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REVIEW ARTICLE

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Evolving perspectives on biofuels in the United States

Abstract Biofuels represent an important source of renewable energy and may play a crucial role in developing sustainable energy strategies for many countries and the world as a whole. The pros and cons of biofuels, however, have been debated both scientifically and politically. They remain a topic of controversy. In this paper, the evolvement of the perspectives and policies on biofuels in the United States in the past several decades was reviewed. Four different periods, that is, the period prior to 1978 (marked by the passage of the Energy Act in 1978); 1978–1989 (ending with the passage of the Clean Air Act Amendments of 1990); 1990–2004 (ending with the passage of the energy act of 2005); and 2005 to the present, which were characterized by defining events of major policy importance were identified. Each time period was assessed using the Ostrom institutional analysis and development (IAD) framework to show the impact of the evolving interests and influences of global players on policy choices related to biofuels in the United States. The US has a long history of supporting corn-based ethanol and more recently advanced biofuels. Changes in perspectives on biofuels from largely unrelated groups led to changes in policy and market dynamics. Until the late 1990s, most perspectives and policies tended to be aligned and significantly supportive of corn-based ethanol in the United States. In the early 2000s, it became clear that the complications associated with first generation biofuels and corn-based ethanol in particular, were too numerous and too severe to overlook. The need for better options has spurred interest in new technologies and more environmentally benign feedstocks, but, there is little prospect for biofuels playing a significant role in the near term without greater alignment among key players.

Keywords renewable energy, biofuels, energy sustainability

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1 Introduction

Achieving sustainability is the greatest challenge to humanity and the defining theme of the present time [1,2]. Energy is a key nexus that intersects the environmental, economic, and social dimensions of sustainability, which occupies a central place in sustainable development around the world [3,4]. As modern society is becoming increasingly dependent on energy, a critically important component of sustainability is to develop renewable energy sources that are alternatives to fossil fuels. Biological energy, particularly biofuel, has received a great deal of attention from both governments and academia in the past several decades [5–8].

The United States passed the "Energy Policy Act of 2005" and became the first to mandate a renewable fuel phase-in, called the renewable fuels standard (RFS). Two years later, the US Congress took a big step toward meeting the challenge of energy security by passing the "Energy Independence and Security Act of 2007", which aimed to expand RFS to 36 billion gallons per year of ethanol by 2022. In parallel to the US efforts, the European Union set a target of 2% biofuels by 2005 and a target of 5.75% biofuels by 2010 in European Biofuels Directive of 2003 [9]. The European Heads of States and Governments endorsed a binding target of securing a 20% share for renewable energy in overall EU energy consumption by 2020, and a 10% binding minimum target to be achieved by all Member States for the share of biofuels in overall EU transport petrol and diesel consumption by 2020 [9]. Brazil is even more ambitious in its goals for biofuels, and the majority of Brazilian fuel is gasohol, which was governmentally mandated at 23% ethanol in 2006 [10].

As legislation, directives, and targets were being instituted by governments around the world, controversies

around the pros and cons of biofuels emerged and have persisted. While a number of researchers have provided evidence for biofuels as a public good for their numerous environmental and economic benefits [11–13], others have questioned some of these benefits, particularly concerning the impacts on food production and water resources [8,14–18]. Policy towards biofuels in the US, and in other parts of the world, has been evolving continuously since the 1970's, largely driven by supply and demand of oil products and grains as well as the social and political consequences of decisions.

The objective of this paper is to analyze the role of key players and their changing perspectives and policies on biofuels in the US, which would lead to a better understanding of the past, present, and future of bioenergy in the US and beyond. To facilitate the analysis and understanding of this complex issue, four time periods for the evolution of biofuel policy in the US were identified, based on defining events that have substantially changed the policy environment, which are the period prior to 1978; 1978 to 1989; 1990 to 2004; and 2005 to the present.

The Ostrom institutional analysis and development (IAD) framework was also employed to show the impact of the evolving interests and influences of global players on policy choices in the US. The IAD framework is a powerful, general model that can be applied quantitatively for simple games, but is also applicable in situations too complex to be approached as simple games [19]. In this case, the framework helps to identify participants, the roles they play, and the settings (action arenas) in which they will make decisions. It also helps to clarify linkages among action arenas and to show how limitations in knowledge and asymmetric access to information lead to tensions among participants and nonparticipants. The Institutional Analysis and Development Framework makes it possible to study and conceptualize the process of policy making at different scales. It guides the process of making comparisons, evaluations, and connections across arenas that otherwise might be seen as separate and distinct from one another. In the case of biofuels, and especially ethanol from biological feedstocks (hereafter referred to as bioethanol), in the US, the influence of substantially independent institutions can be noticed, which in combination exert a strong influence on biofuel policy, even though actors in each area may not have deep and direct interest in biofuels.

The following five action arenas have been chosen for this analysis:

1) The US Federal Government: The US Federal Government which can be thought of as an umbrella for a myriad of action arenas, including congress, senate, committees, and regulatory agencies, to name a few, is the primary driver of the market dynamic for biofuels.

2) Oil-markets: This action arena was chosen because biofuel must compete with fuels from petroleum products, and thus the dynamic of the oil markets will influence outcomes. Pricing of oil products is particularly important to the competitiveness of biofuel and its underlying demand.

3) Grain market: Grain markets were chosen since the alternative demand for corn appears through the grain markets. The competitiveness of bioethanol is heavily influenced by the price of grain and especially corn [20,21]. Additionally, grain markets are of importance because they directly influence rural income and food affordability.

4) United Nations Framework Convention on Climate Change (UNFCCC): The UNFCCC was chosen as an action arena because, over the last few decades, greenhouse gas emissions by fossil fuels have emerged as an international policy challenge. The potential impact of those gases on climate has created a sense of urgency by policy makers to find alternatives to fossil fuels and to create policy to promote alternatives including biofuels. The UNFCCC is the principal arena for making climate policy.

5) World Trade Organization: This action arena was chosen because the Doha round of negotiations will have a very profound impact on agriculture policy in the developed countries. Prior to the Doha round, agricultural policy remained outside of the trade discussions. However, beginning with this new round, developing countries have tied continuing trade liberalization in products and services to agriculture reform in the US and Europe. Developing countries are specifically requiring deep cuts in farm subsidies in developed countries, especially the US and Europe. Though this round of negotiations has not been completed, both Europe and the US have offered deep cuts in farm subsidies.

In 1978, the US Federal Government passed the National Energy Act of 1978. This act was a watershed piece of legislation for biofuels because it was the first time the US provided significant subsidies for the production of a biofuel specifically bioethanol. This event was used in this paper to mark the end of the first time period of the analysis. The second time period (1978–1989) ended with the passage of the Clean Air Act Amendments of 1990. Until the amendments to the Clean Air Act were passed, the principal policy driver for corn ethanol was the tax subsidy arising from the National Energy Act of 1978. With the passage of the Clean Air Act Amendments of 1990, entirely new markets began to open up for bioethanol. These new markets created a richer dynamic in the market place and in policy arenas. The third time period (1990–2004) ended with the Energy Policy Act of 2005. Through this act, the US Federal Government, for the first time, mandated the use of bioethanol in reformulated gasoline and set targets for biofuels in the transportation sector. The final time period (2005–present) continues into the immediate future. In the rest of the paper, a more detailed analysis of the changes in perspectives and policies on biofuels in the US through each of the four periods was provided.

2 The first period: before 1978

Bioethanol is the single largest biofuel product in the US today, and the policy support for this fuel has its origins in US Federal Government agriculture policy. Agriculture policy is of particular importance to all countries as food supply and, therefore, agriculture is central to social stability. Hayami and Godo [22] have developed a compact framework for assessing agricultural goals that drive government policy. They identify three agricultural problems:

1) For developing countries, avoiding food shortages;
2) For middle income countries, lagging farm income;
3) For developed countries, farm income protection.

Irrespective of the problem, the policy response tends to be substantially the same — Government intervention to move prices of agricultural products or to moderate the impact of global prices to suit the country's social needs. Quoting Hayami and Godo [22], "political distortions in both developed and developing countries are the major determinant of food trade. In high-income countries, despite chronic oversupply of food, domestic farm production continued to be subsidized heavily, resulting in substantial burdens on consumers and taxpayers. On the other hand, in low-income countries, governments often employ agriculture-exploitation policies, further aggravating their food shortage."

The scale of these impacts is large. At the high end, Anderson et al. [23] estimate that, by 2015, full liberalization of trade in agriculture would result in $173 billion of annual real income gain worldwide against a 2001 baseline, with the benefits split roughly one third to developing countries and two thirds to developed countries. Yet trade liberalization in agriculture products has met with serious difficulty in the Doha round of the WTO negotiations. Two frequently cited obstacles to completing the round are the need for the EU to be persuaded to make bigger tariff cuts in agriculture, and the US needs to accept bigger cuts in domestic agriculture subsidies (Table 1) [24].

The problem facing both the EU and US can be understood within the Hayami and Godo [22] model. For the US, the problem originated in the early 1920s and relates to farm income. According to Bowers et al. [25], "The relative decline in the farmers' position had begun in the summer of 1920 when the US began the transition from a debtor to a creditor nation after World War I, resulting in a continued loss in the volume and price of exports. Thus, for a decade, farmers were caught in a serious squeeze between the prices they received and the prices they had to pay before the situation became critical and a major element of the Depression." Until then, and especially in the period just after the turn of the century, farm income was relatively stable and farmers held acceptable purchasing power in relative terms. By the early 1930s, their income relative to city workers was seriously eroding, leading to Agriculture Adjustment acts in 1933[1] and 1938[2] and the introduction of the concept of parity. Parity seeks equality of exchange relationship between agricul-

Table 1 Estimated annual real income gain from liberalization of trade in agriculture [24]

Study	Liberalization scenario	Global welfare gains/(10^9 $)		
		Agriculture	Other total	
Ash &Tangermann (2006)	50% cut in domestic agricultural support 50% cut in applied tariffs—All sectors, all regions	26	18	44
Anderson et al. (2005)	Elimination of domestic agricultural support and trade protection in all sectors	173	105	278
Beghin et al. (2002)	Elimination of agricultural support and protection in high-income OECD countries	108	n/a	n/a
Franois et al. (2003)	Elimination of tariffs, all sectors, all regions	109	107	367*
Hertel& Keeney (2005)	Elimination of domestic agricultural support and tariffs—All sectors, all regions	56	28	84
OECD (2003)	Elimination of trade protection, all sectors	34	63	174**
Tobarick (2005)	Elimination of domestic agricultural support and trade protection	20	n/a	n/a
UNCTAD (2003)	50% cut in applied agricultural support and tariffs, all sectors	31	n/a	n/a
USDA (2001)	Elimination of domestic agricultural support and tariffs, all sectors	56	n/a	n/a
World Bank (2003)	Near 100% reduction in domestic agricultural support and applied tariffs	193	98	291

Notes: *—Includes gains from services liberalization; **—Includes gains from trade facilitation

1) 73rd Congress (1933). Agricultural adjustment act of 1933
2) 75th Congress (1938). Agricultural adjustment act of 1938

ture and industry or between persons living on farms and persons not on farms.

A second set of actors important to the biofuels story are the participants in the grain markets. As pointed out by Murphy [26], grain markets are riddled with power imbalances, making the assumptions of perfect competition untenable. Those assumptions include perfect information flows, no barriers to new entrants in the market, and the capacity to adjust supply smoothly and rapidly with changes in demand. Agricultural commodity markets are particularly prone to failure. Agricultural market realities include a range of imperfections [26]:

1) The hourglass' shape of the market: many farmers sell to a handful of processors or grain traders, who then add value to the commodities to make food, which is sold to many consumers.

2) Slow supply and demand responses to changes in the market: while new ways to use food are constantly emerging, people do not double their meat intake if the price of beef drops by 50%. Should a drought wipe out an important part of global production, it would take 6 to 12 months or more to increase supply.

3) Land does not easily come in and out of production: land ownership in most countries is decentralized and individual farmers cannot afford to keep land idle. Typically, a farmer's response to either high or low prices is to increase production. This response makes downward price spirals related to overproduction hard to halt.

4) Land is not mobile: The textile industry can shift production from the US or Italy, to China or Bangladesh, because capital can move to buy and build the necessary factories, and labor is available everywhere. But no amount of trade liberalization can move arable land from the US or Brazil to Bangladesh.

Low prices may marginally reduce production, but, on the whole, agricultural markets do not self-adjust easily. The first land to go out of production is more marginal land defined as those with the lowest per acre yields. Farmers generally cannot afford to miss a year's crop or to absorb the cost of maintaining idle land (and storing equipment that depreciates annually). Over the past century, developed countries have experienced a simultaneous dramatic reduction in the number of people living directly from agriculture, but increased overall yields, with the amount of land in production staying relatively unchanged [27]. Individual farmers cannot affect overall supply through their production choices because they do not grow enough to affect total supply in the market, even locally, let alone at the global level. Economic logic thus dictates that farmers maximize their production whether prices are high or low. High prices bring new producers (and, especially, new land) into production, but low prices are slow to reduce land in production [27]. The opportunity costs of exiting are high because there is no quick way back in and because most agriculture takes years to show a return.

In the period prior to 1978, US agriculture policy was characterized by increasingly sophisticated measures to sustain farm income while avoiding catastrophic budgetary impacts. However, the 1970s were a benign period as the position of agriculture had changed profoundly from where it had been a decade before. World crop shortages and a falling dollar sharply escalated the trend toward greater export demand for American crops. Following the Soviet grain sale of 1972, grain exports nearly doubled between 1972 and 1973. Government grain stocks, which had depressed grain markets, were essentially eliminated. Even higher output by grain farmers was quickly absorbed by the market. It appeared that demand had fully caught up with supply and that demand would continue strong for the near term.

In fact, the agricultural markets had become so favorable that policy emphasized expanded production to respond to growing worldwide demand and to hold down price increases. In March 1981, United States Agriculture Secretary Block proposed a farm bill to reduce the role and expense of Government in agriculture and rely more on export promotion. Shortly after Congress received this proposal, both the House and Senate passed a budget resolution calling for major cuts in spending, including agricultural programs.

There were clouds on the horizon, however. High farm prices increased demand for farmland that drove land values up [28]. Greater dependence on export markets made commodities more vulnerable to price swings from economic or political events in other parts of the world. Meanwhile, continued food price inflation stimulated consumer demands that support for agriculture be reduced [25].

In contrast to the relatively stable grain markets, at least as viewed from a US perspective, the oil markets were more volatile. Oil had a history of use as an instrument of foreign policy prior to World War and was even more so during and following the war. The US cut off supplies of oil to Japan in 1941 to encourage them to withdraw from China, and Arab states embargoed the US, the UK, and Germany following the 1967 war in Palestine [29]. Though in neither case did the policy achieve the desired ends, the attempt served as a warning of things to come. In 1973, the Organization of the Petroleum Exporting Countries (OPEC) instituted a boycott against the US, Netherlands, and Portugal for supporting Israel in the Yom Kippur war. This time, in addition to the boycott, they also cut production which had the effect of driving oil prices from $3/barrel in 1972 to over $11 by early 1974. This time, the effort did have an effect. The US, lead by Henry Kissinger, undertook a program of shuttle diplomacy with Arab States that resulted in an end to the boycott and partial withdrawal of Israel from newly occupied territory [29]. While, in retrospect, a case can be made that embargoes have never been a threat to US energy security [30], this was not the prevailing view in the 1970s. The US perceived itself as vulnerable to the "oil weapon".

By 1970, oil production in the US had peaked and was in decline (Fig. 1). Since consumption continued to rise, imports were also rising sharply.

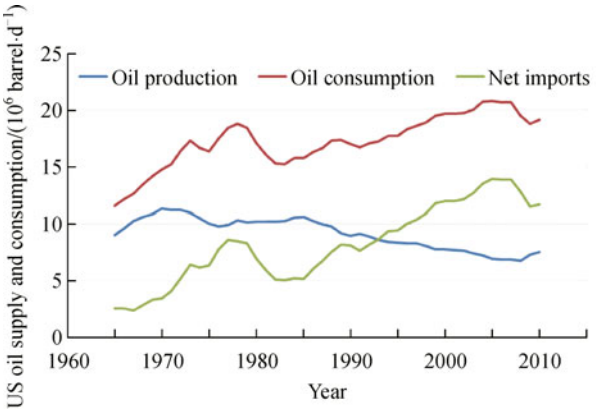

Fig. 1 US oil supply and consumption (millions of barrels per day) [31]

The combination of instability in the Middle East, higher oil imports, and higher oil and gasoline prices led to a series of measures passed by Congress and signed by President Nixon. In 1973, Project Independence was announced. The stated goal of Project Independence was to achieve energy self-sufficiency for the US by 1980 through a national commitment to energy conservation and development of alternative sources of energy. Nixon declared that American science, technology, and industry could free America from dependence on imported oil. Some of the important initiatives to emerge from Project Independence included lowering highway speeds to 55 mph, converting oil power plants to coal, completion of the Trans-Alaskan pipeline, and diverting federal funds from highway construction to mass transit. The energy crisis led to greater interest in renewable energy especially solar power and wind power. It also led to greater pressure to exploit North American oil sources and increased the US dependence on coal and nuclear power.

During this period, the United States Strategic Petroleum Reserve was created, and in 1977, the Corporate Average Fuel Economy (CAFE) standards were enacted by Congress. The cabinet-level Department of Energy was created, followed by passage of the National Energy Act of 1978.

The United Nations Framework Convention on Climate Change (UNFCCC) was not created until 1992; thus as an action arena, it was not relevant during this time period. But environmental concerns were. Earth day was established in 1970 and by 1978 was a global annual event. The possibility of global warming or climate change was suggested already in 1906 in a paper by the Swedish chemist, Svante Arrhenius [32]. Nevertheless, there was no particular action arena for climate, and climate was not yet central to any other arena.

The WTO was in full action as its predecessor organization General Agreement on Tariffs and Trade (GATT), but agriculture was substantially excluded for early rounds, as was energy. Thus, it could be found that in 1978 three action arenas, the US government, the grain market and the oil market were the primary drivers relevant to biofuel in the US.

In 1978, commercial production of biofuel was limited to bioethanol in the US and was virtually non-existent. As grain markets were generally favorable, there was little drive from the agriculture sector for alternative uses of grain, and though energy prices were high and security concerns heightened, the cost of bioethanol was not competitive with oil based products and thus bioethanol plants did not attract investment.

As articulated by Gavett et al. [33] bioethanol did have some attractions:

1) Available technology. Industrial and beverage ethanol industries had perfected the production process. In addition, corn wet-milling facilities can produce ethanol or high-fructose corn syrup, a sugar substitute.

2) Short lead time. A fuel ethanol production facility can start up 11 to 26 months after construction begins, thereby presenting a relatively swift response to the threat of loss of supply of liquid fuels. Other alternate fuels, such as shale oil and gasoline from coal, require far longer start up periods before economic quantities can be produced.

By 1977, events began to change in favor of bioethanol. Corn prices declined for the third year in a row and were now 30% lower than three years earlier (Fig. 2) and events in Iran were again causing concern about energy security. Bioethanol as a policy response appeared in the Food and Agriculture Act of 1977, which authorized loan guarantees of up to $15 million each for four ethanol from biomass pilot plants. Two ethanol plants were considered for financing under this program, but neither was funded [33].

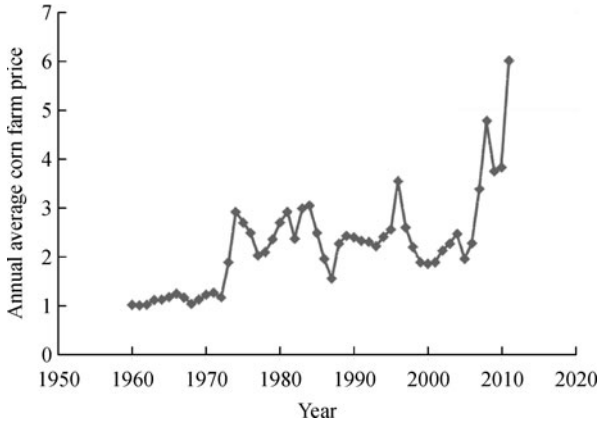

Fig. 2 Annual average corn farm price in US (data from Ref. [34])

In the same year, President Carter took office pledging to

address US energy security. In April, the President introduced an aggressive energy program designed to curb energy consumption and to stimulate alternatives to foreign oil. In October, the much less ambitious National Energy Act of 1978 was passed, which was actually a package of several acts including the Energy Tax Act of 1978. Within the Energy Tax Act of 1978 was a provision that allowed ethanol blends of at least 10% by volume a $0.40 per gallon exemption from the federal motor fuels tax [35]. This was the first time that ethanol was subsidized when produced from agricultural products. While the act was controversial, the bioethanol subsidy was not and played no apparent role in its passage. In fact, in a multivariable analysis carried out by Uri [36], the farm interest groups did not favor the Energy Act package largely because it raised energy prices.

The three action arenas present during this period were the US Federal government, the oil market, and the grain market. The grain market played out in the background through this period acting as a back drop for determining levels of rural income. In contrast, volatility and potential instability in the oil markets brought considerable pressure on the US Federal Government to seek alternatives to its dependence on foreign oil. The decade's long concern for rural development and farm income caused the US Federal government to explore numerous policy options. The National Energy act of 1978 was one of those important policy options that created a new mechanism for supporting agriculture. This approach was particularly attractive since it was perceived over time to be able to address the foreign oil dependency problem, while simultaneously, through the potential for longer term price support, aided the grain markets. The US Federal Government was clearly sensitive to actions in the grain and oil markets, and vice versa. Oil pricing did impact grain production costs, but grain markets through biofuels had no impact on the oil markets. Biofuel volumes were simply too small to matter.

3 The second period: 1978–1989

This period ends with the passage of the Clean Air Act Amendments of 1990. During this time period, bioethanol production from grain rose substantially but remained a minor feature in the fuel market of the US. It was more prominent as a policy option to support agricultural interests. The period began well for corn markets and US producers. Production was generally trending upward, and exports were strong (Fig. 3) as the prices soared (Fig. 2).

However, the situation rapidly deteriorated. Exports began a steep decline in 1980, falling by nearly 50% by 1985. With US production at an all time high, corn prices plummeted, falling from $3.21 in 1983 to $1.50 in 1986.

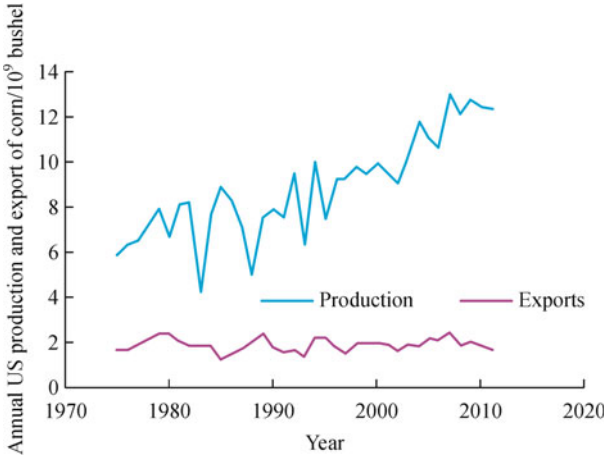

Fig. 3 Annual US production and export of corn in billions of bushels (data from http://www.farmdoc.illinois.edu/)[1)]

Total net income from farming dropped to its lowest levels since 1933. Farm income per farm was lower than at any time since the mid-1960s. Loan delinquencies grew, and farmland values leveled off after tripling over the course of a decade. The 1981 farm bill had been intended to save government funds, but in 1982, the weak farm economy brought a sharp increase in payments to farmers, back to the levels of the 1960s [25].

Farm transfer payments rose rapidly and contributed significantly to the rising federal budget deficit. In 1985, the Congressional Budget Office (CBO) estimated that elimination of deficiency payments would save taxpayers $28.9 billion over five years [37]. Nonfarm sectors of the economy were increasingly showing concern about the very large transfer payments to the agriculture sector and the resulting pressure on the federal budget.

In the energy markets, oil prices rose early in the period largely due to events in Iran and Iraq in 1979 and 1980. The Iranian revolution resulted in the loss of more than 2 million barrels per day of oil production between November 1978 and June 1979. Subsequently as Iran was weakened by the revolution, it was invaded by Iraq in September 1980. By November, the combined production of both countries was only a million barrels per day and 6.5 million barrels per day less than a year before. As a consequence, worldwide crude oil production was 10% lower than in 1979. The combination of the Iranian revolution, and the Iraq-Iran War, caused crude oil prices to more than double, increasing from $14 in 1978 to $35 per barrel in 1981 [38].

Surging prices caused several reactions among consumers: better insulation in homes, more energy efficiency in industry, and automobiles with higher efficiency. These factors, along with a global recession, caused a reduction in demand for crude oil. When combined with an increase in non-OPEC production, supply and demand became

1) Farmdoc University of Illinois (2010) Annual U.S. corn production

unbalanced, and prices began to fall. From 1982 to 1985, OPEC attempted to set production quotas low enough to stabilize prices. These attempts met with failure as members of OPEC produced beyond their quotas.

During most of this period, Saudi Arabia acted to rebalance the market by cutting its production in an attempt to stem the free fall in prices. In August of 1985, the Saudis changed strategies and linked their oil price to the spot market for crude and by early 1986 increased production from 2 million barrels per day to 5 million. Crude oil prices plummeted below $10 per barrel by mid-1986.

Saudi Arabia worked out a broad agreement with both OPEC and non-OPEC members to quotas or production limits in order to achieve a target price of $17 to $19 per barrel. By the end of 1986, an agreement was reached, and though prices continued to be volatile and below the $18 target price (Fig. 4), the decline was stopped, and prices sufficiently stabilized ending the political pressure in the market over the next several years.

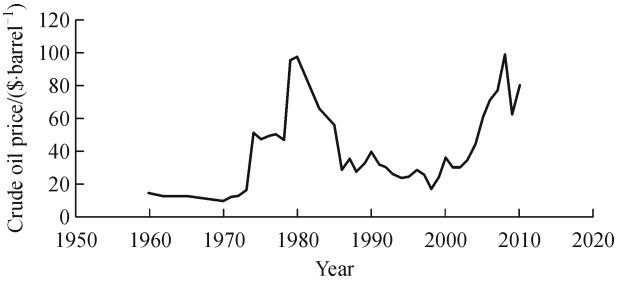

Fig. 4 Crude oil price in 2010 dollars per barrel [31]

In the meantime, ethanol as a motor fuel continued to grow very slowly (Fig. 5), from approximately 2 thousand barrels in 1981 to 20 thousand in 1989. Little of consequence happened in the early part of the period, but in 1986, the US Department of Agriculture released a cost/benefit analysis produced by a team led by Earle Gavett a staff member of the USDA [33]. This report was scathing in its assessment of bioethanol. With pressure on transfer payments to farm interests already building, the report could not have come at a worse time. It immediately drew criticism from congressional figures from districts highly dependent on corn. Representative Stallings of Idaho declared the study seriously flawed, and Senator Dole of Kansas introduced an amendment to the Farm Disaster Assistance Act of 1987 that required that the Secretary of Agriculture establish a seven-member panel to conduct a study of the cost-effectiveness of ethanol production [37]. The report of the panel did not actually establish the viability of bioethanol, but it did report optimistically about the potential for technology to reduce costs.

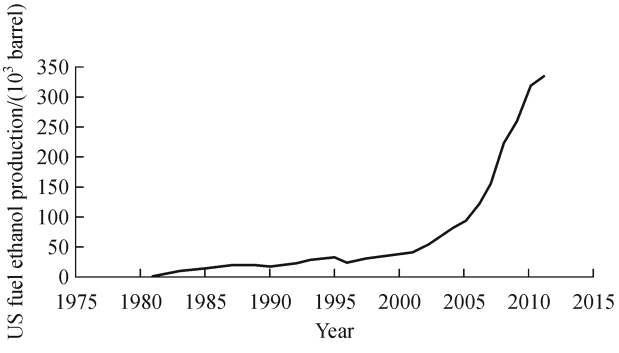

Fig. 5 US fuel ethanol production in thousands of barrels (data from Ref. [39])

Other reports followed, with the repeated emphasis on the environmental and rural development benefits of bioethanol. Finally, a 1988 USDA report [40] argued that, with bioethanol production reaching 2.7 billion gallons by 1995 corn prices would increase substantially reducing deficiency payments to such an extent that there would be a net saving to the government. This report concluded that ethanol could remain cost competitive as a blending agent as long as the existing fuel excise tax exemption remained in place. In the absence of the exemption, ethanol would struggle largely because of the glut in world petroleum markets. The report did remark on the nonmarket benefits of ethanol in meeting environmental, energy security, and agricultural goals, but the benefits were limited as alternatives to ethanol were available. As a shadow of things to come, the report noted that, "ethanol production is self-limiting in terms of its contribution to national energy supplies. Production levels of two or three times current levels, while still a small proportion of the total energy use, would begin to place strong upward pressure on corn and other grain prices...". In 1988 ethanol production was 20 thousand barrels, or less than one tenth of the production of 2008. Finally, the authors suggested that ethanol as a blend stock could support some of the provisions of the Clean Air Act Amendments by reducing carbon monoxide emissions in automobiles but that it would be best used in winter as the higher volatility of ethanol blended fuels increases ozone.

Among the action arenas, bioethanol remained a peripheral issue, but much was happening that would later have a major impact on biofuels. By the end of the 1970s, the scientific community was heavily engaged in the question of climate change. Evidence was clear that the earth's climate had changed in the past, and there was some evidence that it could happen quickly. Though most of this work concerned global cooling and glaciations, in 1977 a study by the US National Academy of Sciences focused on global warming from CO_2 emissions, warning of a future risk of rising seas and failures of agricultural and marine production [41].

During this time period (1978–1989), bioethanol was substantially irrelevant to all the action arena's, with the exception of the US Government, where support coming from representatives of agriculture states remained strong.

The rapid congressional reaction to the Gavett et al. [33] study underscores the depth of that support. With support from Congress, bioethanol production increased from approximately 2 thousand barrels at the beginning of the period to approximately 20 thousand by the end of 1989 with over 50 ethanol production facilities operating. Nevertheless, the industry continued to depend on Federal and State subsidies, and though a substantial increase, 20 thousand barrels remained less than 1% of all petroleum products used in transportation.

The apparent smooth growth at the industry level also masked considerable turmoil for individual companies and plants. The industry was unable to achieve consistent profitability because of changing economic conditions, especially the swings in corn and oil prices and technological problems. Many plants were forced to default on loans, or were forced into bankruptcy, including most of the small plants that received Federal loan guarantees. Ethanol's use as an additive to gasoline to boost the oxygen content became established during the period. Environmental benefits of oxygenated fuels, such as an ethanol/gasoline blend, led several states to develop oxygenated fuel programs. The first mandated program was instituted in the Denver metropolitan area and surrounding counties. The program led to an 8% to 11% reduction in ambient carbon monoxide levels [42]. This and similar programs formed a component of regional air quality plans designed to bring ambient carbon monoxide levels below the standards established by the Clean Air Act Amendments. The use of bioethanol to meet the requirements of the Clean Air Act Amendments becomes a more important theme later.

Again during this time period, the three important action arenas were the oil market, grain market, and Federal Government. The dynamic of the pre 1978 time period continued into this time period, specifically instability and volatility in the oil markets and substantial pressure on rural incomes due to depressed prices in the grain markets. While the impact of corn ethanol on the grain and oil markets was minimal, the reverse was not the case. The volatility of these markets again made corn ethanol an attractive policy option even though analysis by the USDA showed little near or long-term potential.

4 The third period: 1990–2004

This period ended with the Energy Act of 2005. During the period, production of bioethanol rose from 20 thousand to 81 thousand barrels per year. Agricultural markets in 1990 were improved from the very difficult period in the late 1980s but still remained generally unfavorable and volatile. As the period began, corn production remained high while exports fell (Fig. 3). Actual prices fell well short of target prices (Table 2), resulting in a deficiency payment of over $3 billion. In 1990, Congress passed The Food, Agriculture, Conservation, and Trade Act of 1990 [43], as well as the Omnibus Budget Reconciliation Act of 1990.

Table 2 Corn price, target price and deficiency payment for US agriculture support programs [37]

Year	US corn price/($·bu^{-1})	Target price/($·bu^{-1})	Deficiency payment/10^6 $
1975	2.54	1.38	0
1976	2.15	1.57	0
1977	2.02	2.00	0
1978	2.25	2.10	88
1979	2.48	2.20	0
1980	3.12	2.35	0
1981	2.47	2.40	0
1982	2.55	2.70	291
1983	3.21	2.86	0
1984	2.63	3.03	1653
1985	2.23	3.03	2480
1986	1.50	3.03	6195
1987	1.94	3.03	5910
1988	2.54	2.93	2163
1989	2.36	2.84	3504
1990	2.28	2.75	3014
1991	2.37	2.75	2080
1992	2.07	2.75	3625
1993	2.50	2.75	1502

Both acts built on the market-oriented foundation laid by the Food Security Act of 1985 [44]. These initiatives reinforced measures already under way to promote freer trade, to reduce the deficit, and to move U.S. and world agriculture toward greater market orientation.

Pressure to cut the Federal budget deficit also played an important role. The main goals of 1990 farm legislation, food, agriculture, conservation, and trade act, were to further market orientation, reduce government spending on agricultural programs, help maintain farm income through expanding exports, and protect the environment. To lower budget expenditures and increase market orientation, the 1990 legislation reduced payment acreage and introduced planting flexibility. Producers were given the option to respond to market signals in their planting decisions, because they could plant alternative crops on acres that were not eligible to receive income support payments [45].

These efforts did not stem budget deficit problems, however, as deficiency payments remained high. In 1996, following a "better" agriculture market year in 1995, Congress passed a new farm bill called the Federal Agricultural Improvement and Reform (FAIR) Act. The act made two major changes. First, it ended supply controls by eliminating provisions that made farm aid contingent on keeping land out of production. Second, it set up a seven-year schedule of fixed and declining direct farm payments completely delinked from market prices. This change was intended to return agriculture in the US to full market exposure over the seven year period [46].

To promote market mechanisms further, official US government policy actively promoted liberalized international trade measures to open new markets for US products, including at the Uruguay Round of the WTO. This round of trade liberalization talks were completed in 1994, with new rules applicable to agriculture. Specifically, rules were agreed in three broad categories [47].

The first category was market access. Barriers to trade such as quotas, variable levies, and voluntary export restraints to agri-food imports were replaced by a tariff-only system, and a country could not increase tariffs unilaterally. Tariffs were also reduced. Developed countries were required to reduce their tariffs by an average of 36% over six years, with a minimum cut in any one tariff line of 15% [47]. The second category of new rules was for subsidies. Subsidies to farmers were classified according to their impact on production. Subsidies with minimal linkage to the quantities produced, the inputs used or prices paid, were not affected, but most other subsidies were capped. Developed countries had to reduce agricultural subsidies by 20% over six years. The final category was export subsidies. The agreement did not ban export subsidies but imposed severe restrictions on the quantities subsidized and the amount of expenditure on these subsidies. New export subsidies are prohibited. The maximum expenditure on export subsidies in developed countries had to be reduced by 36%, and the maximum quantity of exports that can benefit from the subsidies had to be reduced by 21% over six years to 2000 [47].

In spite of the changes to the international trade system, and US policy support, US corn exports did not rise above the 1996 levels. Rather, exports fell sharply from 1996 to 1997. From 1997 to 1998 there was a rise in exports, but from 1998 to 2000 exports began a slow decline to the end of the period (Fig. 3). While commodity prices had been trending upward before the FAIR Act was passed, the 1996 corn price was a one year spike. Prices immediately began to plummet and by 1999 were solidly below $2/bushel (Fig. 2). Prices of primary agricultural exports (corn, wheat, soybeans, cotton, and rice) declined by more than 40% from the 1996 levels through 2003 [48].

Farm income from the marketplace declined dramatically globally. Congress responded by passing a series of emergency farm bills beginning in October 1998. Farmers received direct cash payments that were decoupled from any sort of production controls. The result was that the US output of corn first declined slightly but then rose again to historically high levels (Fig. 3). US net cash farm income remained relatively stable, but only because government payments ballooned from $7.5 billion in 1997 to $23.2 billion in 2000 before declining back to $13 billion in 2004 [49].

The 2002 Farm Bill (Farm Security and Rural Investment Act of 2002) formalized these payments, which resulted in the agricultural sector receiving more aid than before the 1996 FAIR Act [48]. The global decline brought considerable scrutiny onto US farm policy from the international community and charges that agribusiness and corporate livestock producers were the real beneficiaries of a policy that was hurting farmers worldwide, and especially in developing countries [48]. The international community saw the 2002 Farm Bill as a retreat from earlier US positions on reforming farm policy and liberalizing agricultural trade. Now, the US, appeared two-faced, telling the rest of the world to cut their farm subsidies while increasing its own [50]. In the 2002 act for the first time an Energy Title IX with mandatory funding of $405 million was included. The objectives of Title IX were procurement of bio-based products; grants and loans for renewable energy/efficiency projects; research and development; and the Commodity Credit Corporation Bioenergy Program.

The pressure on the US continued into the next WTO round of negotiations, the Doha Round, which began in 2001 in Doha, Qatar. Since developing countries represented the majority of members of the WTO, any agreement in Doha would require that they clearly benefited. Continued reform of agriculture became a key feature of the Doha Development Agenda created by the conference [50].

For the oil markets, the period began with the invasion of Kuwait by Iraq in 1990. Prices rose briefly but returned to prewar prices by 1991. Low prices where depressed

further with the onset of the Asian financial crisis, which began in 1997. Prices were trending around approximately $20 per barrel but in 1998 dipped briefly below $10 per barrel. Prices remained sufficiently low that a series of megamergers between independent oil companies began in 1998. More significantly, for energy markets a decade later, low prices pushed new exploration to historically low levels. In 1999, OPEC agreed to a cut in production, which began pushing prices higher as did the second Gulf War that began in 2003. Demand began to return especially in Asia by 2004, and prices began what would become a prolonged and historic rise.

On the environmental front, concern about anthropogenic interference in the climate system through greenhouse gas emissions reached a sufficient level that the United Nations held the Conference on Environment and Development in June of 1992, which became known as the Earth Summit. The purpose of the conference was to agree to a treaty to stabilize atmospheric greenhouse gases. The agreement that was reached is known as the UNFCCC.

The treaty itself set no mandatory limits on greenhouse gas emissions and was legally non-binding. The treaty provided for updates that could be agreed to by a "conference of the parties" (COP). These updates, or protocols, were expected to set more rigorous standards. The best known of the protocols to date is the Kyoto Protocol, which set goals especially for developed countries, but they were again non-binding. The treaty entered into effect in 1994 and currently has 192 parties. The US did not ratify the treaty and is not a signatory to the Kyoto Protocol.

Production of bioethanol continued to rise rapidly during the time period, as the market for methyl tertiary-butyl ether (MTBE) declined. MTBE was a popular gasoline additive for providing oxygen in motor fuel. MTBE was banned in several states out of concern for potential health risk from leaks and spills. With MTBE no longer acceptable as a fuel additive, an opportunity opened up for ethanol as an oxygenated fuel additive. The decline of 30000 barrels from the peak of MTBE use betwen 1999 and 2004 was largely made up by bioethanol. Biofuel, and especially bioethanol, continued to benefit from stable government support in the form of subsidies.

For the first time, all five action arenas are now present and have a broad impact relevant to biofuels. The substantial concern about climate change and greenhouse gases led directly to the creation of the UNFCCC following the Earth Summit in 1992. The UNFCCC created the foundation for global policy making with respect to the climate. During this time period, the deliberations of the UNFCCC had minimal impact on the other action arenas, and, therefore, on corn ethanol. No direct linkages between corn ethanol and greenhouse gas reduction were actively promoted, but the stage was set for this linkage in the following time period. The WTO impact was also minimal on bioethanol, because no major policy options emerged supporting or not supporting bioethanol during this period. In contrast, the US Federal Government was feeling an impact from both the UNFCCC and WTO action arenas.

The grain market was experiencing extreme volatility, and generally, downward pressure on farm incomes resulting in high federal budget deficits. For the first time in the scope of this analysis, the oil markets experienced relative geopolitical stability, but price volatility on the down side was unsettling for industry players. Security concerns were, therefore, substantially diminished compared to earlier periods. In spite of the reduced pressure on the Federal government regarding energy security, the emergence of the WTO and UNFCCC action arenas, combined with the extreme pressure coming from rural states because of low grain prices, led to a complex policy environment. This complex policy environment, in turn, led to a number of policy interventions in support of biofuels. Of particular note, was the Clean Air Act Amendments of 1990 that opened a way for ethanol as a fuel oxygenate. Other policy interventions included tax subsidies for blending and investment support for expanding production.

5 The fourth period: 2005–present

Corn prices began the period at about $2.00 per bushel but rocketed to nearly $5.00 per bushel by 2008. Farm income fell in 2005 and 2006, before rebounding to historically high levels in 2008, as corn prices and commodity prices generally moved to unprecedented highs. The rise was so steep that the higher food prices sparked riots in many countries in 2008, and according to the Food and Agriculture Organization of the United Nations (FAO), at least 40 governments imposed emergency measures, such as food price controls or export restrictions [51]. Farm income remains high.

The FAO index of nominal food prices doubled between 2002 and 2008. The nominal index reached its highest level in the last 3 decades. The real index, which was adjusted in order to assess the effect of price increases on consumers, showed its first substantial rise after four decades of decline. By mid-2008, real food prices were 64% above the levels of 2002 [51]. Among the factors responsible for the rise in commodity prices were higher production costs, due to higher petroleum prices, production shortfalls, and strong demand growth — especially for biofuels. With the fall in oil prices, the FAO index also declined but has returned to historical highs.

In the Doha negotiations, the US position was complex. On the one hand, most experts agreed that the US exceeded its support limits in 1999 and 2000; yet the US negotiators continued to press for market opening reforms. The

disconnection between Congress and the Bush administration negotiators arose largely because, among farm organizations, there was little support for trade reform. Exports did not get a big boost from the Uruguay round agreements and remained volatile. Farm organizations saw more potential in biofuels than in exports. Without the support of farm organizations, there was no real incentive for Congress to make the changes in farm policy necessary to meet the spirit of Doha. The degree of misalignment became very apparent when Congress passed the 2008 Farm Bill, called the Food, Conservation, and Energy Act of 2008. This bill returned to many of the earlier farm support policies and is generally seen to be noncompliant with the direction of Doha [52].

The Title IX energy provisions were expanded in the 2008 farm bill but refocused biofuels policy initiatives in favor of non-corn feedstocks, especially cellulosic-based feedstocks, in response to growing concerns about the effects of increasing corn use for ethanol production. The 2008 farm bill authorized $1.1 billion in mandatory funding for energy programs for fiscal years 2008 through 2012. The 2012 farm bill is under intense negotiation as is written with calls from both parties for reform but with little expressed concern for the WTO negotiations.

The concern about climate reached a new level with the publication of the fourth assessment report of the IPCC in 2007. Some of the key conclusions of that report were [53]:

1) Warming of the climate system is unequivocal.

2) Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic (human) greenhouse gas emissions.

3) Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized, although the likely amount of temperature and sea level rise varies greatly depending on the fossil intensity of human activity during the next century.

4) The probability that this is caused by natural, climatic processes alone is less than 5%.

5) World temperatures could rise by between 1.1°C and 6.4°C (2.0°F and 11.5°F) during the 21st century.

6) Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium.

Total global emissions, however, continue to rise. The US in particular has had a steep increase over this time period. Attempts to reinvigorate the UNFCCC process and to reach a new accord with more aggressive targets that would bring total global emissions down, have thus far largely failed.

In the oil markets, the dramatic increase in price that began in 2005 and culminated in a price of more than $145 per barrel in July of 2008, before an even more precipitous decline, qualifies as one of the most extraordinary periods in the industry history. Much has been written about the cause of the spectacular rise and fall but without a widely accepted conclusion.

A number of authors have argued it was largely a supply and demand phenomenon. Dees et al. [54], for example, evaluated the time period between 2004 and 2006, and concluded that the price rise in that period was largely due to concern about supply. During the period, the world oil production capacity was operated at a higher than normal level, and when combined with market expectations that oil could be in short supply in the future, oil prices were pushed higher [54]. Hamilton [55] similarly argued that the price rise was the result of a supply/demand dynamic that went out of balance, because of a failure of production capacity to keep pace with growing demand between 2005 and 2007. He pointed particularly to the lack of increase in production capacity in Saudi Arabia, and in fact, a decline in their output in 2007, as indicative of the problem. Hamilton [55] pointed out the psychological effect on markets, of Saudi Arabia not balancing supply and demand, by adjusting both its production capacity and its monthly output. With demand from developing countries rising and supply stagnate, price had to rise to push demand down enough to balance.

Concern about speculation was sufficiently widespread that investigations were undertaken by the US Senate Permanent Subcommittee on Investigations in 2006. They found, "...there is substantial evidence supporting the conclusion that the large amount of speculation in the current market has significantly increased prices." The Commodity Futures Trading Commission in 2008, also undertook a study, but in a November 2009 statement, reported no evidence for excessive speculation.

Oil prices are currently at historically high levels again comparable to 2008 without the extreme volatility. In a working paper prepared by the Federal Reserve of St. Louis, the authors found that as much as 13% of the price of oil was the result of speculation [56]. Of particular importance to ethanol was the change in law that required oxygenates for reformulated gasoline in the Energy Policy Act of 2005 which allowed companies to meet the clean air standards in any way they chose. Demand for ethanol rose sharply as did the price. Ethanol reached an all-time high, wholesale price of $3.58/gal before falling back. The average wholesale price in 2009 fell below $2.00/gal for the first time since 2005 but has since recovered. The year 2010 saw the highest prices for ethanol ever at $2.70 per gallon.

Federal Government support for first generation biofuel remained strong early in the period. In his 2006 State of the Union address, President Bush put forward a goal to "replace more than 75% of our oil imports from the Middle East by 2025". The Energy Policy Act of 2005 mandated the use of biofuels for transportation in the United States. Congress expanded the 2005 act when it passed the Energy Independence and Security Act of 2007. A key provision

of the Act is a major expansion of the renewable fuel standard (RFS) to thirty-six billion gallons a year of ethanol by 2022, with no more than fifteen billion gallons coming from corn or other grains and no less than twenty-one billion gallons coming from cellulosic feedstock in that final year.

The targets in the mandate are aggressive and are supported by subsidies for production that are large and have been in place for nearly 30 years to make investment in ethanol production attractive. The US has now nearly achieved the limit of 15 billion gallons of grain ethanol required under the 2007 Act, but as ethanol prices rose in 2011 Congress eliminated the subside or grain ethanol with effect January 1, 2012. The subsidy for cellulosic ethanol remains, however.

Bioethanol also came under intense scrutiny as scholars explored both the contribution of bioethanol to greenhouse gas mitigation and energy security. While the debate has been intense and results at times contradictory, a consensus emerged that bioethanol from corn makes only a very small contribution to both net energy and to greenhouse gas mitigation in the US [18,57–59]. Even if first generation biofuel has a positive net impact on carbon dioxide emissions the costs are high. The lowest cost for greenhouse gas reduction is just under $80/ton with technology not fully commercialized and with current technology estimated at about $350/ton. This pricing compares with an early 2008 market price for one ton of carbon dioxide equivalent on the Chicago Climate Exchange of $1.90/ton for 2010 delivery and a 2006 estimate by McKinsey [60] that a $40/ton price for CO_2 emissions would be enough to stabilize atmospheric CO_2 at 450 ppm.

Researchers at Oak Ridge National Laboratory examined the economic implications for energy security of imported oil [61,62]. Greene and Leiby [61] examined a number of different analytical approaches to assess quantitatively the economic cost of high imports. Leiby adopted and developed one of the approaches, a marginal cost approach, which considered the cost that would result from a marginal (small incremental) change in oil imports from the current level, and thus, was an indication of what price the Americans should be willing to pay to achieve a small change. These researchers could only identify ranges of savings, as exact estimates were subject to assumptions that were not easily quantified. Even using the high estimates, however, the savings did not offset the costs of ethanol from corn subsidies.

In addition to the benefits for energy security and greenhouse gas emission reduction, supporters of biofuels also argued that they provided benefits to rural communities and farmers. Though support to rural communities, and especially farmers, were also seen as an important policy goal, just how support for biofuel aids rural communities came into question. Rubin et al. argued that while legislation favoring biofuels tended to focus on energy security and the environment, the real reason for passing bills was to support farmers and landowners [63]. In his assessment, the only way to make sense of the size of the subsidies was as a mechanism to raise commodity prices and attract land currently fallow in setting aside programs into production.

Miranowski [64] argued along a similar line pointing out that higher commodities prices transferred money to farmers and landowners and took pressure off highly visible farm programs. Both of these lines of argument required that the ultimate beneficiary of the subsidy was the farmer and landowners. The distinction was made here between benefit from higher prices and benefit from the subsidy, as higher prices clearly benefited farmers and landowners, whereas subsidies might or might not depend on the sharing of rent among corn producers, ethanol producers, and fuel blenders.

Analyses by Taheripour and Tyner [65] and Rubin et al. [63], suggested that currently, and for the foreseeable future, the beneficiaries of the current subsidy were mainly the ethanol producer. They found that the impact on rural development was at best mixed and might actually result in fewer jobs. With payments drawn from the general public in the form of lower tax revenues and from future generations in the form of government debt, it was hard to justify why $7 to $9 billion should be transferred from these economic interests to ethanol producers for no net gain in social benefit. An additional line of concern arose due to the very rapid run up in grain and food prices, i.e., the potential for food and fuel competition. Tilman et al. [59] estimated that in 2005, 14.3% of the US corn harvest was used to produce 4.0 billion gallons of ethanol, which was energetically equivalent to just 1.72% of U.S demand for gasoline. Johansson and Azar [66] published the results of an economic model of the US agricultural and energy system to assess the possible competition for land and to examine the link between carbon prices, the energy system, and food prices. Their results indicated that bioenergy plantations would be competitive on cropland at carbon taxes of about US $20/ton C. As the carbon tax increased, food prices more than doubled from competition with fuel ethanol plants compared to the reference scenario in which there was no climate policy. They also found that bioenergy plantations appropriateed significant areas of cropland and grazing land [66].

By 2008, the UN was sufficiently concerned to request a review of biofuels policy in the US and Europe because of the extremely high food prices. As reported by Rosenthal [67], Jacques Diouf, the executive director of the United Nations Food and Agriculture Organization urged that current policies should be, “urgently reviewed in order to preserve the goal of world food security, protect poor farmers, promote broad-based rural development and ensure environmental sustainability.” This statement contrasted sharply with the views of the US Department of

Agriculture, which earlier released a study that showed "high energy prices, increasing global demand, drought and other factors — not biofuels — are the primary drivers of higher food costs" [68].

It is perhaps not too surprising that the USDA would come out squarely behind the production of biofuel and corn ethanol. A little more than a year earlier in his 2007 State of the Union address President Bush stated, "It's in our vital interest to diversify America's energy supply — the way forward is through technology... We must continue investing in new methods of producing ethanol, using everything from wood chips to grasses, to agricultural wastes Let us build on the work we've done and reduce gasoline usage in the United States by 20% in the next 10 years... To reach this goal, we must increase the supply of alternative fuels, by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017." Following on from this challenge, Congress passed the Energy Independence and Security Act of 2007 in December 2007. A key provision of the Act is a major expansion of the renewable fuel standard (RFS) to thirty-six billion gallons a year of ethanol by 2022, with no more than fifteen billion gallons coming from corn or other grains and no less than twenty-one billion gallons coming from cellulosic feedstock in that final year.

The US Government stood solidly behind biofuels including bioethanol from grain, but the renewed emphasis on biofuels from nonfood crops, which also appeared in the Energy Act of 2005, did signal a recognition that grain could not be the sole or even the majority feedstock for a meaningful biofuel industry in the US.

In the period 2005 to present, all five action arenas are active and are interactive with each other. They all are also directly impacting on the role of biofuel and in particular grain ethanol as a fuel for reducing greenhouse gas emissions in transportation and improving domestic and international energy security. One of the features of the interaction among the action arenas is that they are now began to see as an element of friction. For example, big agriculture food manufacturers whose interests are better served by low to moderate grain prices expressed concern about the very high price spike of corn in 2008 and the perceived role corn ethanol played in it. The price spike put the food manufacturers at odds with the federal government and their policy of supporting rapid growth of corn based ethanol. The extraordinary run up in oil price reignited energy security concerns and unlike previous crisis where geopolitical events in the Middle East were behind the spikes in price, this run up in price could not easily be attributed to any single factor [56]. Rather, it seemed to be driven by a combination of factors including prolonged increases in demand for crude not matched by increases in investment to increase supply, aggressive oil trading practices by international firms, and a certain amount of "going with the herd". The impact of national policies are also began to be seen in countries with large reserves that limited investment in the oil sector.

In the WTO, the Doha round now has as a core feature, agriculture reform. The US position in the Doha round is complex, and in the eyes of some inconsistent, since they tried to preserve farm subsidies while encouraging open trade with developing nations. Finally, the UNFCCC and the focus the climate negotiations brought on greenhouse gas emissions, created a very complex environment for corn ethanol. While promoters of the fuel attempted to champion the green credentials of ethanol, a growing body of evidence suggested marginal benefits for reduction of greenhouse gas emissions if any at all. Thus, the direction of UNFCCC research work, under the IPCC and in laboratories around the world, also brought this action arena into direct conflict with the US Federal Government policy to promote corn ethanol.

6 Concluding remarks

In conclusion, the IAD framework is a useful construct to look at the full suite of issues and players in the biofuels debate. Through the analysis in this paper that characterized the nature of these action arenas and the forces that drive them, a framework have been created for understanding biofuel policy drivers that will shape the future of biofuels. This set of action arenas will likely be a sufficient set for analysis well into the future. While new policy drivers could emerge, they are unlikely to appear inside an action arena other than those identified in this paper.

The underlying tension among action arenas remains largely unresolved and will likely cast a shadow over the biofuels industry until new technologies emerge that can balance the interests among the five action arenas and create greater alignment among them. In the absence of greater alignment, the future for biofuel is likely to look much like the past. Policy will largely support corn based bioethanol at its current level, along with research support for second generation technologies, but not at a transformation level.

There are possibilities for a different kind of future. A global climate agreement, completion of the Doha round of negotiations, another spike in energy prices, or the emergence of a new disruptive technology could all create conditions for tighter alignment of interests among the IADs, leading to more aggressive policy measures to promote biofuels. It remains difficult to predict how this scenario would play out in detail.

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