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Ethanol from lignocellulosics, U.S. federal energy and agricultural policy, and the diffusion of innovation

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ABSTRACT

Lignocellulosic ethanol is a low carbon fuel source with the potential to assist in climate change mitigation. However, as a new technology in the process of moving toward commercial development, it is important to understand obstacles to its development. We focused on the role that policy may be playing in fostering or impeding its development in the U.S. One of the major ways of understanding technological development is the theory of the diffusion of innovation. This theory identifies factors that can impede and facilitate this diffusion. We assessed the degree to which three of the main U.S. federal energy policies aim at addressing three key aspects of innovation diffusion: time; risk; and communication. We determine that these policies focus more on the producer stage of the lignocellulosic ethanol lifecycle than the landowner or consumer stages. In addition, they contain many provisions aimed at overcoming risk- and communication-related impediments to adoption, but fewer aimed at speeding up the process. Finally, they contain at least one provision likely to be a serious impediment to adoption.

1. Introduction

Renewable alternatives to fossil fuels are increasingly becoming a focus of research and development. These advances are motivated by concerns over energy insecurity, particularly associated with petroleum imports in the United States, as well as the climate change effects linked to the use of fossil fuels [1]. Ethanol and biodiesel, produced from corn grain and soybeans respectively, represent the two most widely used renewable transportation fuels in the U.S. Both directly impact the food supply [2]. Additionally, these crops must be grown on high value agricultural land and need large amounts of fertilizer and pesticides [2,3] derived from fossil fuels [3,4].

Conversion of lignocellulosic biomass to ethanol represents a promising alternative [2,3] with a potential net fossil energy balance greater than double that of corn grain derived ethanol [2,3] as well as many potential benefits including increased national energy security, price stability, decreased dependence on foreign sources of petroleum, lowered trade deficit [5–8], dramatic decreases in GHG emissions [9], and an exceptionally diverse resource base [1]. A 2005 report completed by the U.S. Department of Energy and the U.S. Department of Agriculture states that 1.18 Pg (1.3 billion dry tons) of biomass (of which more than 90% are lignocellulosic) are potentially available from agricultural- and forestlands on an annual basis and could potentially displace greater than thirty percent of petroleum consumption [10].

Petroleum provides roughly forty percent of U.S. energy consumption and nearly two thirds of it is imported. The transportation sector uses approximately two-thirds of U.S.

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petroleum [5]. Reductions in transportation-related petroleum use could therefore reduce petroleum imports. Lignocellulosic ethanol technology is close to commercialization, ongoing manufacturing in U.S. demonstration and pilot scale plants [11], and has a potential price that is competitive with gasoline and corn ethanol [1].

However, it has some potential limitations and disadvantages. First, lignocellulosic ethanol technology remains largely in the research and development stages as conversion bioprocesses undergo improvements to increase yields and reduce costs [2]. Additionally, potential CO_2 releases are possible if land uses change to accommodate energy cropping for biomass production or to make up for agricultural land converted to woody biomass production [12,13], though the use of lignocellulosic wastes as the feedstock is one possible solution [12]. Additionally, Patzek and Pimentel [14] argue that in the long term, high value lands will be chosen for lignocellulosic biomass cultivation for potentially increased production [14], however many species of lignocellulosic biomass such as switchgrass, prairie grasses, and woody plants can be grown on marginal land [2]. Finally, the long-term soil nutrient implications of removing forest and agricultural residues are largely unknown and may raise future productivity problems.

As a new technology, such as lignocellulosic ethanol, with the potential to solve important societal problems moves toward commercial development, it may encounter development obstacles. Understanding how these may be overcome then becomes an important policy question. Our work focuses on understanding the roles that key federal policies may be playing in fostering or impeding U.S. lignocellulosic ethanol development. We use the theory of the diffusion of innovation as an analytic framework for assessing the degree to which several federal energy policies aim at reducing key diffusion obstacles. This theory identifies factors that can impede and facilitate this diffusion. We focus on assessing the degree to which these policies attempt to address three key aspects of innovation diffusion: time; risk; and communication.

1.1. *Technology transfer and innovations*

The diffusion of innovation is "the process by which (1) an *innovation* (2) is *communicated* through certain *channels* (3) over *time* (4) among the members of a *social system*" [15, p. 11]. Innovations can include new technological ideas, objects, or practices [15]. The rate of diffusion, communication channels, innovations, and social contexts each play important roles in the diffusion process and can directly impact an innovation's success. In order to diffuse, innovations must transfer "ideas, skills, processes, hardware, and systems across a variety of boundaries [that may be] national, geographic, social and cultural, or organizational and institutional" [16, p. 8]. Our work focuses on the diffusion of lignocellulosic ethanol-related technology. It is important to note that, in order to diffuse this form of fuel, an entire suite of related technologies must also diffuse, including manufacturing production systems, vehicle engines capable of using ethanol-gasoline mixtures, and consumer infrastructure (e.g. E85 pumps).

Each technology transfer consists of hardware and software components [15]. Hardware includes physical objects and software refers to the information needed to produce, consume, and use the technology. There is often a close relationship between the hardware and software related to a technology. Successful diffusion therefore often depends upon the successful transfer of both [15]. For example, lignocellulosic ethanol production requires producers to successfully complete several different processes: pretreatment; enzymatic hydrolysis; and fermentation. The hardware and software related to each process must therefore transfer to biorefinery operators in order to have successful diffusion.

Software moves across boundaries through communication channels [15]. Every communication channel has a supplying side and an adopting side. While adopters usually get the blame for unsuccessful transfers, suppliers also play an important role [16]. Fig. 1 depicts a successful technology transfer across a communication channel. As illustrated, the linkages between suppliers and adopters are essential to successful transfers.

1.2. *Diffusion of innovations*

Many new innovations fail to diffuse. For those that do succeed, adopters are frequently divided into five categories: innovators; early adopters; early majority; later majority and laggards [15]. With regard to these five categories of adopters, diffusion tends to follow an S-shaped curve. In the beginning, a few early adopters choose to use the innovation, followed by more individuals in the early majority phase and so on. Finally, the number of individuals adopting the innovation slows down since most have already adopted the innovation [15]. Fig. 2 illustrates the S-shaped diffusion curve, including the five adopter categories, and locates U.S. lignocellulosic ethanol and corn ethanol production within the diffusion curve. While lignocellulosic ethanol is still in the very early stages of innovation and diffusion, corn ethanol has diffused further, especially in Midwestern U.S. states. Corn ethanol adoption may be tapering off for a variety of reasons, including the development of more promising technologies such as lignocellulosic ethanol.

Another important issue that accompanies innovations is the rate of adoption (or time it takes to diffuse) of each particular innovation. Significant time may elapse between the development and adoption of an innovation. While some

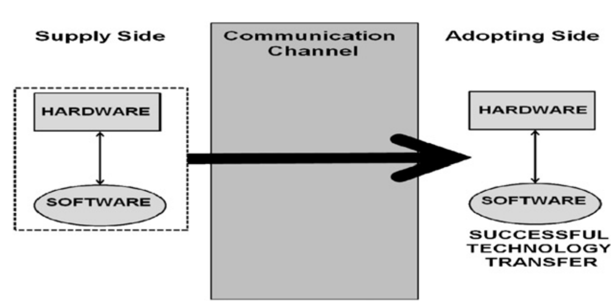

Fig. 1 – Successful technology transfer. The supply side and adopting side complete a successful technology transfer by effectively managing to transfer the hardware and software from the supply side through the communication channel to the adopting side intact.

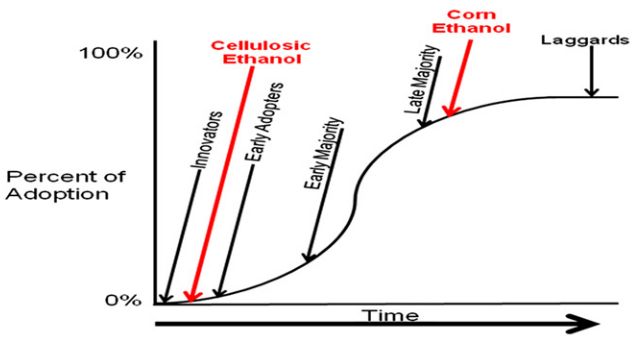

Fig. 2 – Cellulosic and corn ethanol placement in the S-Shaped diffusion curve. [15] S-shaped diffusion curve as adapted to include the five categories of adopters as well as the potential fits for cellulosic ethanol and corn ethanol in the United States.

innovations spread quickly and are successfully put into service within months or a few years, others may take years or even decades to reach widespread acceptance, particularly if they are viewed as risky [15,16]. For instance, while the United States quickly adopted cellular phones and video games, car seatbelt adoption took many years. The time it takes for innovation adoption can be crucial to its success. For later categories of adopters such as laggards, a point in time may arise where the risk of non-adoption becomes greater than that of adoption [17].

Public policies can encourage the diffusion of an innovation and technology transfer. They may do this through the encouragement of diffusion across user categories and through incentives for the production of innovations [18]. Policies may specifically target overcoming particular barriers to the adoption and implementation of an innovation. Important barriers to the diffusion of lignocellulosic ethanol include uncertainty regarding the economic viability of the technology and an associated lack of financing [19]. Prior to issuing loans to support a new technology, financial institutions want to see another operation successfully using that technology, along with a process guarantee. Innovators might find it especially difficult, if not impossible, to find a successful application of a particularly new technology. Producers' ability to ensure long-term stable access to sufficient, low-cost raw material feedstock presents another adoption hurdle [19].

A number of authors have critiqued and extended the classic theory of the diffusion of innovation. Some have pointed out that the process of diffusion is heterogeneous across users [20–24]. Others have shown that the process of diffusion is frequently more complex that predicted by a simple linear diffusion process [23,25,26] particularly with regard to ground level users of the technology. Many focus specifically on agricultural landowners and demonstrate the complexity and difficulty of achieving successful technology diffusion within this group, especially diffusion that protects both social and environmental values. These authors point to the need for the development of innovation mechanisms that are flexible and sensitive to the needs and circumstances of all potential users. They suggest that it may be equally important to assess the degree to which federal policies aim to encourage and promote diffusion at producer, landowner, and consumer stages when researching a technology like lignocellulosic ethanol. However, missing from their analysis is a focus on assessing the degree to which major policies encourage such diffusion, especially for all technology stages, in this case, from landowners to producers to consumers.

2. Research design

We analyzed the three main U.S. federal policies addressing lignocellulosic ethanol to determine the degree to which they attempt to overcome key factors related to its diffusion: time or the speed of diffusion; risk reduction; and the need for effective communication regarding the technology. We assessed individual sections of these policies to determine which factors they addressed and which stage of the lignocellulosic ethanol product lifecycle (landowner, producer, or consumer) each policy component targeted. From the results of this analysis, we looked for patterns regarding the level of attention to the factors and lignocellulosic ethanol lifecycle stages. We then drew conclusions as to whether or not all of the stages of the lignocellulosic ethanol product lifecycle were addressed sufficiently in terms of overcoming issues related to time, risk, and communication.

2.1. *Time*

Diffusion rates are a particularly important factor related to successful diffusion [15]. They are critical in three stages of diffusion: the innovation-decision process; an individual's earliness/lateness in adoption; and adoption of an innovation throughout a society [15]. For efficiency, we refer to the rate of diffusion as "time". We defined a policy as aimed at speeding the rate of diffusion when it set a deadline or tried to encourage fast action, such as establishing minimum production goals by a specific date.

2.2. *Risk*

Due to the novelty of many innovations, the diffusion process contains a level of uncertainty and associated risk [15]. Risk may be perceived due to a lack of information or predictability. We defined risk as including both uncertainty and financial risk. The risk faced at each of the three stages of the lignocellulosic ethanol product lifecycle is potentially different. Landowners face risk due to a lack of biomass harvesting technologies, soil nutrient management practices, demand guarantees, and price supports. Producers face financial risk due to market shifts related to consumer demand, regulatory standards, and feedstock costs. Consumers face risks related to a lack of biofuel infrastructure, lower ethanol energy content compared to gasoline, and the high cost of flexible fuel vehicles. We considered risk to be an element of a policy if it established ethanol subsidies or loan guarantees or attempted to increase the economic efficiency of biomass to ethanol technologies.

2.3. Communication

Finally, communication is a critical component of the diffusion of an innovation [15]. Communication is "a process in which participants create and share information with one another in order to reach a mutual understanding" [15, p. 5]. It is a two-way exchange of information, with individuals on both sides of the message interacting, to convey information about a new idea. We defined policies that encourage information distribution or scientific collaboration between organizations at any of the lignocellulosic ethanol product lifecycle stages as attempting to encourage communication and diffuse lignocellulosic ethanol technology.

2.4. U.S. federal policies and lignocellulosic ethanol

We analyzed the three major and current U.S. federal policies that are most focused upon encouraging the development of the lignocellulosic ethanol industry: the 2005 Energy Policy Act (EPA); the 2007 Energy Independence and Security Act (EISA); and the 2008 Food, Conservation, and Energy Act (FCEA). All three have sections specifically pertaining to lignocellulosic ethanol with the goal of increasing its production and consumption.

2.5. Energy Policy Act (EPA)

The EPA is important because it established the first federal Renewable Fuel Standard (RFS) [27]. The RFS mandates the consumption of 948 ML (250 Mgal) of lignocellulosic ethanol per year by 2012 [1,19,27]. It includes sections aimed at many lignocellulosic ethanol product lifecycle stages (including infrastructure for the sale of E85 which is a blend of 85% ethanol and 15% petroleum); research and development of lignocellulosic ethanol; improved technology transfer; and outreach to inform the public about the benefits, availability, and technology of lignocellulosic ethanol.

2.6. Energy Independence and Security Act (EISA)

EISA aims at increasing United States energy security by decreasing dependence on imported fuels, increasing energy efficiency, and increasing production and consumption of low carbon energy sources [28]. One major EISA provision strengthens and extends the EPA RFS [29]. We included EISA in our analysis because of its focus on developing "advanced biofuels" [30]. EISA defines advanced biofuels as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions…that are at least 50 percent less than baseline lifecycle greenhouse gas emissions" [28] This includes lignocellulosic ethanol. EISA updates and expands the EPA-mandated RFS by requiring the consumption of 136 GL (36 Ggal) of renewable fuel per year by 2022 with 79 GL (21 Ggal) of these coming from advanced biofuels. This sets a limit on the amount of corn-based ethanol that can be used to fulfill the RFS. EISA further requires applicable volumes of lignocellulosic biofuel, beginning with 380 ML (100 Mgal) per year in 2010 and expanding to 61 GL (16 Ggal) in 2022 [28]. Lignocellulosic ethanol has the potential to contribute significantly to the RFS' 2022 advanced biofuel mandate because it is closer to commercialization than any of the other advanced biofuel technologies [31]. EISA also includes consumer information programs, grants for biofuel production, funding for lignocellulosic ethanol research and development, grants and loan guarantees for biofuel production, and a Biofuels and Biorefinery Information Center intended for the purpose of being a technology transfer center [30].

2.7. Food, Conservation, and Energy Act (FCEA)

We included the FCEA primarily due to its Title IX energy provisions [32]. These include subsidies for feedstock producers under the "Biomass Crop Assistance Program" as well as research and development programs for the landowner and producer stages of the lignocellulosic ethanol lifecycle [32]. It also contains more provisions aimed at landowners than the other two acts.

3. Results

3.1. Energy Policy Act (EPA)

Table 1 summarizes key provisions of EPA aimed at speeding up adoption and notes which of the three lifecycle stages each provision aims at impacting. Table 2 summarizes the number of provisions focused on each of the three key diffusion factors and the three key lifecycle stages. Out of the three critical factors in the diffusion of innovation, EPA most directly addresses risk reduction within the producer stage of the lignocellulosic ethanol product lifecycle. However, these components also aim at reducing risk to feedstock producing landowners through the creation of a certain market for their feedstock. Financial assistance for the development of lignocellulosic ethanol includes tax credits, loan guarantees, research and development grants, and production grants and incentives aimed at risk reduction at various stages. Research and development programs can reduce uncertainty regarding technology development, thus reducing risk at the other stages as well. Several programs focus on encouraging more effective communication and apply to landowners, producers, and consumers simultaneously.

Sec. 1501 "Renewable Content of Gasoline" of the EPA most directly addresses time or the rate of diffusion [27]. It includes the RFS requirement of the U.S. consumption of 948 ML (250 Mgal) per year of lignocellulosic ethanol by 2012 [27]. The EPA also aims at decreasing risk through Sec. 1510 "Commercial Byproducts from MSW and Cellulosic Biomass Loan Guarantee Program". This provides loan guarantees for processing facilities, including ethanol processing facilities. As previously stated, financing is a critical barrier to lignocellulosic ethanol development and this section may help to overcome this barrier [19]. Sec. 1001 "Improved Technology Transfer of Energy Technologies" attempts to facilitate communication through the establishment of a working group that collects and disseminates technology transfer information [27].

Table 1 – Energy Policy Act of 2005 and its influence on time, risk, and communication in the context of the diffusion of cellulosic ethanol [19,27].

Policy Section	Description (in reference to cellulosic ethanol)	Time	Risk	Communication	Stage(s) of CE Product Lifecycle Most Affected
Modification of Small Ethanol Producer Credit (sec. 1346)	Small producer defined as 227.12 dam^3 (60 Mgal) per year rather than 113.56 dam^3 per year		X		producer
Renewable Content of Gasoline (sec. 1501)	Implemented the Renewable Fuel Standard	X			all
Assessment of Renewable Energy Resources (sec. 201)	Annual inventory detailing information on characteristics and availability	X	X		landowner and producer
Grants to Improve the Commercial Value of Forest Biomass for Electric Energy, Useful Heat, Transportation Fuels, and Other Commercial Purposes (sec. 210)	Grants to offset biomass costs for facilities in a preferred community		X		landowner and producer
Pilot Program (sec. 721)	Grants for State and Local governments and metropolitan transportation authority for purchase of alternative fuel vehicles and necessary infrastructure to support those alternative fueled vehicles		X		all
Bioenergy Program (sec. 932)	"Research, development, demonstration, and commercial application for bioenergy" [27, p 279] including grants for biorefinery demonstration up to 100 M$		X		producer
Amendments to the Biomass Research and Development Act of 2000 (sec. 941)	Increased annual funding from 54 M$ to 200 M$ and made available through 2015		X		producer and landowner
Production Incentives for Cellulosic Biofuels (sec. 942)	Accelerated commercialization of cellulosic biofuels with up to 100 M$ annually (1 G$ cap) as incentives for cellulosic biofuel production. Priority is given to projects that "have a strategic agreement in place to fairly reward feedstock suppliers" [27, p 942].	X	X		producer and landowner
Regional Bioeconomy Development Grants (sec. 945)	Grants up to $500,000 to "support and promote the growth and development of the bioeconomy within the region served by the eligible entity, through coordination, education, outreach, and other endeavors" [27, p 290]			X	all
Preprocessing and Harvesting Demonstration Grants (sec. 946)	Up to 5 grants per year available to agricultural producers for either cost effective feedstock preprocessing technologies or "multiple crop harvesting techniques" [27, p 291]		X		landowner
Education and Outreach (sec. 947)	Training for feedstock producers and outreach and education of biobased fuels and products to the public			X	landowner and consumer
Systems Biology Program (sec. 977)	Research grants		X		producer
Improved Technology Transfer of Energy Technologies (sec. 1001)	Establishment of a Technology Transfer Working Group to "coordinate technology transfer activities", "exchange information about technology transfer practices," [27, p 334] and disseminate technology transfer information			X	all

Technology Infrastructure Program (sec. 1002)	Promotes the exchange of scientific and technological expertise between National laboratories, universities, nonprofit institutions and government agencies		X	all
Outreach (sec. 1004)	"…provide information, as appropriate, to manufacturers, consumers, engineers, architects, builders, energy service companies, institutions of higher education, facility planners and managers, State and local governments, and other entities" [27, p 338]		X	all
Installation of Alternative Fueling Stations (sec. 1342)	Tax credit (includes E-85)	X		producer and consumer
Commercial Byproducts from MSW and Cellulosic Biomass Loan Guarantee Program (sec. 1510)	Loan guarantees for processing facilities (includes facilities for conversion into ethanol)	X		producer
Renewable Fuels (sec. 1511)	Amends Clean Air Act to include "Cellulosic Biomass Ethanol and Municipal Solid Waste Loan Guarantee Program" which applies to no more than 4 projects which are capable of producing at least 113.56 dam^3 (30 Mgal) per year of cellulosic biomass ethanol	X		producer
Conversion Assistance for Cellulosic Biomass, Waste-Derived Ethanol, Approved Renewable Fuels (sec. 1512)	750 M$ in grants to assist in building production facilities that use "cellulosic or renewable biomass or waste-derived feedstocks derived from agricultural residues, wood residues, municipal solid waste, or agricultural byproducts" [27, p 496]	X		producer and landowner
Advanced Biofuels Technologies Program (sec. 1514)	Program giving funding priority to ethanol or biodiesel feedstocks that supplied less than 10% of that fuel production the previous year with the purpose of developing a minimum of 4 alternative methods for cellulosic ethanol production	X		landowner and producer

Table 2 – Distribution of policy sections by factor and stage of cellulosic ethanol product lifecycle affected for the EPA 2005.

Lifecycle Stage	Time	Risk	Communication
Landowner	3	7	5
Producer	3	13	4
Consumer	1	2	5

3.2. *Energy Independence and Security Act (EISA)*

Table 3 lists the pertinent lignocellulosic ethanol diffusion-related policy sections of EISA while Table 4 summarizes the number of different types of provisions. These include policies designed to impact any stage of the lignocellulosic ethanol product lifecycle (including commercial E85 infrastructure), research and development of lignocellulosic ethanol, improved technology transfer, and outreach to inform the public about the benefits, availability, and technology of lignocellulosic ethanol. The majority of EISA provisions also attempt to reduce the risk of investing in lignocellulosic ethanol development.

Of the five provisions that aim at encouraging effective communication; two focus directly on informing the consumer, one on research and development at the production stage with enforced collaboration, another on the impacts of the RFS on landowners and producers, and the fifth focuses on establishing an information center for landowners, producers, and consumers. EISA attempts to address communication-related diffusion issues related to all three stages of the lignocellulosic ethanol product lifecycle. Four provisions focus on speeding diffusion rates with the potential to impact all three stages simultaneously.

Only one section, the formation of Bioenergy Research Centers, focuses mostly at producers. This provision could speed technology advancement, information distribution, and potentially, adoption rates. EISA Sec. 207 "Grants for the Production of Advanced Biofuels" makes 500 M$ in grants available for advanced biofuels refineries thus reducing producers' financial risk. EISA also addresses the communication component of diffusion through the Sec. 229 "Biofuels and Biorefinery Information Center" provision. This center will collect and disseminate information on all biofuel lifecycle stages. This could reduce risk to each stage of the product lifecycle.

3.3. *Food, Conservation, and Energy Act (FCEA)*

Table 5 lists and briefly describes the FCEA sections that pertain to the diffusion of lignocellulosic ethanol. The act includes policies focused on all stages of the lignocellulosic ethanol product lifecycle, including research and development grants, production subsidies, and information distribution provisions. Table 6 summarizes the number of different types of provisions. We include the amendments to Title IX of the Farm Security and Rural Investment Act of 2002, all of which fall under Sec. 9001 of the FCEA, separately due to the diversity and importance of the sections added to the 2008 Farm Security and Rural Investment Act.

Many FCEA provisions focus on reducing risk and improving communication associated with the diffusion of lignocellulosic ethanol [32]. They do this through research and development grants and financial incentives for landowners and producers. None focus specifically on increasing the diffusion of lignocellulosic ethanol to consumers nor do any provisions specifically focus on speeding the rate of the diffusion of lignocellulosic ethanol. Sec. 7104 creates a Renewable Energy Committee to analyze key aspects of lignocellulosic ethanol development, while Sec. 9002 and 15322 call for research on improvements in biofuels infrastructure and biofuels production. All three mandate the communication of information related to lignocellulosic ethanol through reports and other mechanisms. Reducing time to diffusion to landowners and producers is only indirectly addressed in sections aimed at accelerated commercialization and annual feedstock inventories. However, the act's Biomass Crop Assistance Program provides financial assistance to landowners for biomass harvesting and transportation of biomass [32].

4. Discussion

We focused on identifying components of the three acts focused on encouraging the diffusion of lignocellulosic ethanol as a technology. While it is important to note that it isn't clear that counting applicable sections has definitive meaning, i.e. that three sections aimed at encouraging communication are likely to be better than four, per se, we do believe that the complete absence of components addressing a particular diffusion factor will make it less likely to be overcome. There are examples of particular policies ignoring one of the factors, particularly when analysis is broken out among the three lifecycle stages of landowners, producers, and consumers.

4.1. *Time and diffusion*

Time is an important part of the innovation-decision process, individuals' early or late adoption decisions, and the overall rate of adoption within a country [15]. The three policies focus less on overcoming time-related diffusion constraints than those related to risk and communication. Only three sections of EPA directly address time (with regard to diffusion), four in EISA, and none in the FCEA. Sections such as EISA's Federal Fleet Requirements and EPA's and EISA's RFSs directly impact time by setting lignocellulosic ethanol consumption level deadlines. Others focus on speeding diffusion through encouraging accelerated research (EISA's Bioenergy Research Centers) and commercialization (EPA's Production Incentives for Cellulosic Biofuels).

Most of the sections discussed focus only indirectly on time or diffusion speed. For example, many grants, loan guarantees, subsidies, and reports have deadlines. Many have the potential to affect all stages of the lignocellulosic ethanol lifecycle, if only indirectly. For example, setting increased production and consumption requirements ensures demand for landowners' feedstock. However, of the three factors, time

Table 3 – Energy Independence and Security Act of 2007 and its influence on time, risk, and communication in the context of the diffusion of cellulosic ethanol [28,29].

Policy Section	Description (in reference to cellulosic ethanol)	Time	Risk	Communication	Stage(s) of CE Product Lifecycle Most Affected
Consumer Information (sec. 105)	Labeling of new vehicles manufactured capable of running on alternative fuel, and information in the manual regarding environmental benefits and renewable nature of the fuel			X	consumer
Extension of Flexible Fuel Vehicle Credit Program (sec. 109)	Allows manufacturers to have an increase in the average fuel economy for alternative fuel vehicles through the year 2019 (0.5 km/liter until 2014 and then tapers to 0 km/liter in 2020)		X		producer
Federal Fleet Conservation Requirements (sec. 142)	Beginning in 2010, mandatory increased use of alternative fuel	X			all
Renewable Fuel Standard (sec. 202)	Updated and increased RFS levels from EPA 2005 (136 hm^3, 36 Ggal, in 2022). Also includes mandatory use of advanced biofuels creating a cap on corn ethanol used to fulfill the standards. Beginning in 2009 includes applicable volumes of cellulosic biofuel to aid in fulfilling the scenario.	X			all
Study of Impact of RFS (sec. 203)	Looking for negative impacts on "feed grains, livestock, landowner and food, forest products, and energy" [28, p 38] and investigation of policy options to correct negative impacts			X	producer
Grants for the Production of Advanced Biofuels (sec. 207)	500 M$ for 2008–2015		X		producer
Grants for Biofuel Production Research and Development in Certain States (sec. 223)	25 M$ for 2008–2010 with priority to states with low ethanol production and low cellulosic ethanol production		X		producer
Biorefinery Energy Efficiency (sec. 224)	Establish a program for research and development to convert corn starch ethanol production facilities to accept a wide range of feedstocks (includes cellulosic biomass)		X		producer
Study of Flexible Fueled Vehicles to use E-85 Fuel (sec. 225)	Determine whether optimization of flex fueled vehicles to run on E-85 will increase efficiency		X		producer and consumer
Biofuels and Biorefinery Information Center (sec. 229)	Make available information on renewable fuel feedstocks, processing technologies, Federal and State laws and incentives for renewable fuel production and use, R&D, renewable resources, fuel producers, and users			X	all
Cellulosic Ethanol and Biofuels Research (sec. 230)	50 M$ for 10 research grants. Recipient must collaborate with one of the Bioenergy Research Centers		X	X	producer
Bioenergy Research Centers (sec. 233)	Minimum of 7 Bioenergy Research Centers – goal of accelerated biofuels R&D	X	X		producer
University Based Research and Development Grant Program (sec. 234)	Up to 2 M$ for R&D of renewable energy technologies	X			producer
Prohibition on Franchise Agreement Restrictions Related to Renewable Fuel Infrastructure (sec. 241)	Franchisor cannot restrict franchisee from installing E-85 pump or converting an existing pump		X		producer and consumer
Renewable Fuel Dispenser Requirements (sec. 242)	Report on feasibility of requiring installation of E-85 pumps in areas where a minimum of 15% of the vehicles are flexible fuel vehicles. To be completed within 2 years.	X			all

(continued on next page)

Table 3 (continued)

Policy Section	Description (in reference to cellulosic ethanol)	Time	Risk	Communication	Stage(s) of CE Product Lifecycle Most Affected
Ethanol Pipeline Feasibility Study (sec. 243)	Study includes economics, barriers, market risk and risk mitigation, financial incentives, and technical factors		X		all
Renewable Infrastructure Grants (sec. 244)	Grants for installation, conversion, or replacement – must be used exclusively for renewable fuel		X		producer and consumer
Biofuels Distribution and Advanced Biofuels Infrastructure (sec. 248)	R&D and demonstration		X		producer
National Media Campaign (sec. 801)	Purpose is to increase energy efficiency, promote national security benefits, and decrease oil consumption			X	consumer
Renewable Fuel Capital Investment Company (sec. 1207)	Amends Small Business Investment Act of 1958 by addition of Renewable Fuel Capital Investment Program		X		producer

Table 4 – Distribution of policy sections by factor and stage of cellulosic ethanol product lifecycle affected for the EISA 2007.

Lifecycle Stage	Time	Risk	Communication
Landowner	3	1	2
Producer	4	13	3
Consumer	3	2	3

is the least frequently addressed. More could be done to speed up the rate of diffusion.

4.2. *Risk and diffusion*

Risk is the most commonly addressed of the three diffusion factors, with forty separate sections aimed at decreasing the risk of adoption. Most of these sections focus on the producer stage with, for instance, research, development, and infrastructure grants; financial incentives; or loan guarantees. Each act contains at least one of these types of provisions. The number of sections that focus on reducing risk to the producer is one of the most important results of our analysis. Each act has 13 or 14 sections addressing the reduction of producer risk. The number of risk-oriented sections focused on producers far surpasses the number of sections aimed at speeding diffusion or improving communication. Additionally, neither consumers nor landowners receive nearly as much attention with respect to encouraging diffusion in any of the policies as producers receive.

In particular, few sections focus on overcoming obstacles to lignocellulosic ethanol technology diffusions to landowners. One of the main ones is the FCEA Biomass Crop Assistance Program which subsidizes feedstock extraction and handling. There are also some grants available for research and development at the feedstock stage, including EPA preprocessing and harvesting grants and the FCEA's agricultural feedstock research section. Aside from feedstock research and development grants, neither EPA nor EISA focus on reducing risk to landowners. However, the lack of more attention to this lifecycle stage is an important gap, especially given the findings of earlier authors [20–26] regarding the importance of considering the barriers for all users, and in particular, landowners for innovation diffusion.

Given that ensuring sufficient, consistent supplies of feedstock is a key issue for producers, this creates an important barrier to lignocellulosic ethanol development. Additionally, in the majority of sections where landowner risk is addressed, the provisions mostly address reducing financial risk. There is not enough focus on the technological research and development necessary for economically efficient harvest and collection of biomass. Additionally, few sections focus on the possible need of different approaches for different types of landowners, including forest and farm landowners [21]. Finally, the acts include few provisions aimed at reducing consumer risk related to adoption of lignocellulosic ethanol. This lack of consumer-related provisions is probably due to the prioritization of technology development at this state of diffusion and because consumers are the group least likely to

Table 5 – Food, Conservation, and Energy Act of 2008 and its influence on time, risk, and communication in the context of the diffusion of cellulosic ethanol [32,34].					
Policy Section	Description (in reference to cellulosic ethanol)	Time	Risk	Communication	Stage(s) of CE Product Lifecycle Most Affected
Storage Facility Loans (sec. 1614)	Includes loans for storage facilities for renewable biomass		X		landowner
Renewable Energy Committee (sec. 7104)	Amends the National Agricultural Research, Extension, and Teaching Policy Act of 1977 to include a section for establishment of a Renewable Energy Committee to "study the scope and effectiveness of research, extension, and economics programs affecting the renewable energy industry" (p 327) and produce a report on the findings		X	X	producer
Agricultural Bioenergy Feedstock and Energy Efficiency Research and Extension Initiative (sec. 7207)	Amends Title XVI of the Food, Agriculture, Conservation, and Trade Act of 1990 to include the "Agricultural Bioenergy Feedstock and Energy Efficiency Research Extension Initiative" which consists of research and extension grants (50 M$/year for 2008–2012) for improvements to agricultural biomass production, onversion, and use as well as for diffusion of the research completed by this section that will aid in the aforementioned improvements. Also includes development of a "Best Practices Database"		X	X	landowner
Sun Grant Program (sec. 7526)	Program to provide grants to the Sun Grant Centers and Western Insular Pacific Subcenter		X		producer
Agricultural and Rural Transportation Research and Education (sec. 7529)	Includes grants for research on transportation of biofuels (5 M$/year for 2008–2012)		X		landowner and producer
Energy (sec. 9001)	Amends Title IX of the Farm Security and Rural Investment Act of 2002 ("sec. 9001" – "sec. 9013")	[a]The following sections "9003"–"9012" are the amendments made by sec. 9001			
[a]Biorefinery Assistance ("sec. 9003")	Assistance grants for building demonstration-scale biorefineries producing advanced biofuels (up to 30% of the cost of the project) and loan guarantees for commercial biorefineries (includes reterofitting) up to 90% of the principle and interest of the loan as the loan does not exceed 250 M$		X		producer
[a]Bioenergy Program for Advanced Biofuels ("sec. 9005")	Payments to producers who enter into contracts to ensure production of advanced biofuels (300 M$ for 2009–2012 mandatory funding and 100 M$ discretionary funding)	X			producer

(continued on next page)

Table 5 (*continued*)

Policy Section	Description (in reference to cellulosic ethanol)	Time	Risk	Communication	Stage(s) of CE Product Lifecycle Most Affected
[a]Biomass Research and Development ("sec. 9008")	"Secretary of Agriculture and the Secretary of Energy shall coordinate policies and procedures that promote research and development regarding the production of biofuels and biobased products," [32, p 430] and also development of Biomass Research and Development Board, Technical Advisory Committee, and initiative to provide grants for research in feedstock development, biofuels and biobased products development, and biofuels development analysis (118 M$ mandatory funding for 2009–2012 and 35 M$/year discretionary funding)		X		landowner and producer
[a]Biomass Crop Assistance Program ("sec. 9011")	Assistance to landowners of agricultural or nonindustrial private forestland to establish crops for bioenergy production and to aid with "collection, harvest, storage, and transportation of eligible material for use in a biomass conversion facility," (p440) up to $0.05/kg (45/ton) for 2 years		X		landowner
[a]Forest Biomass for Energy (sec. 9012)	Research and development for use of forest biomass for production of renewable energy		X		producer and landowner
Biofuels Infrastructure Study (sec. 9002)	Study includes assessment of market trends from 2008–2025, feedstock availability, water resource needs, shipping and storage, and modes of transportation and delivery		X	X	producer and landowner
Contracts for Additional Policies And Studies (sec. 12023)	Amends section 522(c) of Federal Crop Insurance Act to include "Energy Crop Insurance Policy" for research and development to insure dedicated energy crops.		X		landowner
Credit for Production of Cellulosic Biofuel (sec. 15321)	Subsidy of $0.27/liter ($1.01/gal) for producers		X		producer
Comprehensive Study of Biofuels (sec. 15322)	Analysis of (1) "current biofuels production and projections for future production" and (2) "maximum amount of biofuels production capable in United States forests and farmlands" [32, p 626]		X	X	landowner and producer
Modification of Alcohol Credit (sec. 15331)	Ammends section 40(h) of 26 USC 40. Reduces credit from $0.13/liter ($0.51/gal) to $0.12/liter ($0.45/gal) after 28.4 GL (7.5 Ggal) produced or imported in one year [34, p.2]		X		producer
Calculation of Volume of Alcohol for Fuel Credits (sec. 15332)	Amends section 40(d) of 26 USC 40. Reduces amount of denaturant that can be included in calculation of the volume of the fuel from 5% to 2% [34]		X		producer
Ethanol Tariff Extension (sec. 15333)	Extends the $0.14/liter ($0.54/gal) duty until 1/1/2011 [34]		X		producer
Limitations on Duty Drawback on Certain Imported Ethanol (sec. 15334)	Amends 19 USC 1313(p). Excludes exports not containing e thanol or a mixture of ethanol from the duty drawback		X		producer

Table 6 – Distribution of policy sections by factor and stage of cellulosic ethanol product lifecycle affected for the Food, Conservation, and Energy Act of 2008.

Lifecycle Stage	Time	Risk	Communication
Landowner	0	8	3
Producer	0	14	3
Consumer	0	0	0

face significant risk associated with lignocellulosic ethanol adoption.

4.3. *Communication and diffusion*

All three acts contain provisions aimed at improving communication related to the diffusion of lignocellulosic ethanol. Most focus on increased information dissemination. Several provisions aim at improving communication about lignocellulosic ethanol with landowners or consumers. These include consumer information programs, such as vehicle labels indicating acceptable fuel mixes, and a consumer outreach program about the environmental benefits of biofuel use. The fairly extensive emphasis on consumer outreach may help explain why the acts do not focus on reducing consumer risk. Building awareness of advanced fuel technologies may be the most important element of diffusion to this group. It is also important to note that the risk for this group is inherently fairly low. Supporting the reduction of consumer risk through, for example, the construction of sufficient E85 infrastructure may be more important at a future date. Provisions aimed at improving communications with landowners include the FCEA "Agricultural Bioenergy Feedstock and Energy Efficiency Research and Extension Initiative" provision which provides research grants for biomass production and requires the creation of a "Best Practices Database" for feedstock harvesting and handling.

Also affecting all stages of the lignocellulosic ethanol product lifecycle are mandatory reporting requirements. These reports will include information such as feedstock availability, research and development outcomes, and policy options pertaining to lignocellulosic ethanol. The findings presented in these reports will communicate what has been completed and still needs to be done as well as what works well and what does not. Another mode of communication that spans all stages of the lignocellulosic ethanol product lifecycle includes the formation of centers such as the EISA Biofuels and Biorefinery Information Center and the EPA Technology Infrastructure Program. Finally, the acts have sections that promote collaboration between various sectors, such as EISA's lignocellulosic ethanol and biofuels research provision. This program provides research grants for collaborators with the Bioenergy Research Centers.

While fewer sections focus on communication than risk, communication is addressed fairly thoroughly. There are sections in the acts aimed at all stages of the lignocellulosic ethanol product lifecycle. Provisions, such as the building of information centers, research centers, and completion and dissemination of reports, have the potential to make contributions toward the communication of key of lignocellulosic ethanol information to all stages to some degree. However, as mentioned earlier, the acts could do more to develop strategies for communicating with different types of landowners, such as forest and farm owners.

4.4. *Integration of the diffusion factors*

One of the most important barriers to lignocellulosic ethanol diffusion is financial [19]. Incentives, such as EPA's Small Ethanol Producer Credit, and FCEA's Credit for Production of Cellulosic Ethanol and Biomass Crop Assistance Program, can aid both landowners and producers with feedstock production and handling costs. There are also various loan guarantee programs and financial assistance for biorefinery construction and retrofitting costs.

Uncertainty regarding the economic and technological viability of lignocellulosic ethanol production creates risk for landowners, producers, and investors [19]. The abundance of research and development programs created through all three acts will assist in reducing this uncertainty and associated risk. Communication will, in turn, potentially assist in reducing risk and facilitate timely diffusion. In total, the three acts aim to overcome facets of time, risk, and communication-related barriers to the diffusion of lignocellulosic ethanol within the United States.

4.5. *Federal policies and potential barriers to the diffusion of lignocellulosic ethanol*

These three major policies do, however, have some weaknesses with regard to promoting the diffusion of lignocellulosic ethanol. For example, EISA's RFS has an arguably narrow definition of renewable biomass feedstock that can be used to produce fuel counting as meeting RFS standards. This definition excludes much woody biomass, including all material harvested on federal forest lands [28]. Even if sufficient amounts are reliably available and biomass can still be harvested and transported to biorefineries in an economically viable manner, the record keeping associated with distinguishing feedstock sources is likely to slow diffusion. It will be difficult and time consuming for a biorefinery to determine and document (1) where each particular feedstock originated and (2) whether it is applicable in terms of the RFS. This has the potential to be a barrier for both landowners and producers. FCEA's Sec. 15332, "Calculation of Volume of Alcohol for Fuel Credits," is an additional provision with the potential to create producer barriers. It reduces the level of ethanol denaturants eligible for the alcohol fuel credit from 5% to 2%. This may create additional risk to producers as they will have to alter their fuel to contain 2% denaturants or less in order to remain eligible for the alcohol fuel credit.

5. Conclusion

The diffusion of lignocellulosic ethanol is dependent upon many factors. We focused on three major U.S. federal policies with a number of provisions designed to overcome time-, risk-, and communication-related impediments to this diffusion. These acts most clearly focused upon decreasing the risk of adoption for lignocellulosic ethanol producers. They contain a number of research and development provisions aimed at improving the efficiency of production technologies and many financial provisions aimed at multiple lifecycle stages. As a result, the policies do not go as far as they could to encourage adoption by landowners or consumers. This is a particularly important omission since access to sufficient, dependable supplies of feedstock will be critical to the development of a strong lignocellulosic ethanol industry and this is unlikely to happen if forest and farm landowners do not choose to produce and sell such feedstock. This could be addressed through the passage of new policies better aimed at meeting landowner needs with regard to harvesting and transportation technologies, and possibly, the establishment of incentives for feedstock production. The EISA definition of renewable feedstock is a particularly serious impediment to the usage of woody feedstock and although there are ongoing efforts in the U.S. Congress to change it, none have to date been signed into law.

Setting aside the landowner issue, in total these policies are likely playing a major role in facilitating the diffusion of lignocellulosic ethanol technology within the U.S. For instance, the number of planned lignocellulosic ethanol plants has increased significantly since the passage of the 2005 EPA [33]. Our analysis is limited by our inability to more concretely assess the effectiveness of these policies in facilitating the diffusion of lignocellulosic ethanol. The policies are all fairly new and no commercial scale lignocellulosic ethanol plants are currently operating in the U.S. However, dozens are planned for completion within the next five years [33]. This points the way to future research that focuses more on assessing the relationship between specific provisions of these acts aimed at overcoming time-, risk-, and communication-related barriers to diffusion and their actual impact on the development of this new and, potentially, important technology.

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