see Unruh [8, 16] for good discussion of energy system 'lock-in').

That said, much of the biofuels research sector, is currently focused quite heavily on determining and developing (F1) "optimal" biofuel production pathways including feedstock, process design, and end-products (and co-products). At this point, the industry is far from determining a 'dominant design' (or more likely a set of dominant designs) for biofuels and in particular, cellulosic biofuels. The significance of this for policy makers, business decision makers, and investors should not be underestimated. If, for example, the dominant designs for biofuel processing results in end-products that are fungible with the existing gasoline system, then any significant investments made in "ethanol capable" or "FAME/FAEE biodiesel capable" infrastructure (for example) could become unnecessary (see also [17] for discussion).

The key for policy makers will be to design policies that recognize the relative economic and societal benefits of the various technologies, and avoid 'picking winners' prematurely and locking out higher value designs too early. For business leaders and research institutions (public and private) it implies that a broad portfolio approach to evaluate the characteristics of the most

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[17] This discussion also relates to the distinction between "cellulosic biofuels" and "cellulosic ethanol". For example: within the Energy Policy Act of 2005 within the discussion of the renewable fuels standard (Title XV – "Ethanol and Motor Fuels") the primary reference to cellulosic fuels is as "cellulosic biomass ethanol".

[18] The term "compatible" here refers to the ability of the fuel to use existing petroleum and gasoline infrastructure including refineries, trucks, pipeline, dispensers, and vehicles.

promising pathways should be pursued.

I2. Firm entry/activity

A strong factor for the development and diffusion of new technologies is the entry of new firms and the expansion of existing firms into the area of interest. Firm entry often brings with it new ideas and experience (F1), new resources (F2), and can help enable the connection to and growth of new markets (F4, F5) and information networks. New firms will also contribute to the support for favorable policy (I1) treatment through lobbying.

The modern biofuels industry had been, until recently, dominated by a relatively small number of large companies. This is no longer the case. Due to the rapid growth in the demand for ethanol many new firms have entered the market, such that by October of 2006, there were 90 different firms producing ethanol alone, up from 75 in 2005, and this number is expected to grow to 110 by the end of 2007 [18].

Such rapid growth in firm entry and activity is not without its risks, especially if it results in an oversupply of product to the emerging market. When this occurs, prices will drop and it will be those firms which have the lowest costs and/or largest cash reserves that will likely survive the shakeout. Such ‘creative destruction’ as it is sometimes called, can be a good thing for the system, especially if it helps to select for good design (and weed out the bad) and management practices.

I3. Feedback from market formation

Feedback from market formation occurs as the market expands to include more actors and a larger customer base and includes increasing returns to scale (reduced costs), increasing legitimacy of the technologies. For biofuels this feedback can take the form reduced capital and variable costs through learning, increased external economies and network effects (e.g. associated biofuel distribution infrastructures), and increased confidence in the technology.

Focus 4: Biofuel vehicles - The role of FFV's and the E?? debate

One question surrounding the future of biofuels in the US is the role of flex-fueled-vehicles, or FFV’s. FFV’s are vehicles that have additional onboard equipment that allows them to be run on any combination of one hundred percent gasoline (E0) up to eighty-five percent ethanol (E85). This equipment generally includes a fuel sensor (to determine alcohol concentration), larger injectors (to achieve equivalent engine power output with the reduced energy content of ethanol), and upgraded fuel tank, lines, and pump (to avoid alcohol degradation of certain polymers). The cost of this additional equipment has been estimated at between $100-300 per vehicle (ref).

The population of FFV’s on American roads began to rise substantially in the late 90’s in response to a provision with the Energy Policy Act of 1992 that allows automakers to gain additional credits to comply with federal Corporate Average Fuel Economy (CAFE) regulations. Each FFV obtains a fuel economy value for the purposes of CAFE of its combined city/highway fuel economy[19] multiplied by ~6.6 (= 1/0.15 to account for the gasoline content). The automakers receive this benefit regardless of whether or not the vehicles use biofuel during customer

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[19] Harmonically weighted fuel economy based on the combined city and highway test drive cycles

operation. As a result of this provision the automakers, primarily Ford, GM, and Chrysler significantly increased their supply of FFV's such that, by current estimates, there are over 4 million on the road today.[20]

The availability of such a large quantity of FFV's, and the lack of E85 refueling stations, has resulted in some policy action (I1) encouraging the availability of E85 infrastructure [9]. Existing gasoline infrastructure is generally not designed to handle E85 and requires upgrading of the tanks, pumps and dispensers to deal with the corrosive effects of the alcohol. Many policies, especially state level policies, have focused on providing incentives to increase the number of dispensers that offer E85 fuel. A couple of key questions for policy makers should arise from this:

1. Does the availability of E85 actually result in increased ethanol consumption?
2. Considering domestic feedstock and production limitations, is the encouragement of E85 a good national strategy for increasing ethanol consumption in the long term?

While it is beyond the scope of this report to answer these two important questions in detail, a few issues are worth mentioning.

The current market for biofuel is for blending ethanol into gasoline up to 10% and is largely invisible to consumers (see Focus 1: Who is the customer?). Once consumers are given a choice, as in the case of E85 and FFV's, they will be subject to all of the associated decision factors (e.g. cost, performance, etc.) that come into play when multiple options are available. As previously discussed in Focus 1, this presents a new challenge to the evolution of the biofuels market that currently does not exist.

Based on limited scenarios modeling (see section 4.1), the amount of domestically available biofuel production may never exceed ~30% of total national on-road transportation fuel energy. If this turns out to be the case, another national strategy to consider for the promotion of biofuels would be to introduce increasing concentrations of biofuels blended into existing gasoline and diesel fuel for the entire US fleet. If the biofuel is ethanol, there is some indication that even existing conventional (non-FFV) vehicles might be able to handle higher levels than the current limit of 10% (by volume) without adverse affects [19]. Additionally, based on discussions with refinery experts, the incremental addition of ethanol up to levels of around E30 might be much easier for refineries to incorporate into their existing production systems than would higher level blends such as E85, which is generally blended during distribution or dispensing. For biofuel end-products that are more compatible with gasoline and diesel, such as biologically derived synthetic diesel or iso-octane, this type of a strategy becomes even easier to implement within the existing distribution system. In both cases, a strategy that encourages increasing levels of biofuel content blended into existing transportation fuels could prove to be more effective as it would not require a change in vehicle consumer fuel purchase behavior[21].

3.2 Blocking mechanisms to biofuels (with focus on Lignocellulosic)

Despite significant market growth over the last 3-5 years and increasing levels of research on new feedstocks and conversion processes, the market for biofuels is almost entirely based on corn ethanol as a blending agent into gasoline. The great promise for

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[20] FFV's have also plaid a strong role in the recent revival of the Brazilian vehicle market (see Focus: The Brazilian experience).

[21] This, as we have seen, is one of the major factors contributing to limited alternative fuel adoption.

the future expansion of the biofuels market is the development and diffusion of fuels based on lignocellulosic ("cellulosic") feedstocks. Despite a significant amount of attention and some pilot plant activity, cellulosic fuels have yet to be produced at a full scale plant. In this section we evaluate a number of blocking mechanisms that are preventing biofuels in general, and cellulosic fuels in particular from greater market expansion.

Blocking mechanisms
B1. Government Policy
B2. Market Uncertainty
B3. Lack of Legitimacy

Government Policy (B1)

Government policy has generally been favorable to biofuels (see I1), however this asset can also be interpreted as a liability as investors put additional risk on products that rely heavily on government policy. As stated in a report from the Deutsche Bank [20] "It is important to note that politics is also the biggest risk to renewable fuels. Without the mandates and tax incentives, ethanol becomes a doubtful proposition, and there is no economic rationale for biodiesel."

And from Verasun "U.S. ethanol industry is highly dependent upon a myriad of federal and state legislation and regulation and any changes in legislation or regulation could materially and adversely affect our results of operations and financial position." (VeraSun, 2006, referenced from [9]).

Despite this risk, the current state of politics and policies for biofuels in general is highly favorable and the same report characterizes it as the "small American farmer versus the wealthy Middle Eastern oil sheikh" and the authors "do not believe the mandates and tax breaks are in danger"[20].

Government policy can also be a blocking mechanism for certain types of biofuels if the policy is written in such a way as to favor certain biofuels at the expense of others. If the policy is overly proscriptive where funding or regulation is concerned it risks 'picking winners' (F3) prematurely.

Local and state government agencies are also very important in the permitting of facilities. In some cases, the permitting process can be arduous for new biofuel facilities [11], especially for those that have less of a 'track record' and where permit officials and regulatory agencies are less familiar with the technology (which would include most cellulosic facilities (B3)). One way to overcome this mechanism is through the diffusion of knowledge (F1) about the benefits, both economic and environmental, to these key actors and institutions.

Although less of an issue in this country because of our abundance of food production (the US is a large net exporter of food products), the concept of the competition between "food vs. fuel" could become a political issue in the future and already does affect biofuels policy in some developing countries[22]. If biofuel feedstock production is expanded in such a way as to significantly affect food prices, either through direct competition for feedstocks or indirect competition for land, then it is possible that there could be policy activity in the US that could favor food production over fuel production.

Market Uncertainty (B2)

While there are a number of areas of market uncertainty for biofuels, the three primary areas discussed here: 1) the availability and cost of biomass feedstock; 2) the cost of the competitive fuels and 3) demand for the biofuel end-product.

Because biofuels rely upon biomass feedstocks, they will be subject to the availability and market price for those feedstocks. In the case of traditional biofuel feedstocks such as corn or virgin food oil, the overall price is set through competition with the overall food market. In years where there is a high demand for those feedstocks in other sectors and/or low supply due to weather conditions, the feedstocks prices could rise substantially[23] affecting the overall biofuel price.

Cellulosic fuels face an additional challenge in that viable markets for the feedstock in most regions have yet to be established. This causes somewhat of a 'catch-22' or 'chicken and egg' problem in which cellulosic processing facilities are disadvantaged because of no pre-existing market availability (of the feedstock) and potential feedstock providers are disadvantaged because of the lack of buyers (a market).

The other major uncertainty is the cost of competitive fuels and their feedstocks, primarily petroleum. Biofuels are traditionally seen as a 'substitute goods'[24] for petroleum based fuels and because of this, the relative price of the biofuel compared to petroleum will likely have a significant impact on demand of the biofuel. Furthermore, the variability in the long run price of gasoline is seen as a major investment risk for investors in biofuel facilities [11]. These risks contribute the desire of industry to have government to play a strong supporting role (I1) in incentivizing or potentially even mandating the supply and demand of the biofuels. Some have even suggested that government should institute a "market floor" for the price of petroleum to remove some of the risk associated with this blocking mechanism[25].

Both of these factors, high feedstock price (sugar) and low petroleum price, together helped to contributed to the temporary "crash" of the Brazilian ethanol program in the early-90's [21].

Lack of Legitimacy (B3)

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[22] India for example, has largely shifted their biodiesel feedstock program to focus on jathopra, a non-food oil plant that can grow on marginal lands, largely because it avoids this issue (ref: conversation with representative from IOC).

[23] Improved efficiency of use of the feedstock can reduce the impact of these price swings on the final biofuel cost

[24] Substitute goods are those which can be used to satisfy the same need.

[25] Richard Lugar and Vinod Khosla, "We can end oil addiction," *Washington Times*, 3 August 2006

Biofuels in general have long faced challenges with certain aspects of legitimacy including economic, environmental and resource concerns. They have often been thought to be too expensive to compete with petroleum based fuels and many have voiced the concern that biofuel feedstocks do not exist in sufficient quantities to make a significant contribution to transportation energy needs (see Focus 5: Biofuels - How much can we produce?). This latter issue has been the subject of recent analysis with some reports suggesting that biofuels could account for as much as 30% of current transportation fuel (reference) demand in the US equating to some 40 billion gallons gasoline equivalent (60B gallons ethanol equivalent). While some have pointed to this number as evidence that biofuels will never supply all our energy needs, especially as fuel demand grows under ‘business as usual’ conditions, others have pointed out that such a quantity could make a significant dent in petroleum consumption, greenhouse gases, and create a substantial number of new domestic jobs [22, 23]. These same authors also point out that, if we were able to substantially reduce our transportation energy needs through improved efficiency and reduced travel, this same quantity of fuel could provide for a larger percentage of demand.

One of the key legitimacy barriers to market expansion of biofuels in general and for cellulosic biofuels in particular is the relative cost of production[26]. For biofuels to become economically competitive, it will be critical to reduce the costs associated with all aspects of the supply chain including feedstock production and harvesting, feedstock transport and storage, conversion, and delivery to the end-user.

Various estimates for cost have been reported, all of which suggest that the production cost of cellulosic biofuels using today’s technology could compete with gasoline produced from oil at gasoline between \$2-3/gallon (untaxed and unsubsidized). However, because full scale plants based on cellulosic conversion have not yet been developed, this range is still somewhat uncertain and contributes to the lack of legitimacy associated with these estimates. To reduce the anticipated costs for each component of the supply chain, significant effort is being expended by government and industry (F3).

Focus 5: Biofuels - How much can we produce?

The total amount of biomass resources available for transportation fuel production is not a known quantity. The primary resources of interest are agricultural and forest residues and dedicated energy crops such as perennial grasses and short rotation woody trees. A variety of studies [22, 24-26] have evaluated how much biofuel might be produced from domestically available biomass feedstocks under certain conditions. A recent study by the USDA and USDOE, “Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasability of a Billion-Ton Annual Supply”, estimates that the US could produce and harvest as much as 1.3 billion dry tones (equivalent) of biomass for purposes of fuel production without significant impact on food and land resources [24]. This estimate (also see figure SB2a below) includes:

- 368 million dry tones from forest sources such as harvested fuelwood, wood-processing and paper mills, construction/demolition debris, and logging residues
- 1 billion dry tones from agricultural lands including crop residues, perennial crops,

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[26] Here it is the relative cost compared to the current and anticipated long run cost of the competition, primarily petroleum.

grains, animal manures, and process residues. This estimate assumes some increases in crop yields, greater residue to grain ratios, and a shift of some idle cropland to dedicated energy crops.

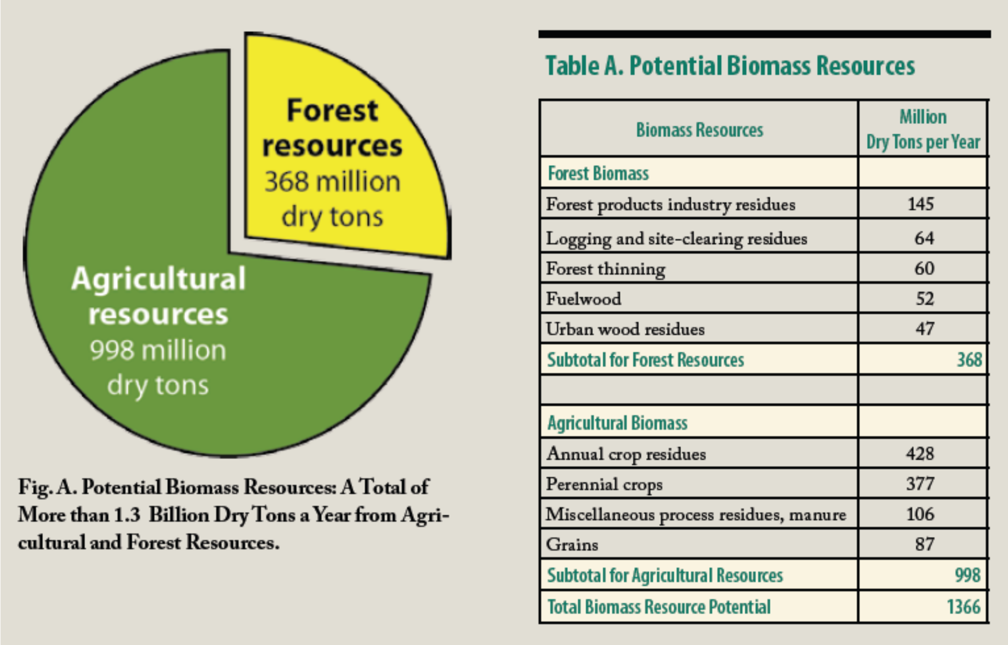

Fig. A. Potential Biomass Resources: A Total of More than 1.3 Billion Dry Tons a Year from Agricultural and Forest Resources.

Table A. Potential Biomass Resources

Biomass Resources	Million Dry Tons per Year
Forest Biomass	
Forest products industry residues	145
Logging and site-clearing residues	64
Forest thinning	60
Fuelwood	52
Urban wood residues	47
Subtotal for Forest Resources	368
Agricultural Biomass	
Annual crop residues	428
Perennial crops	377
Miscellaneous process residues, manure	106
Grains	87
Subtotal for Agricultural Resources	998
Total Biomass Resource Potential	1366

Figure SB2a: Potential US biomass resource

The assessment of biomass resources has also been occurring at the state level. For example California's Biomass Collaborative in their roadmap provided an estimate of biomass resources that could be harvested 'sustainably' at around 80 million bdt/year (see figure SB2b).

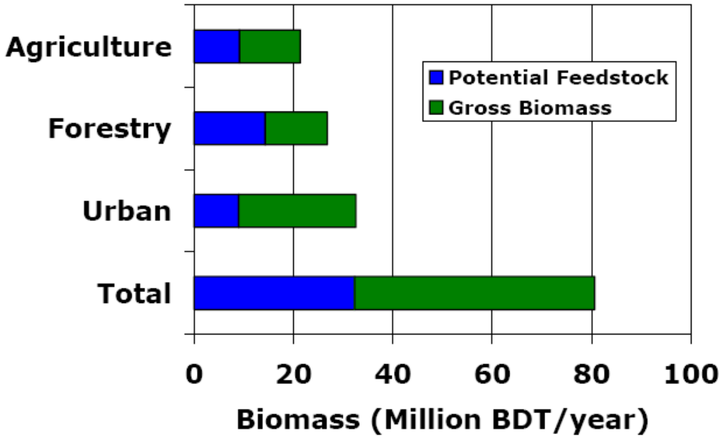

Figure 1.3. Gross annual biomass production in California (2005) and amounts estimated to be available for sustainable use. BDT = bone dry tons.

These assessments can be considered what we might call technically plausible long-term resource assessments. Plausible in that they could develop given certain technology and market conditions. To achieve the full estimate in the "billion ton" study, would certainly require a complete transformation of our agriculture and silvicultural systems including new production and harvesting technologies, collection and distribution markets for the feedstock and, in the case of energy crops, a significant growth in the number of acres dedicated to such crops. Such a transition will take many decades to occur and will be heavily influence by the factors we are evaluating in this analysis.

Even if all of this biomass was produced and collected, not all of it would be available for transportation biofuels production as some would go to other higher value uses (e.g. electricity and heat production). One critical component of how much is actually provided to the market is the regional price of feedstock and some assessments have been made to determine the amount provided at different prices [26].

To put these tonnage values in perspective, one assessment (reference) of the 'billion ton' report is that, given reasonable assumptions for future conversion technology and the fraction that could be used for fuels production, it would be sufficient to produce approximately 60 Billion gallons of ethanol (~40 Billion gallons gasoline equivalent). This amount accounts for around 30% of our current (2005) light duty vehicle consumption (~ 5 quads of fuel energy).

Besides petroleum reduction and agricultural support, biofuels are receiving increasing attention because of their stated ability to reduce emissions and in particular those associated with greenhouse gases. A significant debate about the actual energy and greenhouse gas benefits has resulted in some uncertainty about the 'true' societal value of biofuels, corn ethanol in particular. Recent studies that suggest that, on average, corn ethanol does modestly reduce fossil energy and greenhouse gases [27]. However, the continued debate about societal costs and benefits does create additional uncertainty and risks loss or reduction of government support (B1)[27] [see insert "The Great Energy and Environmental Debate"]. The positive news for cellulosic fuels is that most studies show that biofuels produced from these feedstocks will result in substantial reductions in both fossil energy and greenhouse gases (ref)[28].

Focus 6: Biofuels - The Great Energy and Environmental Debate

One area that has greatly affected the policy discussion on biofuels is the discussion about their actual energy and environmental benefits. It can possibly be summed up by the often quoted and poorly understood question "Doesn't it take more energy to make biofuels than you get back from using them". Despite implying a misunderstanding about the nature of energy conversion and use, the question resonates with many in the policy making world[29] and has resulted in a great debate about the "Net Energy Balance (NEB)" or "Net Energy Ratio (NER)" of biofuels[30]. For an excellent discussion of the difficulties created in defining and evaluating these two terms see Farrell [27].

Following from the first law of thermodynamics, we know that energy is neither created nor destroyed. We can, however, cause energy to undergo transformations into different forms, some more useful than others, and following from the second law of thermodynamics, these

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[27] In addition to energy and GHG's, issues of water use, biodiversity, etc. are also considered in the overall impact of biofuels.

[28] However, even cellulosic fuels are at risk due to the potential confusion by the general public and policy makers who sometimes lump 'biofuels' together.

[29] This quote is often used for hydrogen as well.

[30] The NEB is also sometimes called the Net Energy Value (NEV). Sometimes both NEB and NER are modified to include only "fossil" energy such as the "Fossil Energy Balance".

transformations always incur "losses" and often do have real environmental impacts. For example, when we use natural gas to produce electricity, we are transforming chemical energy into thermal energy and then thermal energy into electrical energy. All of these transformations include losses and other impacts. In fact, in most modern plants, we only are able to convert ½ to 1/3 of the thermal energy into useful electrical energy. Most of the remaining energy is lost as heat into the environment. In other words it "takes more natural gas energy to make electricity than we get back in electricity". We accept this loss because electrical energy is more 'useful' to us for many things than the original natural gas[31]. Producing natural gas also has other impacts on the environment including greenhouse gas and criteria emissions, thermal pollution, etc.

The real question from a societal standpoint should be "What are the overall societal life-cycle costs and benefits associated with the production and use of biofuels, especially with respect to the things that we care about, and how does this compare with the status quo". This becomes a much more complicated question because the "what we care about" can change depending on our personal values. For a particular individual or group, the most important factor may be (for example) petroleum dependency, greenhouse gas emissions, criteria pollution, habitat or species preservation, water use, or some combination thereof. For example if petroleum reduction is the goal then both corn ethanol and cellulosic biofuels provide significant reductions (slightly more for cellulosic) compared to gasoline. If greenhouse gas reductions are goal then cellulosic biofuels have significantly lower GHG's than corn ethanol which has only very modest reductions compared to petroleum (the magnitude of which will depend on the study assumptions).

Proponents of biofuels have pointed to recent studies as evidence of their societal benefits, specifically their contribution to petroleum reduction and greenhouse gas emissions. Detractors have often used the same studies to point out the minimal (and sometimes uncertain) environmental benefits, especially with corn ethanol, claiming that such minimal benefits do not warrant large policy support.

Even when you've decided on which factors are important, the assumptions used in the analysis have sufficient uncertainty that different analysts using similar methodologies come to different conclusions. Factors such as the amount of fertilizer used, assumed yields (field and facility), treatment of soil sequestration and plant nitrogen fixation, co-products and alternative land-use all can vary by study and will have a significant effect on the results.

One recent and oft-cited analysis is from Farrell, et. al. at UC Berkeley [28]. This paper reviews several well-known studies and attempts to evaluate them using similar methodology. Figure 3 and Figure 4 show the results on this meta-analysis. Figure 3 shows the net GHG (CO2 equivalent) per MJ of ethanol on the Y-axis and net energy (MJ/L ethanol) on the X-axis. Figure 4 shows the total life cycle petroleum input on the Y axis and the net energy (MJ/L ethanol) on the X axis. As we can see in Figure 3, there is a wide range of net energy calculations, even when the published values are corrected for different methodologies.

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[31] For example, it would be very difficult to run your TV on natural gas.

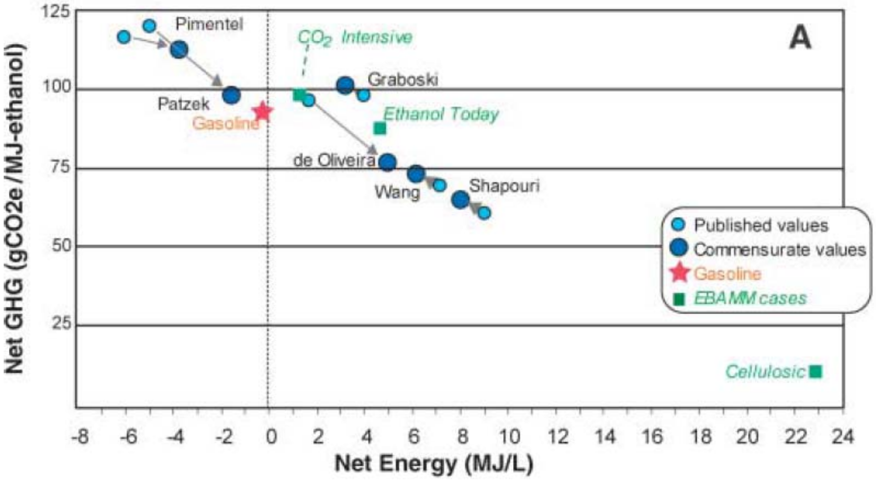

Figure 3: Net Energy and GHG emissions from select studies

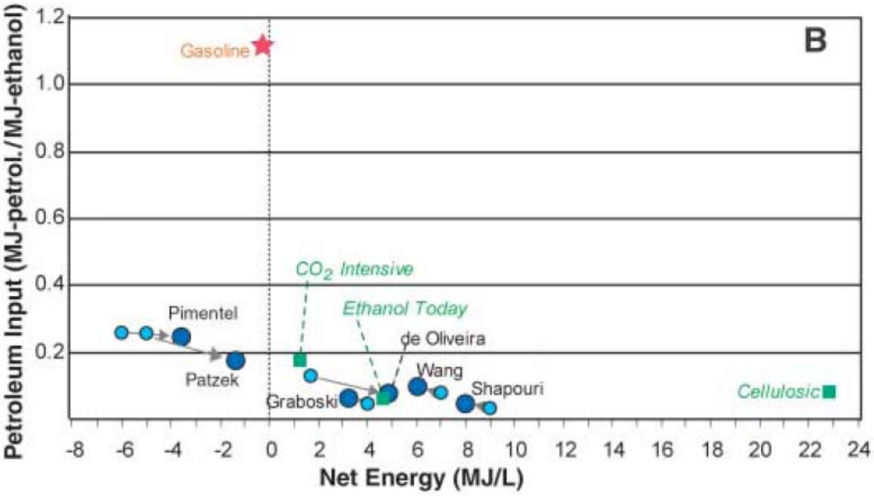

Figure 4: Net Energy and Petroleum input from select studies

The one pathway that almost always comes out a winner in these studies is cellulosic biofuels. Nearly all of the analysis show that biofuels produced from cellulosic feedstocks can dramatically reduce both petroleum consumption and greenhouse gases.

The implications surrounding this debate are significant for policy makers and business strategy. The real or perceived societal costs and benefits of biofuels motivate policy makers to develop, promote (I1) or block (B1) bills that might favor biofuels development and diffusion. Policy could also be designed to favor certain feedstocks and production pathways over others. For example, the current federal Renewable Fuels Standard (RFS) does differentiate between corn ethanol and cellulosic ethanol (the latter receiving 2.5 times the volume credit) and California's low carbon fuel standard (LCFS) intends to promote lower life cycle greenhouse gas emissions by recognizing the upstream emissions associated with feedstock production.

4 Biofuels growth in the US: A Scenario

In order to discuss elements of the biofuels innovation system into the future, we use scenario analysis to describe what that future might look like. This section will undertake a basic scenario analysis of the US biofuels market out to 2050. A scenario is used here to describe a small subset of futures under which a biofuels market could develop within the US. From the IPCC Special Report on Emissions Scenarios:

> Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems. Some systems, those that are well understood and for which complete information is available, can be modeled with some certainty, as is frequently the case in the physical sciences, and their future states predicted. However, many physical and social systems are poorly understood, and information on the relevant variables is so incomplete that they can be appreciated only through intuition and are best communicated by images and stories.

To undertake such analysis, we have used an updated and modified version of the U.S. DOE's VISION model. The VISION model is a publicly available model that has been developed by the DOE to provide estimates of the potential energy use, oil use and carbon emission impacts through 2050 of advanced light and heavy duty vehicle technologies and alternative fuels. For a general description of the model and how it works, see [29][32].

The VISION model includes a base case or "business as usual" case which is based on certain vehicle efficiency assumptions and transportation energy use projections. The choice of a base case is very important in that much of the potential for new technologies is compared against a base case which itself is rarely ever static[33]. Base cases generally include some level of modest technology improvement commensurate with historical levels. They generally do not include any significant shifts in the way that we, as a society, operate our transportation/mobility systems. The values chosen for the VISION base case are from a variety of reference documents and projections with some of the more significant assumptions described here and in the appendix.

Among some of the key "base case" assumptions used here:

- Biofuel consumption grows from 2.28BGGE in 2000 to 13.3BGGE in 2050 mostly from use as a blend in gasoline (up to 7%). The biofuel is almost entirely ethanol which is entirely derived from corn.
- Conventional fuel economy continues to improve modestly from 2000-2050 (from 28.2mpg to 33.9mpg for cars, from 20.8mpg to 26.7mpg for trucks)

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[32] Note that the VISION model has been updated since this documentation. This scenario uses the updated version (from December 2006) which has slightly different base case assumptions (detailed below). Documentation is forthcoming.

[33] Sometimes static (often called 'do nothing') projections for technology are made and almost always result in significantly greater energy and emissions than the base case.

- Very minimal market growth of hybrids to 2050 (12.7% for cars, 10% for light duty trucks)
- Diesel grows in market share to 2.0% for cars and 19.8% for light trucks in 2050
- GHG (carbon equivalent) emissions are estimated based on GREET 1.7 and include the full life cycle (well-to-wheel) of resource extraction, processing, transport and end-use (see appendix for values).
- No significant biodiesel penetration.
- Vehicle Miles Traveled (VMT) continues to grow based on population and GDP growth from 2.5x10E12 miles (2000) to 5.5x10E12 miles (2050).
- Additional information about the base case assumptions are described in the appendix 7.1.

The following graph shows the base case results for diesel/gasoline consumption (combined), biofuels consumption, and the resulting greenhouse gas emissions. The growth in gasoline/diesel consumption (despite modest improvements in efficiency) and associated greenhouse gas emissions are driven primarily by the growth in VMT.

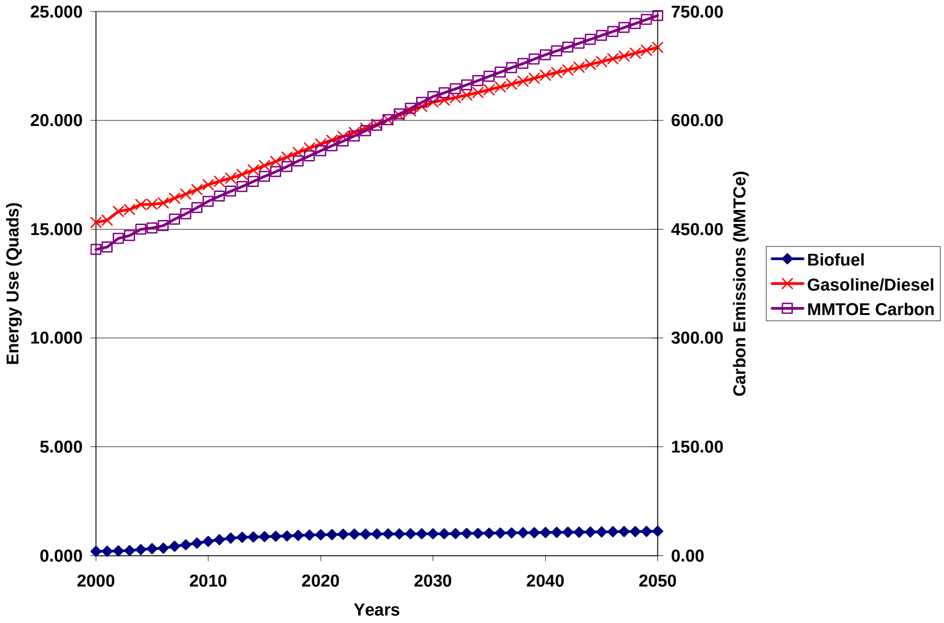

Figure 5: Base case energy use and carbon emissions

4.1 Biofuel Scenarios

The first thing one learns when undertaking scenarios is that the number of scenario permutations is nearly infinite, even for a relatively straightforward analysis with a small set of changing variables. One also finds that almost no matter which set of scenario assumptions one has chosen, the next reviewer (or viewer) of the scenario will almost certainly have a different set of assumptions that they would like to see the analysis run with. In fact, it is the very nature of such dissonance, which makes scenarios such a valuable communications tool. By running the scenario tool under different assumptions, one can begin to "tease-out" the factors that are of most interest to the evaluator. And since various evaluators, or "actors" in TSIS parlance, have different interests, the scenario(s) can be an instrument with which we communicate with each other about what is most important to us.

The second thing that the scenario analyst learns is that the greater number of changing assumptions one includes in the scenario, the less easily understandable the results. This is especially true for variables that might change over time, for example, the efficiency of various vehicles or of the biofuel conversion processes, the make-up of the electricity grid, or the yield of certain biomass crops. This analysts experience suggests that it is better to hold as many variables possible constant (while making them explicit) when varying the primary item of interest (e.g. biofuel consumption) to determine its effects on the results (e.g. GHG emissions, petroleum consumption, etc.). The use of a good base case can also be enormously useful by making certain changes explicit in all of the scenarios (for example: population or GDP growth).

As for output from the scenarios we will focus on a small set of metrics including:

- Energy use over time by fuel
- Greenhouse gas emissions over time
- For biofuels – energy use by feedstock
- Carbon index (MMTCe/Quad) for total energy
- Carbon index (MMTCe/Quad) for biofuel only

4.1.1 Scenario #1: Base_Biofuel

The "base biofuel" scenario described here evaluates the implications of achieving the US DOE's "30 by 30" goal of the biofuels program[34] which states:

> The Biomass Program adopted the President's goal to make cellulosic ethanol technologies cost competitive by 2012. To assess the impact it could have in contributing to reducing dependence on foreign sources of energy, it analyzed the biomass resource potential identified in the DOE/USDA Billion Ton Study (PDF 8.5 MB). Based on that analysis, the Biomass Program set a goal to reduce 30 percent of our current transportation fuel usage by 2030. This goal is equivalent to 60 billion gallons of ethanol.[35]

We call this scenario "Base_Biofuel" because the primary assumption of interest is that the biofuel targets are achieved through a combination of traditional corn and cellulosic biofuels, but all other factors remain the same as in the base case (eg: VMT growth, fuel economy, etc.). Even this level of basic scenario assumption requires a number of "sub-assumptions" for the growth of the biofuels market including how fast the market grows, which feedstocks are used (and percentage of each), etc. The following describes the major assumptions for this scenario:

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[34] http://www1.eere.energy.gov/biomass/biofuels_initiative.html

[35] 60 billion gallons of ethanol is approximately 40 billion gallons of gasoline equivalent (ethanol has approximately 2/3 energy content)

- Initial biofuel production is dominated by corn ethanol which peaks in 2015 at 1.15 Quads (~16 billion gallons of ethanol).
- Cellulosic biofuels including those made from agricultural and forest residues begin to make inroads after 2010 and are the dominant source by 2020.
- Dedicated energy crops (switchgrass assumed here) begin at low levels after 2010 and ramp up to reasonably high levels by 2050 (1.2 Quads).
- All feedstocks are constrained below the levels estimated by the DOE "billion ton supply" report [24]. The fuel energy content by feedstock over time is shown in Figure 6.
- Biofuels production reaches 5.1 quads (60 billion gallons of ETOH, 40 billion gallons gasoline equivalent) by 2030 and increases only modestly from 2030-2050 (to 5.6 quads).
- The life cycle or "well to wheel (WTT)" greenhouse gas emissions (carbon equivalent) based on GREET 1.7 for agricultural waste are estimated to be the same as corn stover (3.02 MMTCe/quad of Fuel consumed)[36]. The WTT GHG emissions for energy crops were assumed to be the same as switch grass (5.49 MMTCe/quad of fuel)[37].
- No imports of biofuels from other countries

As previously stated, it is almost certain that various actors will differ in some way with respect to their assumptions about the future biofuels market. The purpose of this analysis is to clearly state these assumptions and use them to form the basis of discussion. For example, this analysis assumes the life cycle emissions from the different biofuel production pathways do not change over time[38]. With continued R&D, guidance, and policy influence, it is very likely that these numbers will change, however it is not the purpose of this analysis to presuppose what those numbers might be.

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[36] For references purposes, the WTW emissions associated with using gasoline is 26.87 MMTCe/Quad of fuel consumed.

[37] The important thing here is that the value used be close to the aggregate WTT emissions associated with that particular feedstock (including processing).

[38] Note that the GREET 1.7 numbers actually do assume a certain level of maturity for cellulosic processes.

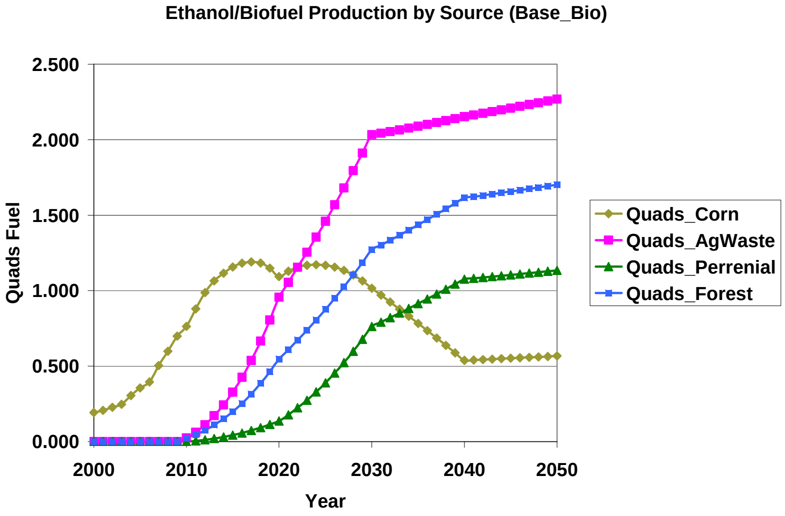

Figure 6: Biofuel energy by source (Quads of fuel)

Evaluating the biofuel market growth assumptions (shown graphically in Figure 6) against our TSIS framework might suggest that the growth in biofuels production from cellulosic sources is quite aggressive and would only come about with a fairly substantial investment (F2) in the development and diffusion of the technologies that such production relies upon. The initial growth of the corn ethanol market in this scenario is also quite aggressive although consistent with some existing market projections [20]. Corn ethanol in this scenario also reaches a peak of around 16 billion gallons (ethanol) in 2015, levels off and then begins to decline in 2025. This latter reduction may be consistent with policy efforts (I1) to reduce carbon emissions and shift to lower carbon feedstocks but will likely be resisted by the industry that has been built up around it. We have also chosen a scenario in which the production and use of dedicated energy crops like switchgrass lags the use of existing agricultural and silvicultural wastes assuming that farmers would want to see viable markets (F5) established before they would commit substantial land and capital resources (F2) to new feedstocks.

4.1.2 Scenario #1 Results and Discussion

From this scenario we can calculate the resulting petroleum consumption, greenhouse gas emissions and carbon coefficients for the total energy system. From Figure 7, we see that despite this rapid growth in biofuels production, petroleum consumption is still substantially higher, more than 20% higher in 2050 (although quite a bit lower than in the base case). Greenhouse gas emissions are also increased by almost 50%, despite a shift for biofuels to low carbon (life-cycle) feedstocks and processes. This is due to three primary factors – 1) the continued growth in VMT, 2) the supply constraint on biofuels after 2030 and 3) only modest improvements in vehicle fuel economy.

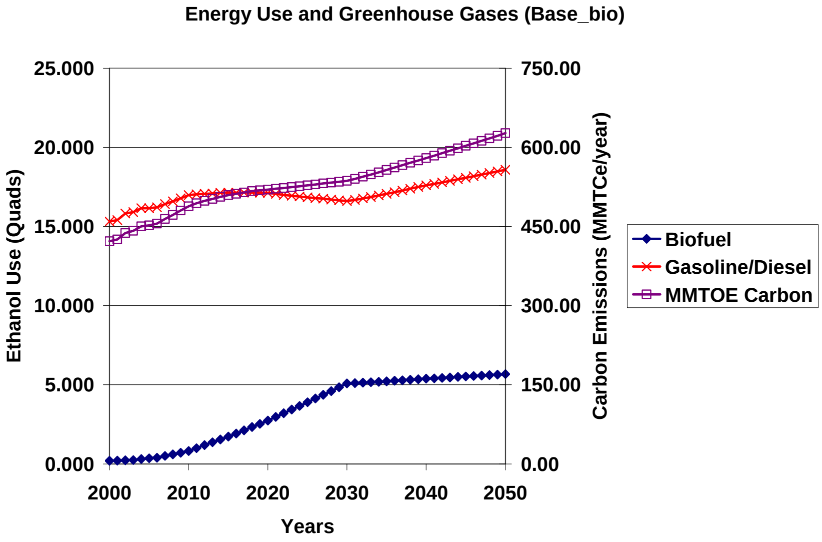

Figure 7: Energy use and greenhouse gases (base_bio)

Another metric of interest is the carbon intensity of the transportation fuel mix against this scenario. The carbon intensity is defined here as the total life cycle carbon equivalent emissions in metric tons (MMTCe) divided by the total amount of fuel energy delivered in quads (MMTCe/Quad). To illustrate the difference between the biofuels carbon intensity and the total transportation fuel carbon intensity (including biofuels) we track these values separately. Figure 8 shows the resulting carbon intensity for both. As we transition from entirely corn ethanol in 2000 to primarily cellulosic ethanol in 2050, the biofuel carbon intensity decreases from 20 MMTCe/Quad to around 5.5 MMTCe/Quad, nearly a 75% reduction. However, because the dominant fuel in 2050 is still petroleum based, the overall carbon intensity is only decreased from 27 MMTCe/Quad in 2000 down to ~22.5 MMTCe/Quad in 2050 – around a 17% decrease.

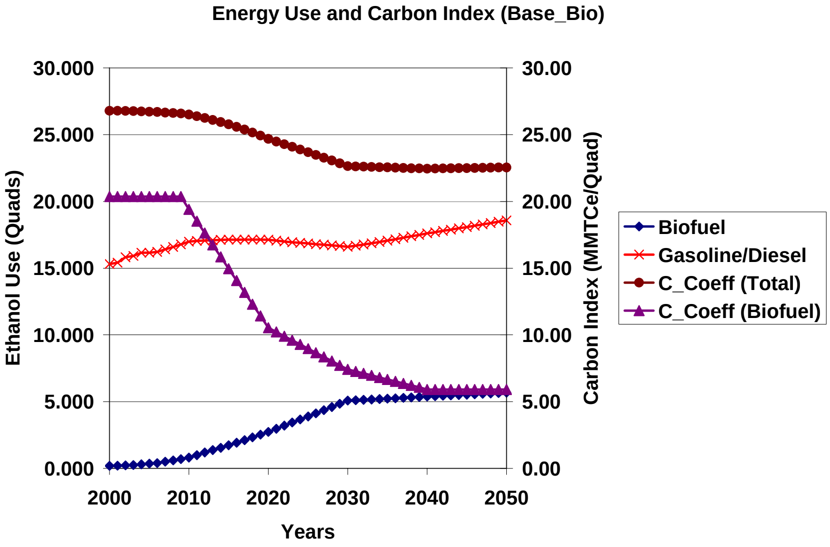

Figure 8: Energy use and carbon coefficient (base_bio case)

5 TSIS Conclusions and Next Steps

This report is an initial attempt to define and describe the major functions of a biofuels innovation system and begins to address the inducement and blocking mechanisms that are likely to shape the future market. We find that a variety of factors have contributed to the current biofuel situation in the US with a dominant position for corn ethanol. Going forward, we've begun to look at the mechanisms that are in place that may help or hinder the biofuels market generally and cellulosic biofuels specifically. We have evaluated one scenario for the growth of the biofuels market and we see that achieving large penetration of biofuels into the transportation market will require an aggressive growth in the market for cellulosic biofuels, including those from energy crops. Even with an aggressive biofuels growth scenario, greenhouse gas emissions continue to rise due to continued increase in driving. This suggests that other policies that would encourage additional alternatives (e.g. hydrogen, plug-in hybrids), greater fuel efficiency and decreased driving will be necessary if we are to achieve deep cuts in the greenhouse gas emissions.

While developing this report, it was realized that greater understanding could be achieved with the TSIS framework and scenarios approach laid out here. This paper represents the first phase of a multi-phase project. Our intention is to further develop the TSIS framework for biofuels, adding additional detail and expanding on several focus areas including long term policy and business strategies and a greater focus on specific biofuel production technologies. The next phase will also take a closer look at the innovation process and articulate where various inducement mechanisms might have the greatest influence on the future success of the biofuels market. We will also attempt to understand the major regional differences for certain biofuel feedstocks as well as policy regimes and how this might affect the TSIS within that region (e.g. California).

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7 Appendix

7.1 Key Scenario Assumptions

7.1.1 Carbon Coefficients

The carbon coefficients that are used in our scenario model are from the DOE/Argonne's GREET model [30] and represent the full fuel cycle or 'well-to-tank' emissions associated with feedstock extraction/production, distribution, conversion, and dispensing. The values are shown in Table 3 and are on a million metric ton of carbon equivalent per quad of fuel delivered (MMTCe/Quad).

Gasoline	26.87				
LPG	21.95				
Jet Fuel	19.33				
Distillate fuel	27.04				
Residual	25.47				
Kerosene	19.72				
Electricity	See utility sheet				
CNG	21.27				
F-T Diesel	29.47				
Bio-Diesel	25.00				
Methanol	26.88				
	Corn	**Corn Stover**	**Switchgrass**	**Woody Biomass**	**Forest residue**
Ethanol (1)	20.37	3.02	5.49	-3.39	5.24

Table 3: VISION Carbon Coefficients (MMTCe/Quad of Fuel)

7.2 Energy Policy Act of 2005

The Energy Policy Act of 2005 (or EPACT) is the primary federal policy on energy and has a number of provisions that are important to biofuels development. Key provisions of the act include (sources from[39]):

RENEWABLE FUEL PROGRAM

- Directs EPA to promulgate regulations ensuring that applicable volumes of renewable fuel are sold or introduced into commerce in the United States annually.
- Regulations apply to refiners, blenders, and importers.
- If regulations are not issued, the applicable percentage for 2006 is set at 2.78%.
- Sets forth a phase- in for renewable fuel volumes over 7 years, beginning with 4 billion gallons by 2006 and ending at 7.5 billion gallons in 2012.
- Provides EPA discretion on the future uses of renewable fuels including a minimum requirement of renewable fuels use in 2013 shall not be less than the percentage of 7.5 billion gallons of renewable fuel to the total number of gallons of gasoline in 2012.
- Requires EIA, for the years 2006 through 2011, to provide an annual estimate of volumes of gasoline sold or introduced into commerce for the coming year.

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[39] http://www.ethanolrfa.org/objects/pdf/PublicPolicy/Regulations/RFAIssueBrief-SummaryofFinalEnergyBill.pdf

- Based on these estimates, DOE must publish regulations to ensure renewable fuel obligations for refiners, blenders, and importers are met.
- Creates a 1-year credit-trading program for refiners, blenders or importers of petroleum.

CELLULOSIC BIOMASS PROGRAM
- Creates a credit-trading program where 1 gallon of cellulosic biomass ethanol or waste derived ethanol is equal to 2.5 gallons of renewable fuel.
- Creates a cellulosic biomass program of 250 million gallons in 2013
- Creates a Loan Guarantee Program of $250 million per facility
- Creates a $650 million Grant Program for cellulosic ethanol
- Creates an Advanced Biofuels Technologies Program of $550 million.

RENEWABLE TAX PROVISIONS:
- Extends Biodiesel VEETC Tax Credit through December 31, 2008
- Creates Alternative Fuels Installation Fuel Refueling Property of up to 30%.
- Modifies the Small Ethanol Producer Credit to 60 million gallons
- Create a new Small Agribiodiesel Producer Credit

Research, Development, and Demonstration:
- Integrated Bioenergy Research & Development (§971) - $49 million/yr over 5 years
- Funds DOE Bioenergy Program -$738 million over 3 years
- Up to $100 million (each) for biorefinery demonstrations

Commercialization
- Renewable Fuels Standard (RFS) which requires refiners to provide increasing levels of renewable fuels through 2012 (see table X).
    - By 2013 the amount of cellulosic biofuel

R&D
- DOE Bioenergy Program -$738 million over 3 years
- USDA/DOE Program -$2 billion authorized over 10 years for enhanced research –feedstock production, biomass re-calcitrance; product diversification

7.3 DOE Biomass Program Goals

The Office of Energy Efficiency and Renewable Energy's Office of the Biomass Program has implemented the Biofuels Initiative (BFI), with the goal of reducing U.S. dependence on foreign oil by meeting the following targets:

- To make cellulosic ethanol (or ethanol from non-grain biomass resources) cost competitive with gasoline by 2012.

- To replace 30 percent of current levels of gasoline consumption with biofuels by 2030 (or 30x30).

7.4 Twenty In Ten: Strengthening America's Energy Security

Reducing Gasoline Consumption Through The Growth Of Alternative Fuel Sources

The President's Plan Calls For Facilitating The Growth Of Renewable And Alternative Fuel Sources By Increasing The Size And Expanding The Scope Of The Current Renewable Fuel Standard (RFS).

- The RFS, established by the President and Congress in the Energy Policy Act of 2005, has contributed to the rapid acceleration of the development and use of renewable fuels. Significant ongoing technological advances have made it possible to increase and expand the standard to displace even larger volumes of gasoline.
- Under current law, fuel blenders must use 7.5 billion gallons of renewable fuels in 2012.
- Under the President's proposal, the fuel standard will be set at **35 billion gallons of renewable and alternative fuels in 2017.** This will displace 15 percent of projected annual gasoline use in 2017. The President's proposal will also increase the scope of the current Renewable Fuel Standard (RFS), expanding it to an Alternative Fuel Standard (AFS).
    - The Alternative Fuel Standard will include sources such as corn ethanol, cellulosic ethanol, biodiesel, methanol, butanol, hydrogen, and alternative fuels.
- The increased standard will contain multiple "safety valves."
    - The EPA Administrator and the Secretaries of Agriculture and Energy will have authority to waive or modify the standard if they deem it necessary, and the new fuel standard will include an automatic "safety valve" to protect against unforeseen increases in the prices of alternative fuels or their feedstocks.

- **American Technology And Innovation Will Lead To Energy Security.** President Bush believes our scientists, farmers, entrepreneurs, and industry leaders will continue to lead the world in developing and investing in cutting-edge technology, infrastructure, and farming methods. Advances in many fields will play an important role, such as continued improvement in crop yields, optimization of crops and cellulosic materials as fuel feedstock, and cost reduction in the production of cellulosic ethanol and other alternative fuels. The increased and expanded fuel standard creates a tremendous incentive for research, development, and private investment into alternatives to oil.

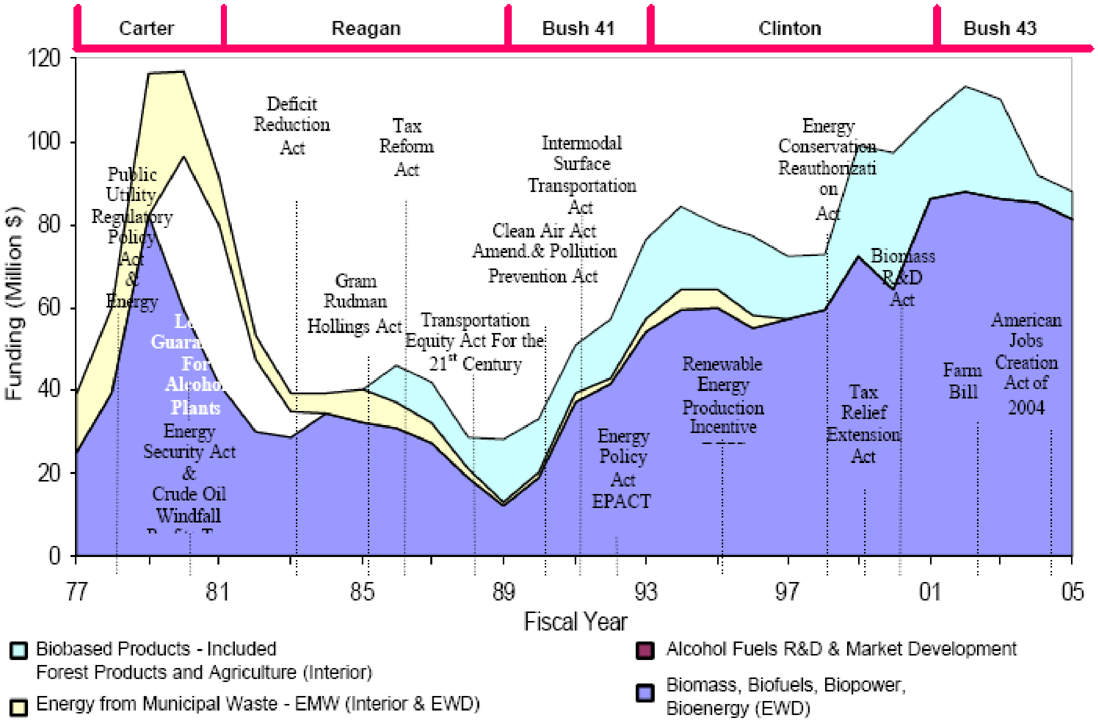
- **Global Production Of Alternative Fuels Helps Us Reach Our Goal And Increases Our Energy Security.** The President expects most of the expanded fuel standard to be met with domestically-produced alternative fuels. However, importing alternative fuels also increases the diversity of fuel sources, which further increases our energy security.

- **The President's Plan Enables America To Lead The World To Energy Security.** By establishing such a visible and ambitious fuel standard, America's global leadership will help encourage our friends and allies to consider similar policies. Actions by America's friends and allies to increase their production of oil and oil alternatives, diversify their supplies, reduce their consumption, and increase their oil reserves will enhance the energy security of America and the rest of the world. Conversely, foreign actions that undermine free, open, and competitive markets for trade and investment in energy supplies diminish the energy security of America and the world. This is why America opposes the political manipulation of oil and gas exports.

7.5 Other Policy References

7.5.1 Biomass related R&D 1977-2005

Reference below from: [1]



Financial incentives were found on the OBP webpage www.eere.energy.gov/biomass

Figure 1-6: Major Policy Shifts, Key Legislation, and Federal Funding Levels for Biomass-Related R, D & D, 1977-2005

Regulations, financial incentives, and executive orders that have influenced biomass R&D over the past 25 years include [1]:

- Public Utility Regulatory Policy Act & Energy Tax Act (1978)

- Energy security Act & Crude Oil Windfall Profits Tax Act / Loan Guarantees for Alcohol Plants (1980)
- Economic Recovery Tax Act (1981)
- Surface Transportation Assistance Act (1982)
- Transportation Equity Act for the 21st Century (1988)
- Pollution Prevention Act (1990)
- Energy Policy Act EPACT (1992)
- Energy conservation Reauthorization Act (1998)
- Biomass R&D Act of 2000
- Farm Bill, Title IX (2002)
- Executive Orders:
    - Alternative-Fuel Vehicles: 12844 (1997), 13031 (1997)
    - Biobased Products Increased Use by the Federal Government: 13101 (1998)
    - Biobased Products and Bioenergy Increased Use: 13134 (1999)
    - Increased Renewable and Energy Efficiency in Government Use: 13123 (1999)
    - Developing and Promoting Biobased Products and Bioenergy: 13134 (1999)

Other major federal legislation drivers of the current program include the following:

Energy Policy Act of 1992 (EPAct) EPAct grew out the efforts of the previous Bush Administration to establish a national energy policy. It has been a failure in terms of its intent to encourage the use of alternative fuels in the transportation sector. EPACT focused too much on purchases of alternative fueled vehicles, without paying enough attention to its real goal of seeing alternative fuels enter the marketplace. Flexible fuel vehicles such as the kind that can use ethanol or gasoline have indeed found their way into the marketplace, but few fleets and car owners are actually using the fuel. The NEP report acknowledged this failure and suggested that "[r]eforms to the federal alternative fuels program could promote alternative fuels use instead of mandating purchase of vehicles that ultimately run on petroleum fuels."

Biomass R&D Act of 2000[39] In 2000, the Biomass Research and Development Act created the Biomass R&D Initiative (http://www.bioproducts-bioenergy.gov/), a multi-agency effort to coordinate and accelerate all Federal biomass R&D. It also created a Biomass R&D Board and a Biomass R&D Technical Advisory Committee. The Board's role is to coordinate interagenc y R&D and minimize any duplicative efforts. The Technical Advisory Committee, comprised of industry and academia representatives, ensures that the Federal effort does not duplicate industry's efforts by reviewing the two agencies' annual progress and making recommendations for future activities. The R&D Board and technical advisory committee are described in more detail in Section 4.1.

Farm Bill of 2002, Title IX[40] Included several sections important to biomass including:

- Federal Procurement of Biobased Products (Section 9002),
- Renewable Energy Systems and Energy Efficiency Improvements (Section 9006),

- Biomass Research and Development (Section 9008) includes the joint DOE/USDA solicitation for FY 2002-FY 2004, and
- Continuation of the Bioenergy Program (Section 9010)

7.5.2 Laws That Helped Make Ethanol A Transportation Fuel[40]

Public Law Number & Name
93-473: Solar Energy Research, Development, and Demonstration Act
95-618: Energy Tax Act
96-126: Interior and Related Agencies Appropriation Act
96-223: Crude Oil Windfall Tax Act
96-294: Energy Security Act
96-304: Supplemental Appropriation and Rescission Act
96-493: Gasohol Competition Act
97-424: Surface Transportation Assistance Act
98-369: Deficit Reduction Act
99-499: Superfund Amendments & Reauthorization Act
100-647: Technical and Miscellaneous Revenue Act
101-508: Omnibus Budget Reconciliation Act
102-486: Energy Policy Act
103-66: Omnibus Budget Reconciliation Act of 1993
105-34: Taxpayer Relief Act of 1997
105-178: Transportation Equity Act for the 21st Century

7.5.3 Federal Programs relevant to Biofuels and Bioenergy[41]

U.S. Department of Energy - http://www.energy.gov/
Biomass Research and Development Initiative - http://www.bioproducts-bioenergy.gov
Energy Efficiency and Renewable Energy - http://www.eren.doe.gov/
Biomass Program - http://www.eren.doe.gov/biomass.html
Federal Energy Management Program - http://www.eren.doe.gov/femp/
Hydrogen Information Network - http://www.eren.doe.gov/hydrogen/
Industrial Technology Program - http://www.oit.doe.gov/
Office of Science - http://www.science.doe.gov/
Basic Energy Sciences - http://www.sc.doe.gov/production/bes/bes.html
Office of Fossil Energy - http://www.fe.doe.gov/

U.S. Department of Agriculture - http://www.usda.gov/
Biobased Products and Bioenergy Coordination Council - http://www.ars.usda.gov/bbcc/index.htm
Agriculture Research Service - http://www.ars.usda.gov/
Animal and Plant Health Inspection Service - http://www.aphis.usda.gov/
Commodity Credit Corporation - http://www.fsa.usda.gov/daco/bio_daco.htm
Cooperative State Research, Education And Extension Service - http://www.reeusda.gov/
Economic Research Service - http://www.ers.usda.gov/

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[40] http://www.eia.doe.gov/kids/history/timelines/ethanol.html
[41] http://www.brdisolutions.com/pdfs/FinalBiomassRoadmap.pdf

Energy Policy and New Use - http://www.usda.gov/agency/oce/oepnu/index.htm
Forest Service - http://www.fs.fed.us/research/
Natural Resources Conversion Service - http://www.nrcs.usda.gov/
Rural Development - http://www.rurdev.usda.gov/

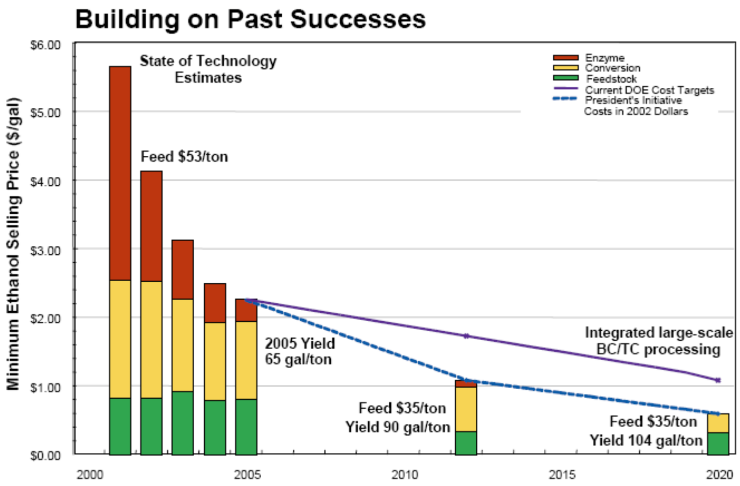
National Science Foundation - http://www.nsf.gov/
Biological Sciences - http://www.nsf.gov/home/bio/
Engineering - http://www.nsf.gov/home/eng/
Mathematical and Physical Sciences - http://www.nsf.gov/home/mps/

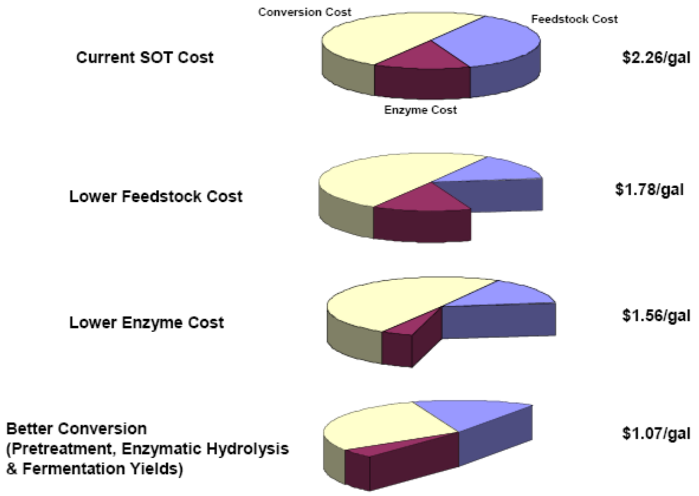
Environmental Protection Agency - http://www.epa.gov/
AgStar Program (joint with USDA and DOE) - http://www.epa.gov/agstar/
Comprehensive Procurement Guidelines - http://www.epa.gov/cpg/
Environmental Technology Verification - http://www.epa.gov/etv/
Industry Partnerships, Project XL - http://www.epa.gov/ProjectXL/
Landfill Methane Outreach - http://www.epa.gov/lmop/
Methane Energy - http://www.epa.gov/methane/
Prevention, Pesticides, and Toxic Substances - http://www.epa.gov/oppts/
Research and Development - http://www.epa.gov/ORD/
Science Policy Council - http://www.epa.gov/osp/spc/

Department of Commerce - http://www.commerce.gov/
Advanced Technology - http://www.atp.nist.gov/
Office of Science and Technology Policy - http://www.ostp.gov/
Tennessee Valley Authority - http://www.tva.gov/
Public Power Institute - http://www.publicpowerinstitute.org/

7.6 Biofuel Cost Information (references)

For cellulosic fermentation (from [31]):





<u>For thermochemical conversion (from [32]):</u>

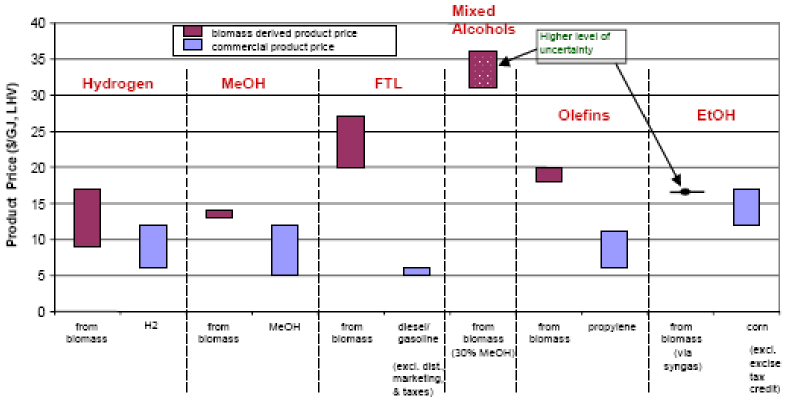


Figure 15: Product Price in $/GJ (LHV)

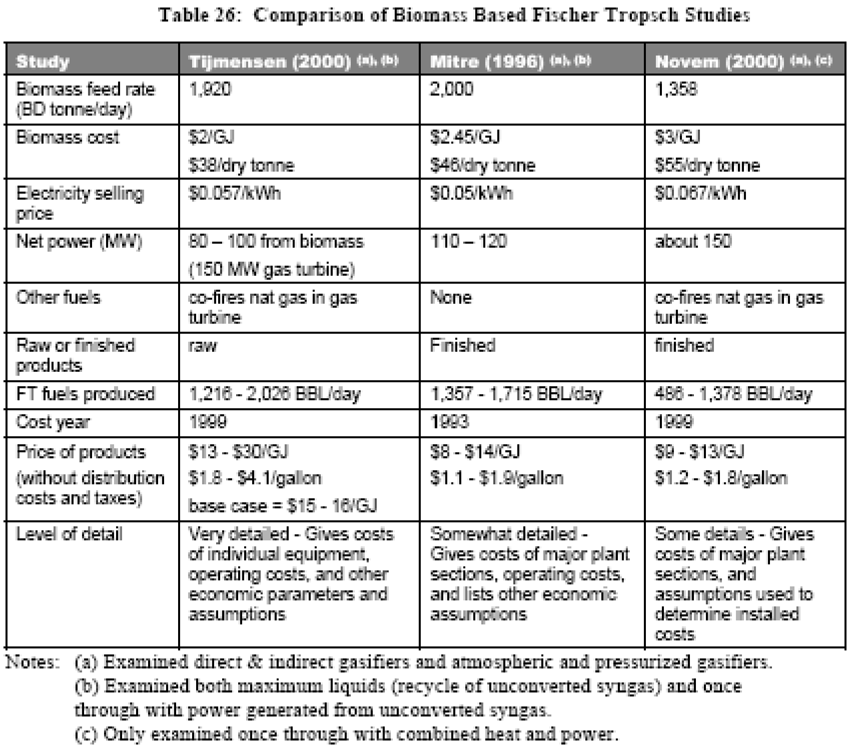
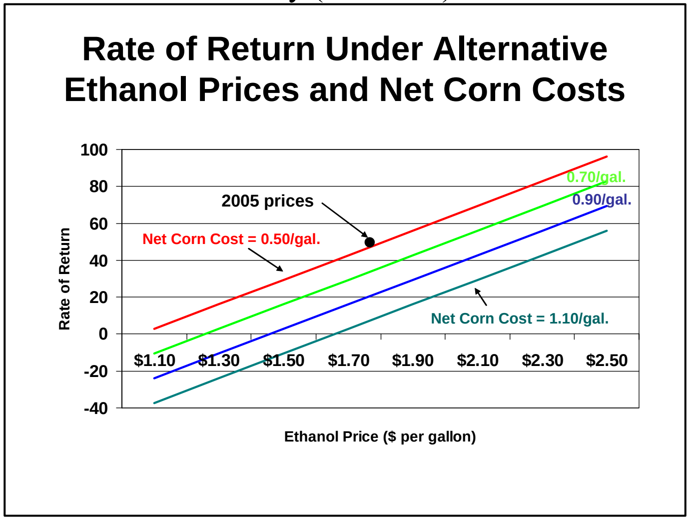


Table 26: Comparison of Biomass Based Fischer Tropsch Studies

Study	**Tijmensen (2000) (a), (b)**	**Mitre (1996) (a), (b)**	**Novem (2000) (a), (c)**
Biomass feed rate (BD tonne/day)	1,920	2,000	1,358
Biomass cost	$2/GJ $38/dry tonne	$2.45/GJ $46/dry tonne	$3/GJ $55/dry tonne
Electricity selling price	$0.057/kWh	$0.05/kWh	$0.067/kWh
Net power (MW)	80 – 100 from biomass (150 MW gas turbine)	110 – 120	about 150
Other fuels	co-fires nat gas in gas turbine	None	co-fires nat gas in gas turbine
Raw or finished products	raw	Finished	finished
FT fuels produced	1,216 - 2,026 BBL/day	1,357 - 1,715 BBL/day	486 - 1,378 BBL/day
Cost year	1999	1993	1999
Price of products (without distribution costs and taxes)	$13 - $30/GJ $1.8 - $4.1/gallon base case = $15 - 16/GJ	$8 - $14/GJ $1.1 - $1.9/gallon	$9 - $13/GJ $1.2 - $1.8/gallon
Level of detail	Very detailed - Gives costs of individual equipment, operating costs, and other economic parameters and assumptions	Somewhat detailed - Gives costs of major plant sections, operating costs, and lists other economic assumptions	Some details - Gives costs of major plant sections, and assumptions used to determine installed costs

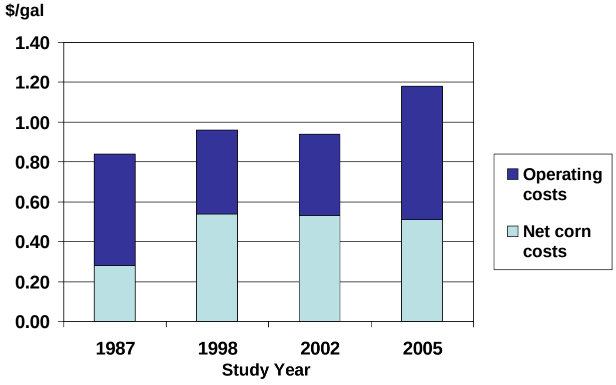
Notes: (a) Examined direct & indirect gasifiers and atmospheric and pressurized gasifiers.
(b) Examined both maximum liquids (recycle of unconverted syngas) and once through with power generated from unconverted syngas.
(c) Only examined once through with combined heat and power.

From USDA cost study (reference):



Rate of Return Under Alternative Ethanol Prices and Net Corn Costs

Ethanol Production Cost at Dry Mill Plants

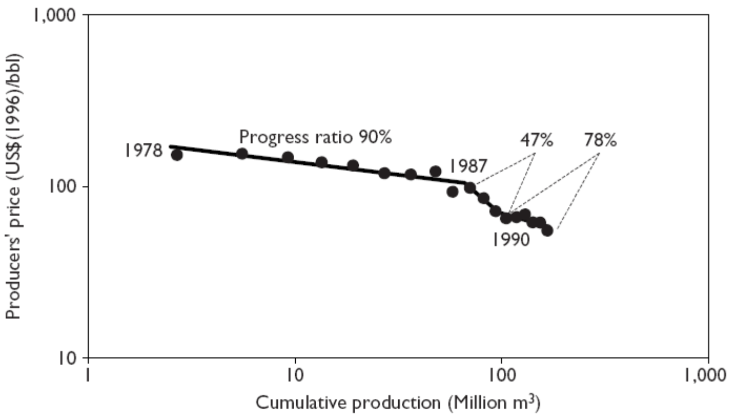


Characteristics of Ethanol from Corn Versus Cellulosics

	Corn	*Cellulosic materials*
Capital cost to build plant, per gallon	$1.25-$1.50	$4.30 -$5.44
Conversion process	Simple	Complex
Enzyme cost, per gallon	3 cents	15 -20 cents
Byproducts	Protein & oil	Electricity
Energy used in processing	NG & Electricity	Self-sufficient
Alcohol content of beer, percent	14-20	4
Fermentation time, number of days	2	7
Labor use in processing plants	Low	High
Ethanol cost of production, per gallon	$1.10	$2.30
Ethanol yield per dry ton, gallons	113	79
Transportation cost of raw materials	Low	High

Cost evolution of ethanol in Brazil[33]

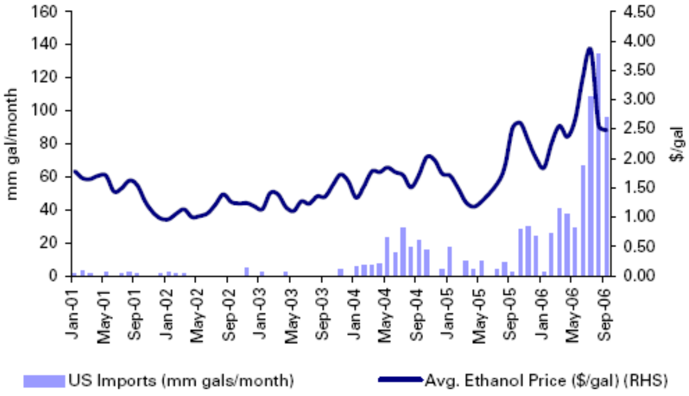
Figure 2.8. Brasilian Ethanol, 1978-1995



Experience curve for production of ethanol in Brazil. Data from Goldemberg (1996).

Ethanol imports from Sankey [20]:

Figure 4: U.S. Ethanol Imports vs. Price (Jan 2001 – Sep 2006)



Source: EIA,, Bloomberg