The Emerging Biobased Economy

A multi-client study assessing the opportunities and potential of the emerging biobased economy

Developed by Informa Economics, Inc. in Participation with MBI International and The Windmill Group.

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I. Introduction

- As mentioned in the original prospectus, "The purpose of the study is to provide analytic insight and foundations needed to successfully evaluate decisions and assumptions already in place involving biobased products. The study also will help participants to identify opportunities and risks and provide for objective evaluation of case studies, as well as, a framework for strategically positioning their operations in the context of the emerging biobased economy."

- The study is laid out in the following format:
    - Introduction – a brief overview of the critical supply and demand forces of the petroleum and energy industries and the developing role of renewable resources.
    - Summary of Study Findings – a compendium of the salient highlights/findings from the study.
    - Biomass Policy Assessment – a descriptive assessment of the policies (US and abroad) that are helping to shape the biobased economy.
    - Technology Assessment – a review of the existing and emerging technologies and chemistry that is transforming the biobased economy.
    - Product Assessment – highlights the size and potential of numerous product segments that are impacted by biobased inputs.
    - Biorefinery Discussion – a review of the existing and emerging trends of the biorefinery concept.
    - Land Resources - a discussion of the role of agricultural lands relative to the bioeconomy.
    - Impacts - scenarios of oil prices and governmental support on the biomass and agricultural economies.

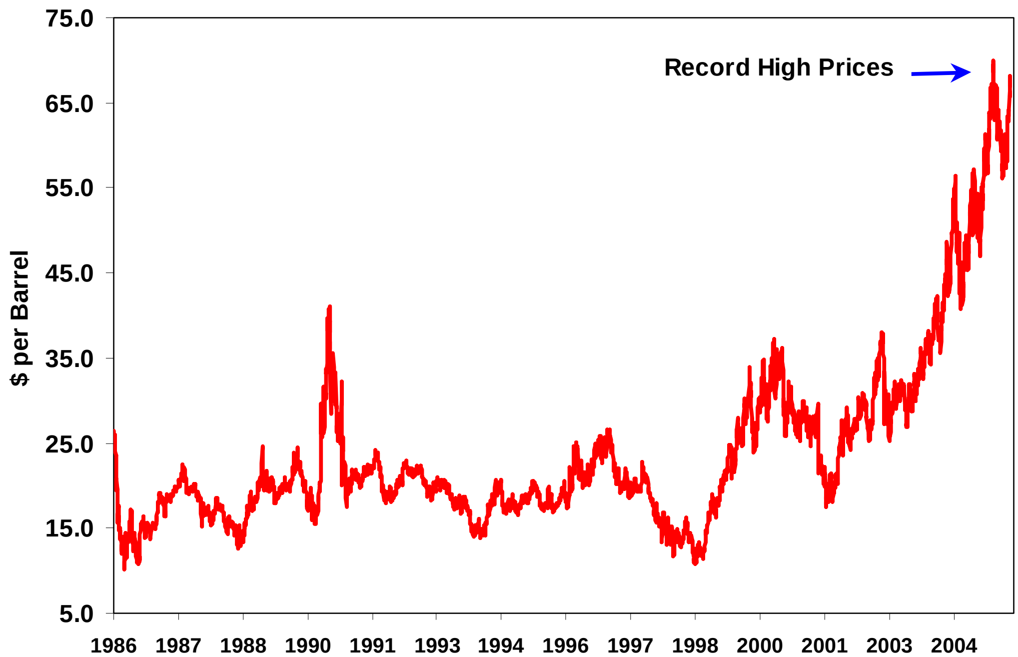
- In order to understand the potential role of biomass in today's economy, one must first gain a perspective concerning the balance and role between the available supply and consumption of the primary energy inputs.

- Our reliance on energy sources, be it finite hydrocarbon fossil fuels (such as petroleum and coal) or renewable supplies (such as hydroelectric and wind) play a vital role as the building blocks in the composition of every economy. Unlocking and utilizing these energy resources in an efficient manner translates into the economic lifeblood that sustains our transportation, industrial, residential and commercial sectors.

- Any significant change in the price of these natural energy resources is quickly felt throughout the economy because of the high degree of interconnectedness and the major volumes of energy that are consumed by the different sectors.

- Recently, nominal oil prices for West Texas Intermediate (WTI) crude reached record high levels to just below $80/barrel (Figure 1). WTI prices averaged only $19.09/barrel from 1986 to 1999, reaching a low of $10.25/barrel and a high of $41.07, during this period.

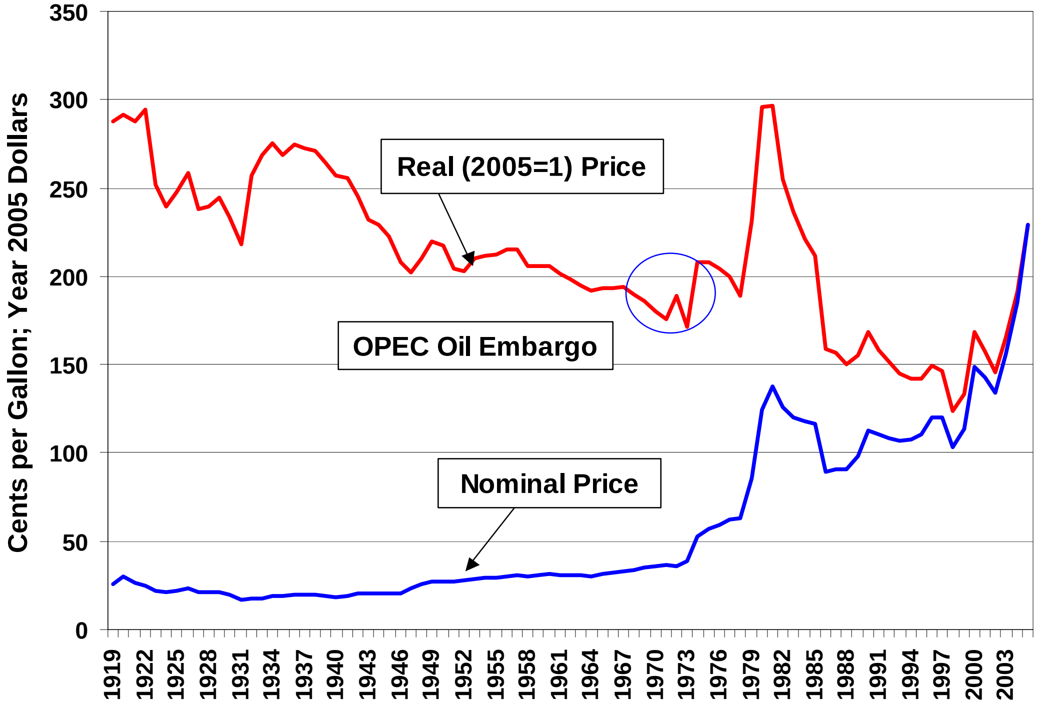
Figure 1: Oil Price, West Texas Intermediate: 1986 to Present



Source: DOE, Energy Review

- In real terms, adjusted for inflation, oil prices have actually been in a long-run steady decline from 1919 (Figure 2). There have, however, been brief periods of oil price increases but the real prices regressed back to the long-run price decline trajectory. The recent oil price spike has taken real prices to levels that have not been experienced since the late 70's and early 80's. The longer the high real prices persist, the greater the negative impact on the economy as the "cost of doing business" increases for all economic sectors.

Figure 2: Real Gasoline Pump Price: Annual Average 1919-2005



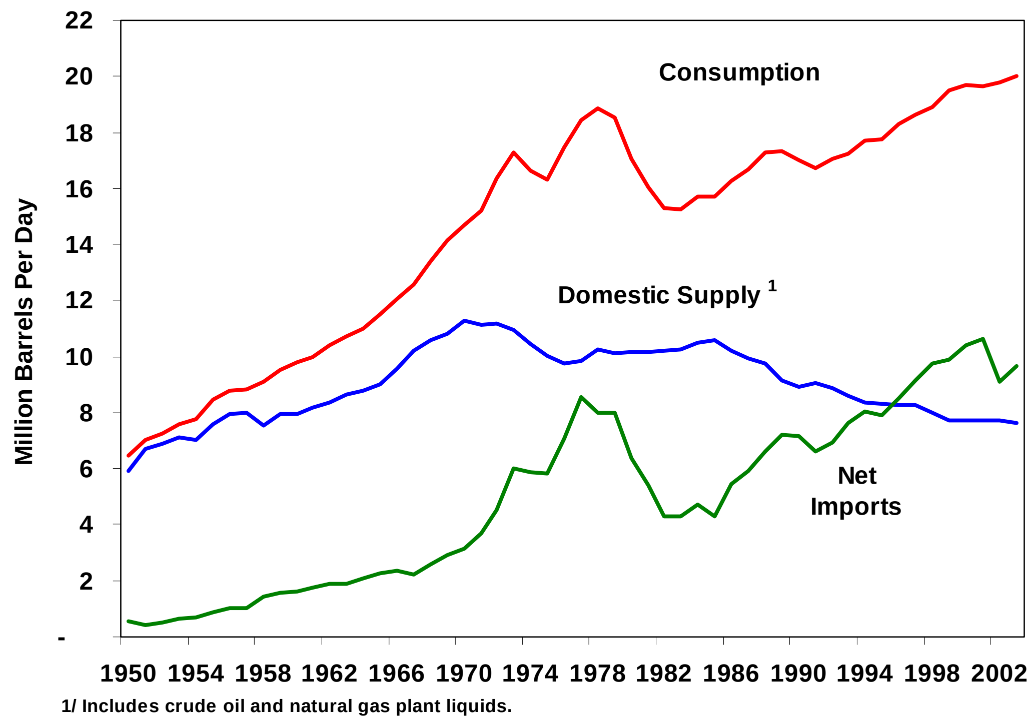
Source: DOE, Energy Review

- The higher real petroleum prices have led to a significant movement in the US to debate the necessity of reducing our dependence on foreign imports of petroleum. The current administration has acknowledged the need to quickly find alternative, and preferably renewable, sources of energy to replace our nation's "addiction to oil" (President George Bush). The US Department of Energy (DOE) is quoted as saying "By expanding and accelerating our biomass research and development activities, we will help reduce our dependence on foreign oil by speeding development of domestically produced transportation fuel (ethanol) and other products largely derived from oil today."

- Since the mid 1950's, the US has imported more energy than it has exported. US consumption of petroleum, the most important US energy resource, has expanded from approximately 6.2 million barrels a day in 1950 to almost 20 million barrels a day in 2003 (Figure 3). During this period of time, the role of petroleum imports to meet US consumption has changed dramatically. In 1950, imports of petroleum were insignificant relative to domestically produced petroleum. Now imports of petroleum have surpassed the level of domestic petroleum supplies.

- Fortunately, most of the oil imports have been met by North American countries, with Canada and Mexico providing over 31% of US petroleum needs during 2005 (Table 1). The concern, of course, are consistent future supplies of petroleum from geopolitically sensitive regions of the world such as the Middle East and specific countries such as Nigeria, Iraq, and Venezuela which accounted for oil imports of 10.2%, 5.2% and 12.8% respectively in 2005.

Figure 3: US Petroleum Situation: 1950-2003



Source: US Energy Information Administration

Table 1: US Imports of Crude Oil, by Country of Origin – 2005 (Jan-Sep)

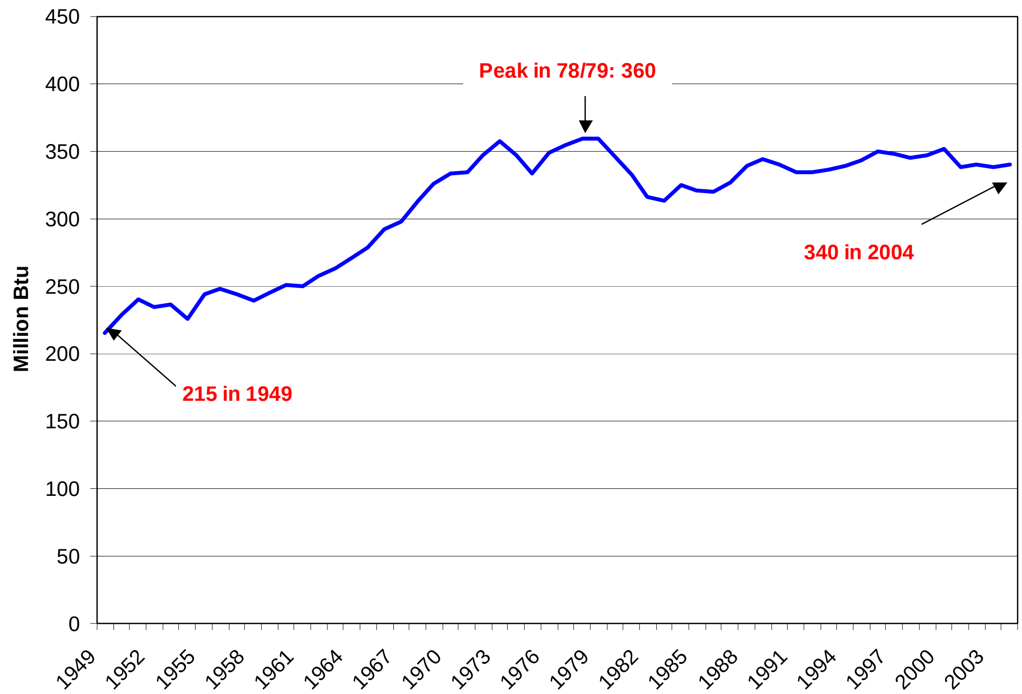
	Country of Origin	Thousand Barrels	Percent Total
1	Canada	1,616	16.0%
2	Mexico	1,530	15.1%
3	Saudi Arabia	1,444	14.3%
4	Venezuela	1,297	12.8%
5	Nigeria	1,032	10.2%
6	Iraq	524	5.2%
7	Angola	426	4.2%
8	Ecuador	270	2.7%
9	United Kingdom	239	2.4%
10	Algeria	228	2.3%
	Rest of World	1,046	10.3%
	Total	10,117	100.0%
	Non OPEC	5,292	52.3%
	Arab OPEC	2,211	21.9%
	Other OPEC	2,614	25.8%

Source: US Energy Information Administration

- Despite the greater dependence on imports for the country's energy needs, consumption per person has actually shown signs of stabilization. In 1949, energy use per person equaled 215 million British Thermal Units (Btu) (Figure 4). Energy consumption increased steadily until the oil shocks of late 1970's and early 1980's, peaking at approximately 360 million Btu's per person. The oil price shocks caused a modest pullback in consumption to an average of 340 million Btu's person from 1988 to the present.

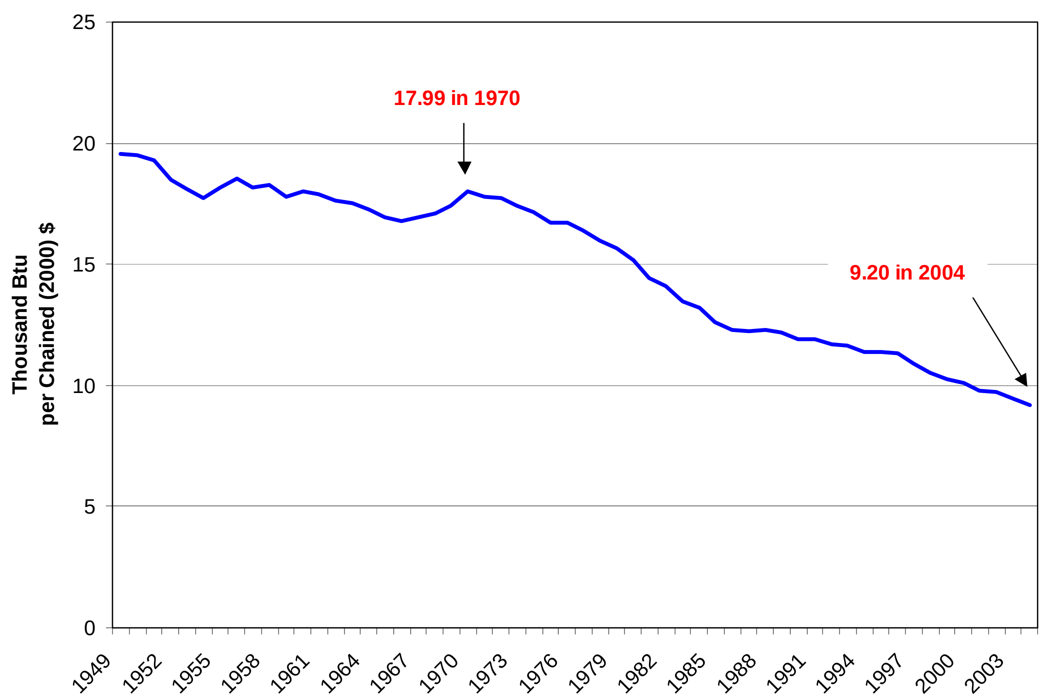
- Another reason for the leveling off of energy consumption per person can be potentially explained by the shift in the US economy from being broadly manufacturing oriented to more service oriented (Figure 5). Since 1949, energy consumption per Gross Domestic Product (GDP) (deflated) has fallen consistently from the 1970's to the present. Many of the "heavy industry" sectors such as steel, pulp and paper mills and automobile manufacturing have moved offshore thus reducing large amounts of energy inputs.

Figure 4: US Energy Consumption per Person



Source: US Energy Information Administration

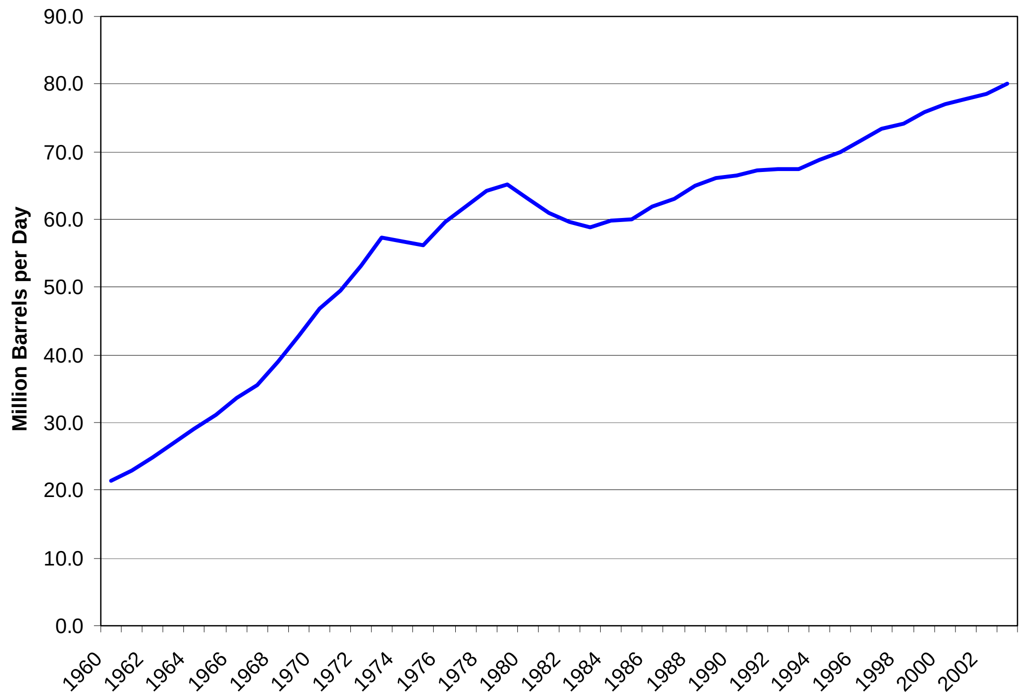
Figure 5: US Energy Use per Dollar of Gross Domestic Product



Source: US Energy Information Administration

- A growing concern in the global supply and demand balance for energy is not just the US level of consumption and geopolitical instability but rather the significant demand growth for energy inputs in emerging global economies such as China and India.
- The world consumption of petroleum has risen from just over 20 million barrels a day in 1960 to 80 million barrels a day in 2003, a compound annual growth rate (CAGR) of approximately 3.2% (Figure 6).

Figure 6: World Daily Consumption of Petroleum

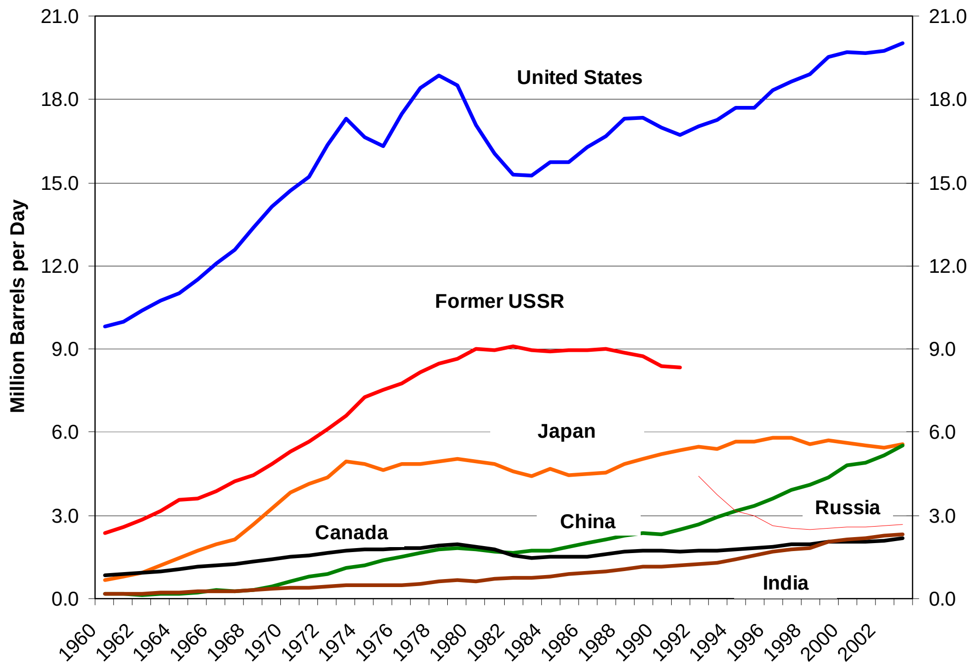


Source: US Energy Information Administration

- The US is unquestionably the most significant petroleum consuming economy in the world (Figure 7). The former USSR was second in importance until the breakup in the early 1990's. Now Japan is the second largest petroleum consuming economy with China rapidly closing the gap.
- Figure 8 highlights the growth trends in petroleum consumption for key global economies from 1960 to 2003 based on indexation. Since 1960, China has increased their consumption of petroleum faster than any country rising over 3,000%, while India has increased consumption by

almost 1,500%, and both the US and Canada have experienced long-run growth rates that were below the world trend.

Figure 7: Leading Petroleum Consuming Countries, Average Daily Consumption



Source: US Energy Information Administration

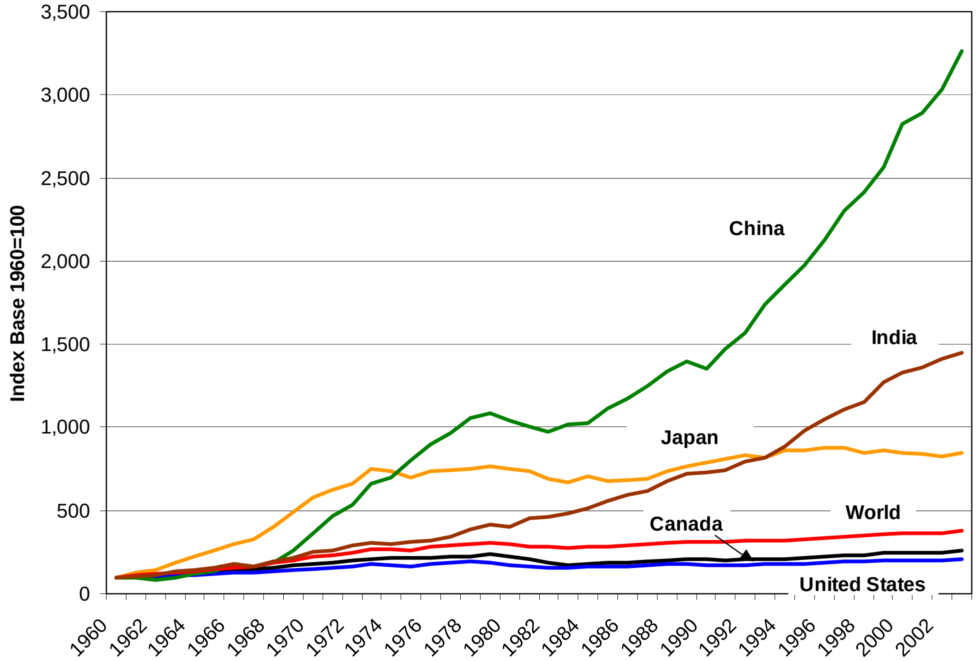
- Numerous European Union countries have declined in their relative rankings of petroleum consumption as emerging economies have rapidly increased they share of total petroleum demand (Table 2).

- From 1960 to 1969, the US consumed on average 37.6% of the global demand of petroleum (Table 3). From 1990 to 2003, the US percent share of global petroleum consumption has fallen appreciably to 25.4%, still however, a significant portion of total world demand.

- Often in the shadows of China and India, South Korea has also experienced rapid consumption in petroleum with annual growth rates exceeding 5.0% over the last 20 years (Table 4).

- The US relies heavily on petroleum as a primary source of energy; there is however other significant sources which play an intricate role in the energy balance equation in the country (Figure 9). Besides petroleum, the US uses an extensive amount of natural gas, coal, and nuclear electric power and to a lesser extent renewable energy.

Figure 8: Indexed Growth of Petroleum Consumption for Key World Countries



Source: US Energy Information Administration

Table 2: World Petroleum Consumption, 1960-2003 Key Countries, Average Million Barrels a Day Consumed by Selected Time Periods

	1960-69	Rank	1970-79	Rank	1980-89	Rank	1990-03	Rank
WORLD	**30.74**		**57.03**		**61.84**		**72.56**	
Total OECD	**22.47**		**40.41**		**39.11**		**45.68**	
Total Non-OECD	**8.27**		**16.62**		**22.72**		**26.88**	
United States	11.56	(1)	16.98	(1)	16.27	(1)	18.42	(1)
Japan	1.69	(3)	4.65	(3)	4.69	(3)	5.56	(2)
China	0.24	(12)	1.28	(9)	1.93	(5)	3.81	(3)
Russia							2.92	(4)
Germany	1.45	(4)	3.13	(4)	2.73	(4)	2.83	(5)
France	1.05	(7)	2.33	(5)	1.87	(6)	1.96	(6)
Canada	1.10	(6)	1.76	(8)	1.63	(9)	1.90	(7)
Mexico	0.35	(10)	0.75	(12)	1.48	(10)	1.90	(8)
Italy	0.97	(8)	1.93	(7)	1.80	(7)	1.89	(9)
South Korea	0.05	(14)	0.33	(14)	0.61	(14)	1.88	(10)
Brazil	0.36	(9)	0.86	(10)	1.15	(11)	1.88	(11)
United Kingdom	1.42	(5)	2.07	(6)	1.66	(8)	1.79	(12)
India	0.24	(13)	0.51	(13)	0.88	(13)	1.72	(13)
Spain	0.25	(11)	0.83	(11)	0.94	(12)	1.27	(14)
Former U.S.S.R.	3.56	(2)	7.16	(2)	8.94	(2)		

Source: Energy Information Administration, Informa

Table 3: World Petroleum Consumption, 1960-2003 Key Countries, % Share of World Petroleum Consumed by Selected Time Periods

	1960-69	Rank	1970-79	Rank	1980-89	Rank	1990-03	Rank
WORLD	**100%**		**100%**		**100%**		**100%**	
Total OECD	**73.1%**		**70.9%**		**63.3%**		**62.9%**	
Total Non-OECD	**26.9%**		**29.1%**		**36.7%**		**37.1%**	
United States	37.6%	(1)	29.8%	(1)	26.3%	(1)	25.4%	(1)
Japan	5.5%	(3)	8.1%	(3)	7.6%	(3)	7.7%	(2)
China	0.8%	(12)	2.2%	(9)	3.1%	(5)	5.3%	(3)
Russia	0.0%						4.0%	(4)
Germany	4.7%	(4)	5.5%	(4)	4.4%	(4)	3.9%	(5)
France	3.4%	(7)	4.1%	(5)	3.0%	(6)	2.7%	(6)
Canada	3.6%	(6)	3.1%	(8)	2.6%	(9)	2.6%	(7)
Mexico	1.1%	(10)	1.3%	(12)	2.4%	(10)	2.6%	(8)
Italy	3.1%	(8)	3.4%	(7)	2.9%	(7)	2.6%	(9)
South Korea	0.2%	(14)	0.6%	(14)	1.0%	(14)	2.6%	(10)
Brazil	1.2%	(9)	1.5%	(10)	1.9%	(11)	2.6%	(11)
United Kingdom	4.6%	(5)	3.6%	(6)	2.7%	(8)	2.5%	(12)
India	0.8%	(13)	0.9%	(13)	1.4%	(13)	2.4%	(13)
Spain	0.8%	(11)	1.5%	(11)	1.5%	(12)	1.7%	(14)
Former U.S.S.R.	11.6%	(2)	12.5%	(2)	14.5%	(2)		

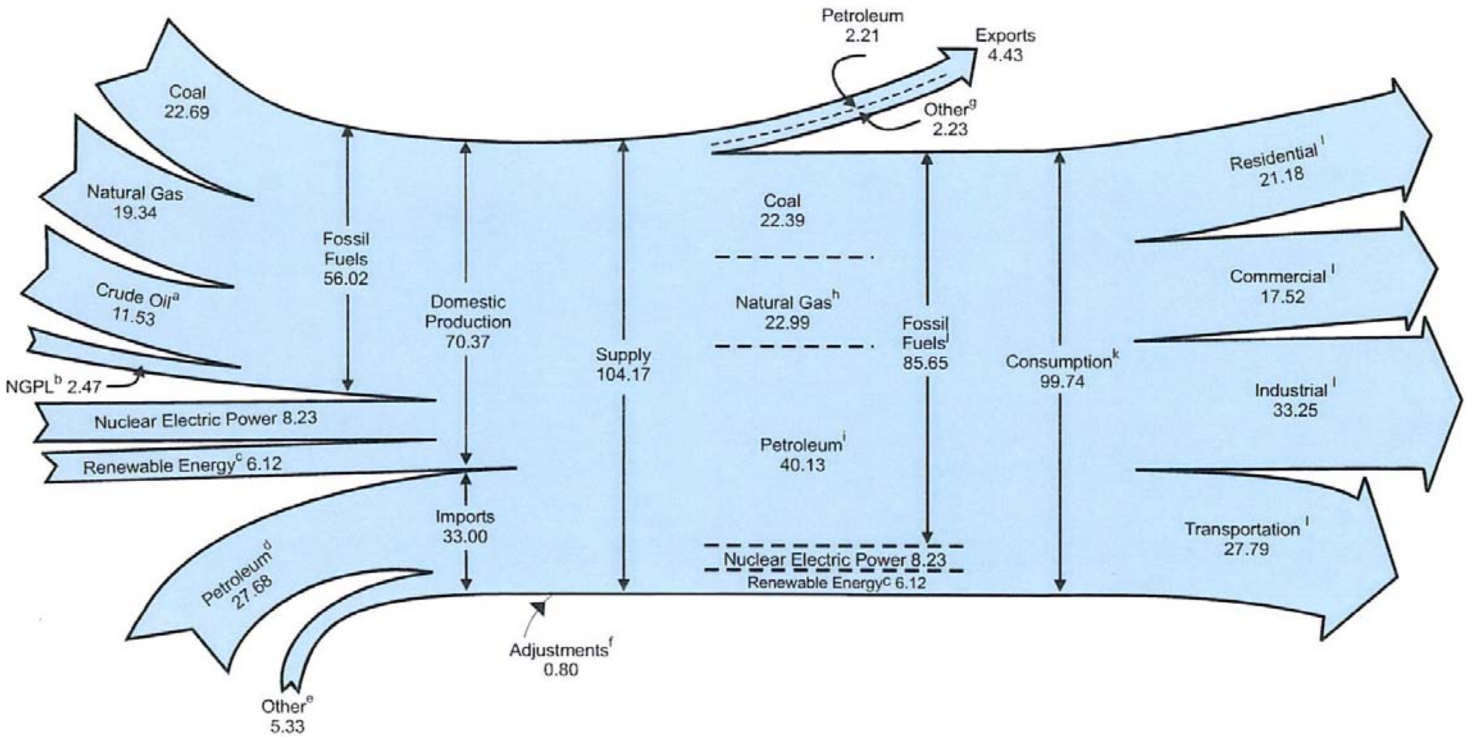
Source: Energy Information Administration, Informa

Table 4: World Petroleum Consumption, 1960-2003 Key Countries, Compound Annual % Growth Rates by Selected Time Periods

	Anl Rate 1960-69	Rank	Anl Rate 1970-79	Rank	Anl Rate 1980-89	Rank	Anl Rate 1990-03	Rank
China	11.1	(7)	12.8	(1)	3.3	(4)	7.0	(1)
South Korea	35.1	(1)	11.4	(2)	5.3	(2)	5.7	(2)
India	8.7	(8)	5.7	(6)	6.7	(1)	5.4	(3)
Spain	19.3	(3)	6.5	(5)	-0.1	(9)	3.3	(4)
Brazil	6.6	(11)	9.3	(3)	1.5	(5)	2.8	(5)
Canada	6.0	(12)	2.9	(9)	-0.7	(12)	1.7	(6)
Total Non-OECD	**8.3**		**6.2**		**1.7**		**1.7**	
WORLD	**8.1**		**3.8**		**0.5**		**1.4**	
United States	4.2	(14)	2.6	(11)	0.2	(7)	1.3	(7)
Total OECD	**8.0**		**2.8**		**-0.1**		**1.3**	
Mexico	4.6	(13)	9.2	(4)	3.4	(3)	1.1	(8)
France	12.8	(6)	2.7	(10)	-2.3	(14)	0.9	(9)
Japan	19.4	(2)	3.2	(8)	0.2	(6)	0.5	(10)
Italy	16.1	(4)	2.0	(12)	-0.2	(10)	0.0	(11)
Germany	15.6	(5)	2.0	(13)	-1.9	(13)	0.0	(12)
United Kingdom	8.6	(9)	-0.7	(14)	0.0	(8)	-0.3	(13)
Former U.S.S.R.	8.3	(10)	5.6	(7)	-0.3	(11)		

Source: Energy Information Administration, Informa

Figure 9: US Energy Flow, 2004 (Quadrillion Btu)

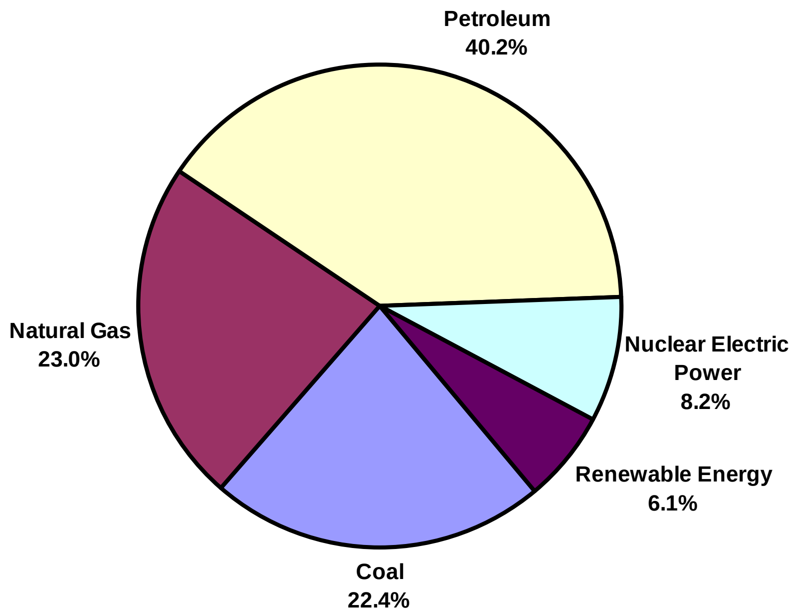


[a] Includes lease condensate.
[b] Natural gas plant liquids.
[c] Conventional hydroelectric power, wood, waste, ethanol blended into motor gasoline, geothermal, solar, and wind.
[d] Crude oil and petroleum products. Includes imports into the Strategic Petroleum Reserve.
[e] Natural gas, coal, coal coke, and electricity.
[f] Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.
[g] Coal, natural gas, coal coke, and electricity.
[h] Includes supplemental gaseous fuels.
[i] Petroleum products, including natural gas plant liquids.
[j] Includes 0.14 quadrillion Btu of coal coke net imports.
[k] Includes, in quadrillion Btu, 0.30 ethanol blended into motor gasoline, which is accounted for in both fossil fuels and renewable energy but counted only once in total consumption; and 0.04 electricity net imports.
[l] Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales. See Note, "Electrical Systems Energy Losses," at end of Section 2.
Notes: • Data are preliminary. • Totals may not equal sum of components due to independent rounding.
Sources: Tables 1.1, 1.2, 1.3, 1.4, 2.1a, and 10.1.

Source: Energy Information Administration – Annual Energy Review 2004

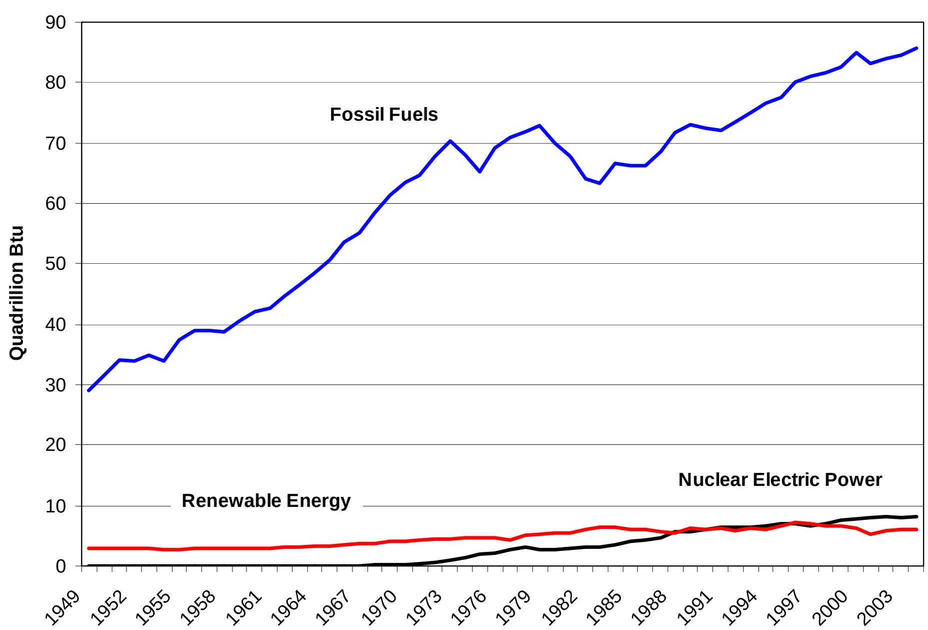
- Fossil fuel based energy sources (coal, natural gas and petroleum) account for approximately 85.6% of all the energy consumed in the US, with the remainder being nuclear electric power at 8.2% and renewable energy at 6.1% (Figure 10).

Figure 10: US Sources of Energy Consumed, 2004



Source: Energy Information Administration – Annual Energy Review 2004

Figure 11: Energy Consumption by Source

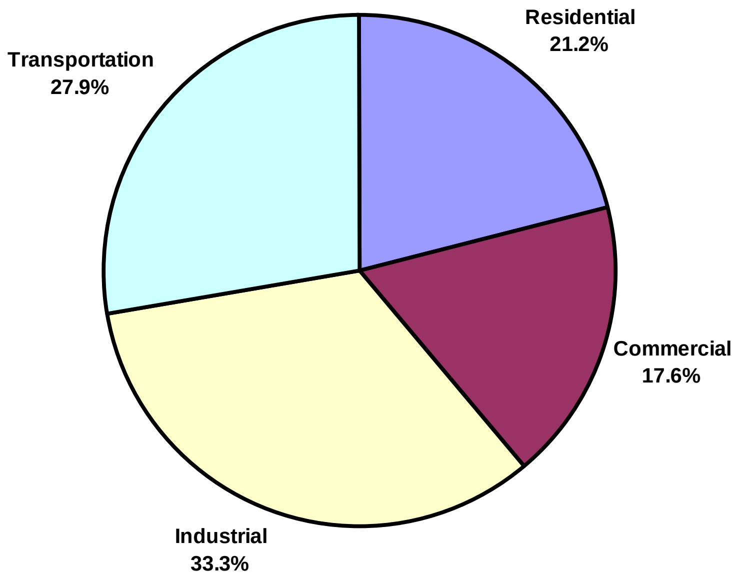


Source: Energy Information Administration

- Figure 11, highlights how since 1949, fossil fuel consumption as a percent share of total consumption has risen dramatically relative to nuclear electric power and renewable energy sources.

- US energy is consumed by four basic sectors, (1) residential 21.1%, (2) commercial, 17.6% (3) industrial 33.3% and (4) transportation 27.9% (Figure 12).

Figure 12: US Consumption of Energy by Sector, 2004



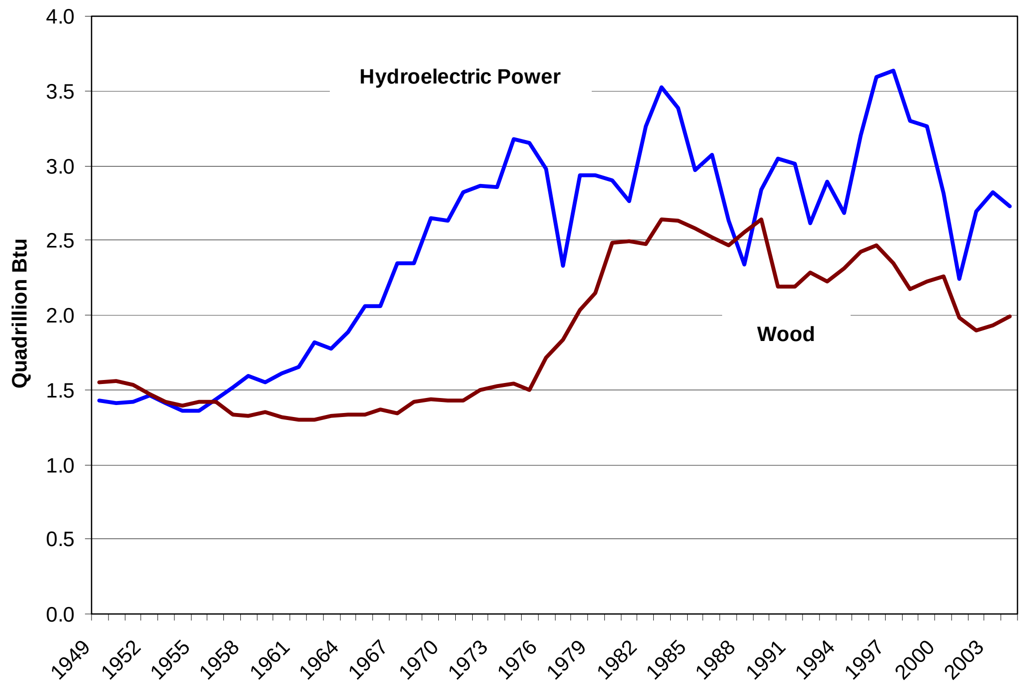
Source: Energy Information Administration – Annual Energy Review 2004

- The renewable energy category is further segmented into the following sources:
  - **Hydroelectric:** Hydroelectricity generated by pumped storage is not included in renewable energy.
  - **Wood:** Wood, black liquor, and other wood waste.
  - **Waste:** Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.
  - **Alcohol:** Ethanol blended into motor gasoline.
  - **Geothermal:** Geothermal electricity net generation, heat pump, and direct use energy.
  - **Solar:** Solar thermal and photovoltaic electricity net generation, and solar thermal direct use energy.

- The trends in US renewable energy consumption are displayed in Figure 13 and Figure 14 and Table 5 through Table 7. Hydroelectric power and wood based power contribute the largest amount of renewable energy by a wide margin compared to the other sources of renewable energy.

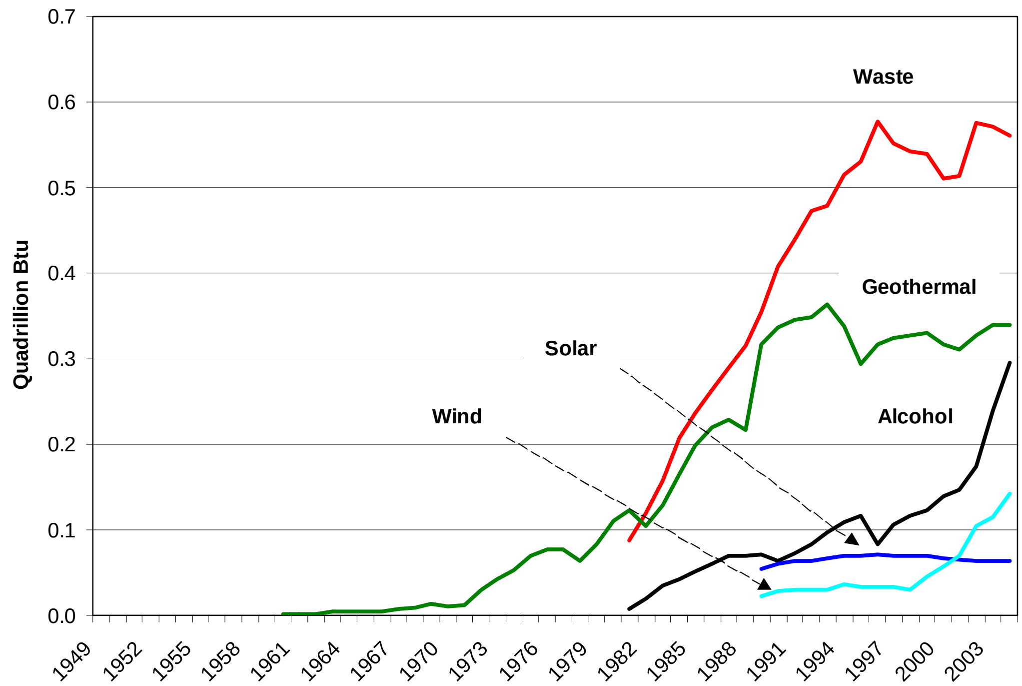
- The trend in hydroelectric and wood based power generation has remained flat from the 1980's to the present. In general, the other smaller contributing renewable energy sources have shown greater increases in their rate of adoption compared to hydro and wood. Wind and alcohol (ethanol) based renewables have grown the most significantly from 1990 to 2004 with CAGR's of 12.1% and 11.7% respectively. Despite the noteworthy growth of ethanol and wind, they still contribute relatively minor portions of total renewable energy consumption in the US.

Figure 13: US Renewable Energy Consumption by Source - Part I



Source: Energy Information Administration

Figure 14: US Renewable Energy Consumption by Source - Part II



Source: Energy Information Administration

Table 5: US Consumption, 1960-2004 of Major Renewable Energy Resources by Selected Time Periods (Quadrillion Btu)

	1960-69	Rank	1970-79	Rank	1980-89	Rank	1990-04	Rank
Total Renewables	**3.37**		**4.59**		**5.95**		**6.27**	
Hydroelectric	2.02	(1)	2.87	(1)	2.97	(1)	2.97	(1)
Wood	1.35	(2)	1.67	(2)	2.55	(2)	2.19	(2)
Waste	na		na		0.23	(3)	0.52	(3)
Geothermal	0.01	(3)	0.05	(3)	0.18	(4)	0.33	(4)
Alcohol Fuels	na		na		0.05		0.13	(5)
Solar	na		na		0.06		0.07	(6)
Wind	na		na		0.02		0.05	(7)
Biodiesel	na		na		na		0.003	*

Source: Energy Information Administration, Informa
* Note for 2004 only, the National Biodiesel Board estimated 25 mil. Gallons of production

Table 6: US Consumption, 1960-2004 of Major Renewable Energy Resources by % Share & Selected Time Periods (Quadrillion Btu)

	1960-69	Rank	1970-79	Rank	1980-89	Rank	1990-04	Rank
Total Renewables	**100%**		**100%**		**100%**		**100%**	
Hydroelectric	59.9%	(1)	62.5%	(1)	49.9%	(1)	47.4%	(1)
Wood	40.0%	(2)	36.3%	(2)	42.8%	(2)	35.0%	(2)
Waste	na		na		3.8%	(3)	8.3%	(3)
Geothermal	0.2%	(3)	1.1%	(3)	3.0%	(4)	5.3%	(4)
Alcohol Fuels	na		na		0.8%		2.1%	(5)
Solar	na		na		0.9%		1.1%	(6)
Wind	na		na		0.4%		0.9%	(7)

Source: Energy Information Administration, Informa

Table 7: US Consumption, 1960-2004 of Renewable Energy: Compound Annual % Growth Rates by Selected Time Periods

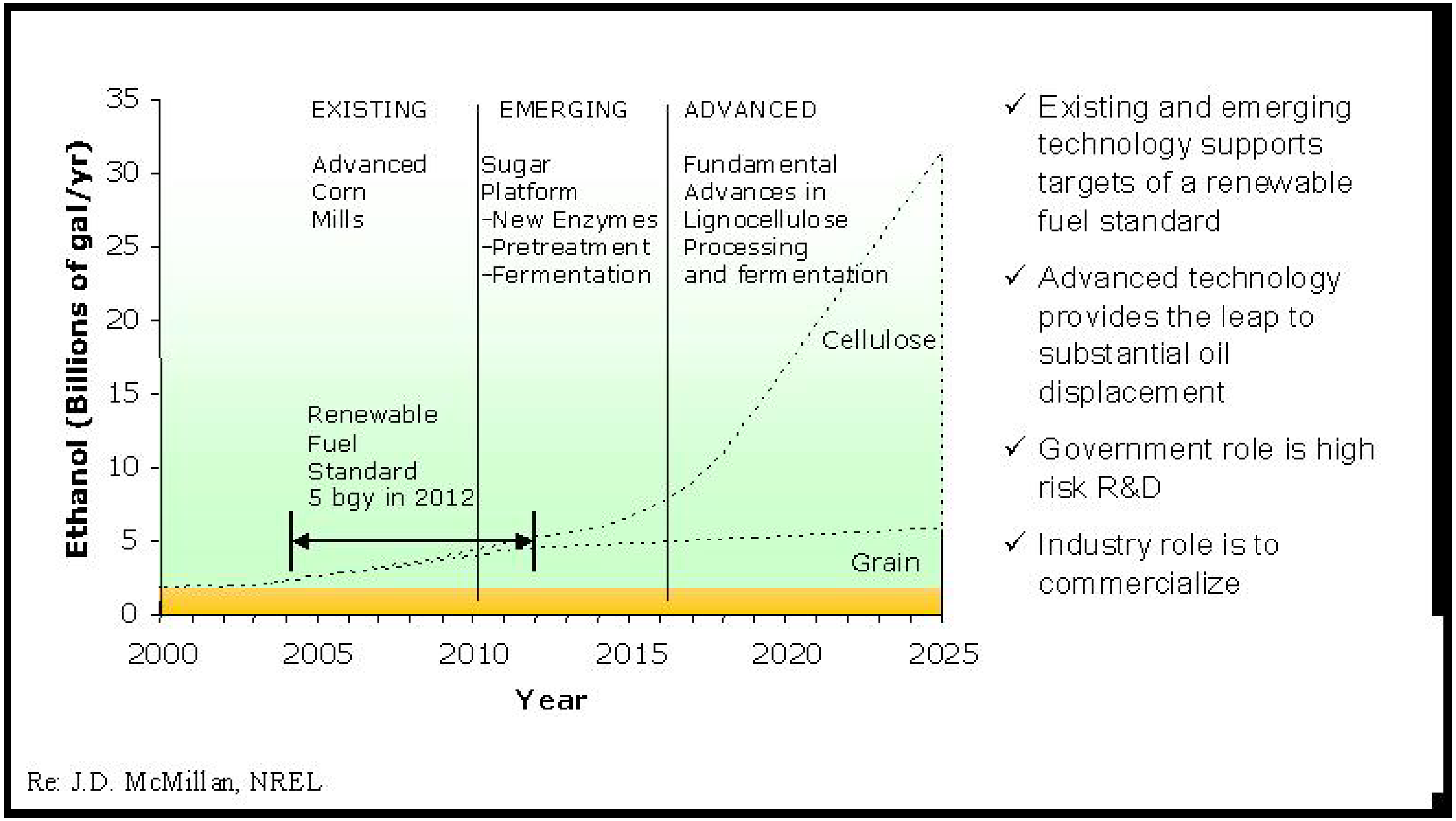
	1960-69	Rank	1970-79	Rank	1980-89	Rank	1990-04	Rank
Total Renewables	**3.8**		**2.7**		**1.5**		**-0.02**	
Wind	na		na		na		12.1	(1)
Alcohol Fuels	na		na		33.6	(1)	11.7	(2)
Waste	na		na		19.0	(2)	2.3	(3)
Solar	na		na		na		0.35	(4)
Geothermal	33.0	(1)	25.3	(1)	12.5	(3)	0.08	(5)
Wood	0.97	(3)	4.6	(2)	0.67	(4)	-0.69	(6)
Hydroelectric	5.7	(2)	1.2	(3)	-0.24	(5)	-0.79	(7)

Source: Energy Information Administration, Informa

- The DOE and the current administration has expressed extremely aggressive goals to replace the US's dependence on petroleum imports.

- Figure 15 shows the specific case of DOE's goals for ethanol (grain and cellulosic). The targets are certainly challenging and laudable but are they realistic? This national security issue is helping to drive the current agenda for the emerging biobased economy along with high oil prices. We will explore many of the critical drivers such as policies, technologies and products (e.g., ethanol and biodiesel) in this study to create a coherent mosaic of the status and potential of the biomass/renewable economy.

Figure 15: DOE Program Goal – A Vision of Oil Savings



Are Renewable Energy Sources the Only Answer to Meeting Our (US) Energy Import Needs, What About Another Hydrocarbon Source? Ever Heard of Oil Sands?

- Where are oil sands located? Oil sands (also known as bitumen) are found mostly in Alberta, Canada with much smaller reserves in Venezuela.
- Canadian reserves are estimated to hold 175 billion barrels of recoverable oil from the oil sands (as much as Saudi Arabia's reserves). Geologists think that another 315 billion barrels will be accessible when new technologies are full developed.
- Knowing that the oil sands exist is one thing, extracting the black gold is quite another process. Simplified, the process begins with the mining of oil sands using giant bulldozers and dump trucks. The oil sands are taken to processing facilities where steam is used to separate the oil from the sand and clay, this requires large volumes of water and natural gas. A sludge type residual is left over and there are issues concerning greenhouse emissions.
- The final product is heavy or "sour" crude versus the light "sweet" crude which is more commonly associated with oil from the Middle East or West Texas. Since the product has a heavy viscosity, moving it by pipelines is prohibitive. The highest and best use for the sour oil is in the manufacturing of diesel.
- Current investment projects are breaking even when world crude-oil prices are $20/barrel.
- What's the bottom-line; the oil sands will eventually begin to yield significant volumes of crude from Canada, but it is going to take time. Experts estimate that in the long-run the oil sands fields could generate as much as 25 million barrels of oil/day. In the shorter-run, production is expected to reach 5.0 million barrels of oil/day over the next 20 years.
- Note: Canada is presently the number eight oil producer in the world at approximately 3.14 million barrels/day.

II. Findings: Status and Potential of the Biobased Economy

- This section summarizes the essential findings of this study within the context of three categories: policy, technology and biobased products. The reader should consider this as a foundation/prelude to the presentation at the end of March.

A. Policy

- Biofuel production is growing very rapidly, primarily in developed countries but also in a number of large, developing countries like Brazil, China and India. The key driver of investment in biofuel production was (and, remains in some areas) air quality policies, but that objective is being eclipsed by efforts to replace significant amounts of imported petroleum. Much of the political support for biofuels is coming from rural and agricultural interests who expect stronger future markets for grain, and, potentially for their land resources. These two policy objectives have been highly complementary in the past.

- The United States did not sign the Kyoto Protocol and thus has no obligation under that agreement to reduce greenhouse gas emissions. Nevertheless, it has a policy of reducing the intensity of greenhouse emissions per unit of GDP and may well adopt more restrictive policies concerning greenhouse gasses in the future if it concludes that they are essential to control climate changes. In the meantime, the EU, Japan and a number of other countries are implementing new policies and programs primarily with the objective of meeting their Kyoto commitments.

- A broad range of incentives and regulations is now in use to stimulate biofuel production and use, but a general trend appears to be toward more rigorous use mandates. Such policies appear to be more powerful than investment or tax related incentives and perhaps more equitable as well, since they imply that costs of compliance are to be borne by consumers rather than by diverting tax revenues.

- The economic structure of biofuels today primarily reflects efficiencies for carbohydrate-based ethanol or biodiesel production processes based on grains, sugar or oilseeds. And, it appears that a number of those processes can now compete with imported petroleum at prices of $60/barrel or higher. Ethanol produced in Brazil is estimated to cost $25/barrel; US Corn Belt ethanol is estimated to cost $50/barrel based on corn at $2.10/bushel or below. EU biodiesel costs an estimated $60/barrel while EU ethanol costs perhaps $90/barrel.

- It is not clear what US ethanol based on cellulose would cost if produced on a commercial scale, but it is generally estimated to be more expensive than Corn Belt ethanol.

- These comparisons suggest that in the current commodity price structure, a significant amount of ethanol production is competitive with petroleum and that that quantity can be expected to increase rapidly if petroleum prices increase from their current levels. The US Energy Information Administration now expects $50/barrel oil prices for the next 25 years, so biofuel production likely will remain a viable commercial option, especially with expanded government incentive programs and mandates.

- Political support for renewable fuels programs is strong in the United States, and appears to be growing. In a private survey in October 2005, Informa researchers found that support among Congressional offices for the current renewable fuels policies was stronger than it had been before the Energy Policy Act was passed; and, that support for biodiesel programs is at least as great as that for ethanol.

- The range of new programs being designed and implemented globally suggests that support for biofuels programs is as strong overseas as in the United States.

- The policy purposes of biofuel programs are changing and imply potentially large increases in markets for biofuels in North America. At the same time, they do not necessarily imply that all of those markets will be supplied by North American biofuels.

- Earlier programs had the purpose of providing oxygenates for motor fuels and providing strength to agricultural markets, objectives that could be achieved by significant but manageable increases in domestic production—so there was little effective political pressure to open US renewable fuel markets to foreign production.

- However, domestic agriculture cannot easily accomplish the national objective of fuel independence from foreign (or, of Middle East) production. It can reach the current production mandate by 2012 without disruption of agricultural markets; and, it likely could reach significantly higher targets, especially if ethanol from cellulose can be produced competitively. However, objectives of significantly larger shares of consumption—e.g., 20% to 25% of motor fuel use appear to be beyond the capacity of domestic production at this time.

- The stronger the policy push toward energy independence becomes, the less likely it is that that market can be as protected as it is now from competing biofuel sources.

- There are two basic arguments that support a policy of importing biofuels from competing producers. The first hangs on the possible preference for importing ethanol from Brazil and other developing countries rather than crude oil from the Middle East. The second is an efficiency argument based on the low production cost of biofuels produced in tropical regions where costs are one-half those of US Corn Belt ethanol plants.

- Currently the United States has a $0.54/gallon tariff on ethanol imports and little is imported. However, if US producers cannot produce enough ethanol to meet policy targets consumers can be expected to lobby for greater access to foreign supplies. In addition, the US ethanol tariff is on the table in the current Doha Round talks. Brazil has already begun to push for ethanol access in the EU through the bilateral EU-MERCOSUR negotiations, and has raised the issue of access to the US ethanol market in the Doha Round.

- Overall, the current trends suggest that the current policy support for biofuels production will expand significantly in North America and around the world over the next decade and beyond. Both of the primary policy drivers—energy independence and efforts to reduce greenhouse gas emissions appear to have strong public support, even to the extent that the United States can be expected to significantly strengthen its controls on emissions in the intermediate-term future.

- In addition, it is likely that the biofuel systems will become increasingly market oriented, especially since the production efficiencies of carbohydrate and cellulose production in Equatorial zones are so much greater than those in temperate zones. That suggests that much of the biofuel supply likely to be used in North American and European motor fuel systems could be imported from tropical regions—but it does not necessarily suggest that the North American biofuels system will not be able to compete for a significant share of that market growth.

- It is likely that the demand for motor fuels in both developed and developing countries is so great that biofuel production from both tropical and temperate regions will be needed. A number of policy tools are available to insure markets for ethanol from cellulose and carbohydrates produced in temperate zones, including dynamic standards and mandates for biofuels and production incentives, among others.

- It is not likely, within the 2015 time frame, to see any commercial cropland conversion from traditional crops to dedicated biomass, e.g., switchgrass, unless the government plays a significant role in research and development funding.

- However, the use of biomass from cropland in the Conservation Reserve Program (CRP) would be a natural raw material supply if the concerns of wildlife interests were met and appropriate financial terms were set

B. Technology

- Research is in the development stage to process straw, corn stover, etc., cellulose whiskers (very small fibers) from potentially varied raw materials (wheat with a biobased polymer to form a resin that that can be used as a low cost, biodegradable replacement for glass fibers in polymer composites).

- Further, it is expected that that these products could be manufactured in a biorefinery setting, in conjunction with traditional or second wave ethanol production. The related manufacture of fine chemicals is also anticipated.

- Since manufacture of biocomposites would not require the degree of cellulose transformation ethanol production does, it is believed that this technology is potentially available within the medium term.

- A byproduct of cellulose fracture is lignin. While the product has many potentially beneficial characteristics, we note that recent literature and the statements of prominent scientists indicate a pessimistic attitude toward lignin as a significant financial contributor to a cellulose biorefinery. Indeed, having surveyed what we believe is the full range of publicly available information, we found that all such plans and feasibility studies treat lignin as a boiler fuel only. All cited the difficulty of separating and refining the product.

- One of the essential elements in the economical and efficient production of cellulosic ethanol is the development of biorefineries. The concept of a biorefinery is analogous to a petroleum refinery where a feedstock, crude oil, is converted into fuels and co-products such as fertilizers and plastics. In the case of a biorefinery, plant biomass is used as the feedstock to produce a diverse set of products such as animal feed, fuels, chemicals, polymers, lubricants, adhesives, fertilizers and power.

- While similar to oil refineries, biorefineries exhibit some important differences. First, biorefineries can utilize a variety of feedstocks. Consequently, they require a larger range of processing technologies to deal with the compositional differences in the feedstock. Second, the biomass feedstock is bulkier (contains a lower energy density) relative to fossil fuels. Therefore, economics dictate decentralized biorefineries closer to feedstock sources.

- The economics of biorefineries are dependent upon the production of co-products such as power, protein, chemicals and polymers to provide revenue streams to offset processing costs, allowing cellulosic ethanol to be sold at lower prices. Generation of co-products also results in greater biomass and land use efficiencies along with a more effective use of invested capital.

- There is an emerging body of thought among leading industry participants and observers that the initial breakthrough in cellulosic conversion to ethanol will be the transformation of corn kernel cellulosics in traditional dry mill ethanol plants (Tiffany and Eidman, Bothast, Stowers).

- The benefits of this process would be substantial. The plants would have an immediate yield increase of 5% to 10 % with minor variable cost increase. In addition, the volume of distillers dried grains (DDGS) would be substantially reduced. The profitable disposition of DDGS has emerged as one of the most vexing problems facing the fuel ethanol industry.

- As with the corn based ethanol industry, a biorefinery based on biomass, whether agricultural residue, biomass from CRP lands or wood, will locate in proximity to the raw material (see Map 1, p. 279 through Map 15, p. 293).

- Given the low value of biomass as a raw material, generally estimated in the range of $30.00/ton to $45.00/ton, logistics will be a critical consideration. Many industry observers believe that a system of terminals, analogous to the grain elevator system will be required. At such terminals, bulk could be reduced physically and possibly chemical pretreatment would occur before transport to the biorefinery.

- Thermochemical conversion of biomass to fuels is essentially the same process as that for conversion of petroleum; however, there are significant barriers to thermochemical conversion of biomass. Current processing facilities are too large to be economically feasible for biomass processing. Analysis indicates that for thermochemical conversion to reach economic feasibility the technology must be integrated into a larger biorefinery.

- Biomass pretreatment technologies are in development that holds promise for efficient and economical conversion of biomass to fermentable sugars. Recent improvements include dramatic reductions in the cost of enzymes for conversion of cellulosic biomass to sugars. These sugars can be used as feedstock to produce fuels and chemicals; however, commercial scale conversion has not yet been demonstrated.

C. Products

- There is a favorable political environment for ethanol. Ethanol is a "political commodity," and with the Volumetric Ethanol Excise Tax Credit contained in the JOBS Act of 2004 extending the main federal tax incentive through 2010, as well as the Renewable Fuels Standard contained in the Energy Policy Act of 2005 requiring a minimum level of renewable fuels usage through at least 2012, the policy underpinnings of the industry have been established and are visible several years into the future. Ethanol enjoys strong support from the agricultural community and increasingly from politicians that see it as a means toward enhancing the energy security of the US.

- There is a favorable economic environment for ethanol. Crude oil prices are only modestly below record highs, and long-term equilibrium price levels are expected to remain significantly higher than the historical average. The US also is highly productive at growing corn, and assuming normal weather corn prices would be expected to remain moderate, as acreage expands to accommodate increasing usage in ethanol. Given these factors and the efficiencies that have been gained over time in ethanol processing, the economics of ethanol production are expected to remain favorable through the intermediate term, again assuming normal weather.

- Biodiesel feedstock will be shifted primarily from the export markets and potentially from inventories. Thus, virgin vegetable oil biodiesel production will likely come primarily from soybean oil; it currently has the largest exportable supply and lowest vegetable oil cost (corn oil exports are also large, but this oil is on average 4.5 cts/lb more expensive than soybean oil).

- Biodiesel capacity is forecast to be 688 million gallons in 2008 and rise steadily to 711 million gallons by 2010. By 2015, Informa's outlook is close to 860 million gallons. It is expected that the share of total feedstock usage accounted for by soybean oil will average 82%. Animal fats, other vegetable oils and, to a lesser extent, greases are expected to account for the remaining 18% of the feedstocks for biodiesel.

- If the current tax incentive is not extended beyond 2008, then capacity expansion, if any, will be limited. Without the $1/gallon tax incentive, biodiesel production will not be profitable unless crude oil prices are in excess of $70-$75/barrel --assuming average crude soybean oil prices are in the 22 cts/gal to 24 cts/gal range.

- At current soybean oil prices of 19cts/lb and diesel prices of $1.75/gal, the gross margin per gallon is about $0.77/gal. That implies that a 30-mgy facility this year could have a gross profit of $23.1 million; that is equivalent to 75% to 80% of the capital equipment costs required to build a new biodiesel plant. Hence, the current environment offers significant economic incentives to expand biodiesel production.

- The global market for fermentation products is expected to grow at a rate of 4.8%/year during the next five years. The market is expected to reach $17.8 billion by 2009.

- As biobased feedstocks become less expensive, and petroleum feedstock continues to increase, biobased products will continue to replace petroleum-based products in the market.

- It is expected that industrial biotechnology will be the major driver for growth in the chemical industry during the next five years. Biotechnology is expected to contribute 70% of the total chemical industry growth during this time, primarily in the specialty and fine chemical markets.

- While new biopolymers have entered the market in recent years, the most significant factor affecting the rate of technical substitution of biobased resins for petrochemical products will be the increasing cost of oil and energy. The maximum substitution potential of biobased polymers has been estimated to be about 33% of total polymer production; however, several variables could significantly influence this including diminishing supplies and higher prices for petroleum feedstocks.

- BASF expects the market for biodegradable plastics to grow by more than 20%/year for the next five years and has explored many technologies to move closer to a bio-driven organization.

- Global production of biobased plastics is expected to top 1.3 billion pounds by 2008.

III. Survey of Global Governmental and Corporate Policies Concerning Biomass

A. Introduction

The OPEC oil embargos and subsequent price shocks of the 1970s stimulated a worldwide movement to find alternatives to petroleum-based fuels. The United States and Brazil implemented a series of incentive programs to encourage production of bio-based fuels, with a primary focus on transportation fuels made from organic matter instead of petroleum.[1] In spite of sharply increased research efforts and incentive programs, biofuel production grew slowly through the 1980s constrained by low petroleum prices. Until recently, ethanol was more expensive than gasoline and market growth depended heavily on government policies—especially policies to improve air quality in the United States.

Today, biofuel production is growing rapidly in a number of developed and developing countries for several reasons:

- Bio-based fuels like ethanol contain more oxygen than gasoline so blended fuels burn cleaner and reduce air pollution;
- Use of biofuels is seen as a way to reduce dependence on foreign oil; and
- Shifting to bio-based fuels to replace petroleum can cut net emissions of greenhouse gases.

Much of the current interest in biofuels has been driven by high petroleum prices – in August 2005 oil prices reached a peak of $70/barrel and the US Energy Information Administration (EIA) recently forecast that oil prices will be remain around $50 for the next 25 years. Recent biofuels initiatives reflect a strong and growing interest in

[1] Ethanol and biodiesel—the primary biofuels today—can be blended with or directly substitute for gasoline and diesel, respectively. The primary categories of biofuels include:

- **Ethanol**, also known as ethyl alcohol or grain alcohol, can be used either as an alternative fuel or an octane-boosting, pollution-reducing additive to gasoline.
  - **Ethanol from grain** (chiefly the starch in kernels of field corn) is the primary means of current ethanol production in the United States.
  - **Ethanol from sugar cane** is the primary source of ethanol production in Brazil.
  - **Advanced Bioethanol Technology** allows fuel ethanol to also be made from cellulosic (plant fiber) biomass, such as agricultural forestry residues, industrial waste, material in municipal solid waste, and trees and grasses.
- **Biodiesel**, made from animal fat or vegetable oil, is a renewable pollution-reducing alternative to petroleum diesel.
- **E-Diesel**, a fuel that uses additives to allow blending of ethanol with diesel, is being developed by several companies.
- **Methanol**, also known as "wood alcohol," can be made thermo chemically from biomass, but is now usually made from natural gas or coal. Research on biomass methanol has waned, because making ethanol from cellulosic material looks more promising now.

Ethanol is by far the most important biofuel today, with corn the primary feedstock. But there is growing interest and continuing research into alternative feedstocks for ethanol production as well as the use of oil-based feedstocks for use in producing biodiesel and bio-based industrial lubricants.

reducing reliance on petroleum imports from the Middle East. Environmental concerns, especially about global warming, also contribute to the development of biofuel policies.

Although the emphasis differs widely from country to country, energy and environmental policies are closely intertwined globally, so they are discussed in the same context in the following sections.

In the United States, demand for ethanol has been primarily driven by provisions in the Clean Air Act of 1990, which mandated the use of oxygenates in the Reformulated Gasoline Program and Winter Oxygenate programs. Outside the United States, air quality issues appear to have played a smaller role in biofuel development policies. In fact, air quality legislation in the EU and Japan caps the maximum amount of ethanol and biodiesel permitted in transportation fuel.

None of the developed countries in Asia (Japan, South Korea, and Taiwan) has a fully developed biofuel strategy. Grain exporting countries with their abundant grain stocks have an advantage in the production of biofuels from grains and oilseeds, but the Asian grain/oilseed importers do not have surplus feedstocks, so biofuel policies depend more on cost competition with petroleum.

By contrast, some developing countries in Asia and South America have abundant land, tropical climates, and high rainfall, which provide them with a competitive advantage in the production of low cost biofuel feedstock – both carbohydrates and cellulose. As a result, they are generally building on this potential, and either have or expect to produce biobased fuel that is competitive both with temperate zone biofuels and petroleum-based fuels. Biofuels from developing countries are moving rapidly to replace petroleum imports. Brazil in particular is expanding ethanol production rapidly. China also is a significant biofuel producer, although a distant third after the United States and Brazil. Malaysia is a low-cost producer of palm oil, which can be used in biodiesel. Several current biofuel projects in Asia involve the construction of biodiesel plants that would use Malaysian palm oil as a feedstock. These programs and the policies that support them are discussed in detail in the following sections

The chapter begins with a discussion of biofuel policies in the United States, based on both energy and environmental policies, and then analyzes global biofuel policies and programs, primarily in the EU and Japan. The energy and environmental policies of the EU are described in detail, followed by a discussion of biofuel projects and policies in Asia and South America (primarily Brazil).

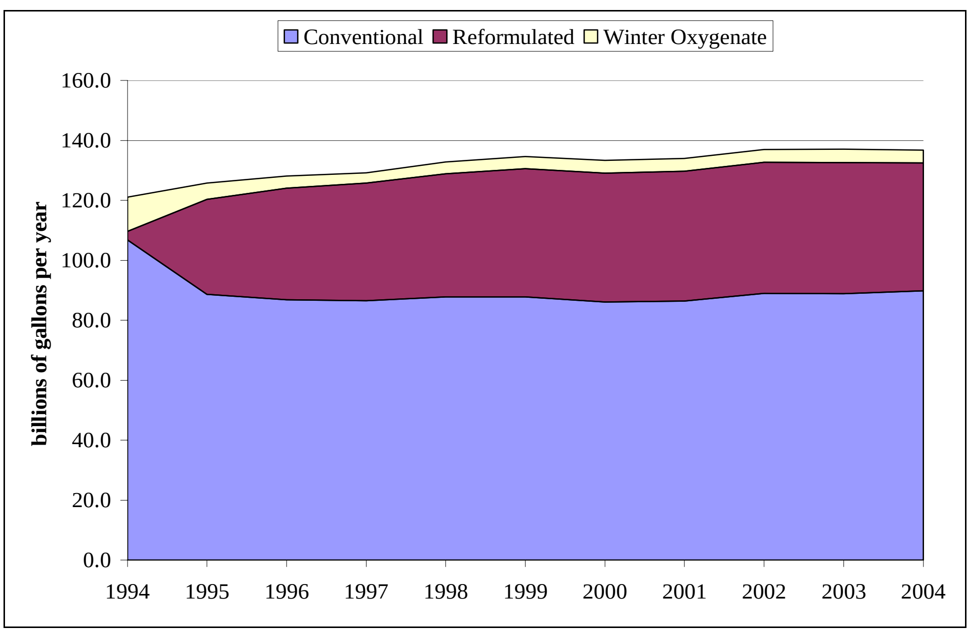
B. US Energy and Environmental Policy

The development of efficient biofuel production processes has been a US policy goal since the first oil embargo of the early 1970s, but progress has been slow, driven mainly by government policies and policy incentives. More recently, biofuel production and use has grown rapidly, especially since the mid 1990's, driven by federal policies aimed at reducing air and water pollution. The combination of concerns about the war on terror and the recent high energy costs are now being translated into strong, new policy incentives for investment in biofuel technology to reduce dependence on foreign oil, reduce greenhouse gas emissions, and to boost local economic activity and benefits to the agricultural economy.

Ethanol production received a significant boost as an indirect result of the Clean Air Act amendments in 1990 that established the Winter Oxygenated Fuel Program that required fuels sold in areas with high carbon monoxide levels to contain 2.7% oxygen. Later, the federal Reformulated Gasoline Program required 2% oxygen content in areas with high levels of ozone (smog) forming compounds. Two main oxygenates can be added to gasoline to meet the requirements of these programs: methyl tertiary-butyl ether and ethanol. MTBE is less costly to manufacture than ethanol but can pollute ground water supplies. While the health effects of water contaminated with MTBE are unknown, many states have banned its use, most notably California, New York, and Pennsylvania – making ethanol the only alternative for use in reformulated gasoline.

By 2004, about one-third of US gasoline relied on oxygenates to comply with the Clean Air Act – 31% under the Reformulated Gasoline Program and 3% under the Winter Oxygenate program (Figure 16). MTBE was the oxygenate of choice, but as it was successively banned by states, the demand for ethanol grew until it reached 4 billion gallons by 2005.

Figure 16: US Gasoline Production by Type



Source: US DOE, EIA

The growth in ethanol demand led to concerns of supply shortfalls. The result was a large ethanol production mandate in the 2005 Energy Policy Act legislation that includes a number of incentives to encourage ethanol and biodiesel production and use as well as research on new biofuel technologies to permit the use of alternative feedstocks such as cellulose.

1. Federal Biofuel Legislation

The following sections list and discuss the major legal authorities and the policies they enable.

The Energy Policy Act of 2005

The Energy Policy Act of 2005 (EPACT) created a national Renewable Fuels Standard (RFS). It establishes a baseline for renewable fuel use, beginning with 4 billion gallons per year in 2006 and expanding to 7.5 billion gallons by 2012. The vast majority of the renewable fuel used will be ethanol, resulting in a doubling of the domestic ethanol industry in the next 6 years.

Under the RFS program each gallon of cellulosic ethanol or waste-derived ethanol counts as 2.5 gallons. While the 2.5-to-one ratio ends in 2012, after that time, the RFS will require a minimum of 250 million gallons of cellulosic biomass fuels be produced annually.

Other provisions in the Energy Policy Act include the Renewable Energy Production Tax Credit, (extended for another two years) and the Clean Renewable Energy Bonds (for public power), which support project financing for the renewable energy industry.

Additionally, the law includes provisions for grant-and-loan and loan guarantee programs intended to help support biomass renewable energy projects in the growing renewable energy market. There also are specific provisions authorizing funding to spur development of cellulosic biofuels facilities and integrated biorefineries.

In 2006, the United States has more than 4.3 billion gallons of ethanol production capacity and nearly 2 billion additional gallons under construction, suggesting that the domestic ethanol industry will be able to meet the goals of the RFS. In addition, the EPACT of 2005 expanded coverage of the “small producer tax credit” to producers of up to 60 million gallons a year, an increase of 30 million gallons. It also created a similar tax credit for agri-biodiesel producers.

Volumetric Ethanol Excise Tax Credit (VEETC)

The Volumetric Ethanol Excise Tax Credit was implemented in 2004 and replaced the federal ethanol excise tax credit that existed previously. VEETC does the following:

- Streamlines the tax refund system for below the rack blenders to allow a tax refund of 51 cents/gallon on each gallon of ethanol blended with gasoline to be paid within 20 days of blending gasoline with ethanol;
- Permits the full amount of user excise taxes levied to be collected and remitted to the Highway Trust Fund (HTF), eliminating the negative impact of the previous program on the Highway Trust Fund. The change is expected to generate more than $3 billion/year in additional HTF revenue;
- Streamlines the excise tax collection process when ethanol is blended with transportation fuels;
- Creates a simplified system of excise tax collection complemented by a regimented petroleum, renewable fuel, and terminal delivery system, and also eliminates the restrictive blend levels (5.7%, 7.7% and 10%) dictated by the tax code to reflect former Clean Air Act requirements while providing more flexibility to oil companies to blend as much or as little ethanol to meet their octane or volume needs;
- Eliminates the need of the alcohol fuels income tax credit that is subject to the alternative minimum tax. Any taxpayer eligible for the alcohol fuels tax credit will be able to use the volumetric ethanol excise tax credit system, which means they will be able to file for a refund for every gallon of ethanol used in the marketplace without regard to the income of the taxpayer or whether the ethanol is used in a taxed fuel or tax exempt fuel.
- Provides new market opportunities for ethanol, biodiesel, and E-85 in off-road and other non-taxable markets, and ETBE.

Small Ethanol Producer Tax Credit

Small ethanol producers receive a 10-cent/gallon production income tax credit on up to 15 million gallons of production annually. The credit is capped at $1.5 million/year/producer. In 2004, H.R. 4520, allowed the credit to be passed through to the farmer owners of a cooperative. The legislation also allows the credit to be offset against the alternative minimum tax (AMT).

Biodiesel Tax Credits

The American Jobs Creation Act of 2004 that created the Volumetric Ethanol Excise Tax Credit also includes a tax credit for biodiesel. The Energy Policy Act of 2005 extended that credit through December 31, 2008. The law's main provisions include:

- A volumetric excise tax credit for agri-biodiesel of $1.00/gallon. Agri-Biodiesel is defined as diesel fuel made from virgin oils derived from agricultural commodities and animal fats.
- The volumetric excise tax credit for Biodiesel remains at 50¢/gallon. Biodiesel is defined as diesel fuel made from agricultural products and animal fats.
- The volumetric excise tax credit for Renewable Diesel is $1.00/gallon. Renewable diesel refers to diesel fuel derived from biomass using a thermal depolymerization process.

The 2005 Act also created a new credit for small agri-biodiesel producers equal to 10 cents/gallon on the first 15 million gallons of agri-biodiesel produced at facilities with annual capacity not exceeding 60 million gallons. Historically, small ethanol producers were allowed a similar credit. The tax credit is capped at $1.5 million/year per producer and like the small ethanol producer credit can be passed through to the farmer owners of a cooperative and the credit is allowed to be offset against the alternative minimum tax. This credit sunsets December 31, 2008.

Federal Reformulated Gasoline (RFG) Program

The federal Clean Air Act Amendments of 1990 required those cities with the worst smog pollution (ozone nonattainment areas) use reformulated gasoline beginning in 1995.

In the Clean Air Act, Congress specified that RFG contain two percent oxygen by weight. The oxygenate provision was ended by the Energy Policy Act of 2005, and replaced by a nationwide renewable fuels standard.

Federal Winter Oxygenated Fuels Program

The federal Clean Air Act Amendments of 1990 established a winter oxygenated fuels program to combat carbon monoxide emissions from vehicles. Beginning in 1992, gasoline sold during the winter months in areas designated as nonattainment areas for carbon monoxide pollution has to contain 2.7 percent oxygen by weight. The addition of oxygenates such as ethanol to gasoline significantly decreases carbon monoxide pollution. In fact, several areas have increased the minimum oxygen content to 3-3.5% by weight.

Ethanol is now the oxygenate being used in this program, and some areas are demonstrating attainment for carbon monoxide and including the continued use of oxygenated fuel in their maintenance plan.

Commodity Credit Corporation (CCC) Bioenergy Program

USDA established the Commodity Credit Corporation Bioenergy Program in fiscal year 2001. Under the program, the CCC makes payments to eligible bioenergy producers to encourage increased purchases of agricultural commodities for the purpose of expanding production of bioenergy (ethanol and biodiesel) and to encourage the construction of new production capacity. The 2002 Farm Bill continued the program through fiscal year 2006, providing $150 million annually.

Bioenergy producers apply to CCC to participate in this program. Eligible commodities include barley, corn, grain sorghum, wheat, oats, rice, soybeans, canola, sunflower seed, rapeseed, safflower, flaxseed, mustard, crambe, sesame seed and cottonseed; fats, oils and greases; and cellulosic commodities such as switch grass and hybrid poplars.

To be eligible, ethanol producers must produce and sell ethanol commercially and have authority from the Bureau of Alcohol, Tobacco, Firearms, and Explosives to produce ethanol for fuel or sell denatured ethanol rendered unfit for beverage use.

Payments are based on the increase in bioenergy production compared to the previous year's production. The program is structured to encourage participation by smaller producers. Producers with less than 65 million gallons of annual production capacity are reimbursed on a ratio of one feedstock unit for every 2.5 feedstocks used, while larger facilities are reimbursed on a ratio of one to 3.5. Additionally, a payment limitation restricts the amount of funds any single producer may obtain annually under the program to 5% of the total funds available.

Biomass and the Budget

Two biomass support programs now in operation include the Renewable Energy & Energy Efficiency Systems Grants/Loans program and the Value-Add program. Both provide grants to farmers and rural businesses.

However, funding for the Renewable Energy & Energy Efficiency Systems Grants/Loans program is proposed for cuts in FY2007 to $3 million, which is down from $23 million. By contrast, the Value-Add program is proposed for $40 million for FY2007.

Grants totaling $20.8 million were awarded to 150 applicants from 32 states under the Renewable Energy & Energy Efficiency Systems Grants/Loans program in 2005. Of these funds, over $7 million will be used for biomass-related energy projects, such as the production of biofuels or methane from anaerobic digesters. Similarly, the Value-Add program funded 169 projects, some of which help develop marketing and production of energy from biomass, with over $14.4 million this year.

Additionally, in the Department of Energy's FY2006 appropriations bill, the DOE biomass research and development program received a little over $91.6 million, however, this includes more than $52.3 million in earmarks, making more than 57 percent of the funds already pegged for "special" projects as opposed to core program research and development.

For 2007, President Bush's proposed FY2007 budget includes $150 million – a $59 million increase over FY2006 – to help develop bio-based transportation fuels from agricultural waste products, such as wood chips, stalks, or switch grass. These funds will also go into accelerating research into "cellulosic ethanol," a promising variation on biofuel production. An indication of the growing interest in biofuels can be seen in the number of bills introduced or under discussion on the topic.[2]

Outlook for 2006

US policies to increase biomass fuel production are extremely popular and were highlighted in President Bush's 2006 State of the Union address. However, this also highlights a problem for the government – the general lack of support for basic research into biofuel technology. As the President announced his new biofuel goals, numerous press reports pointed out that the Administration had not requested the appropriations for research at levels established by Congress in the Energy Act of 2005. Also, as the administration was presenting new biomass priorities, it was in the process of reducing funding and laying off staff at EPA's main biomass research lab. The administration has recently made a number of statements intended to convey support for biomass technology development programs.

As long as gasoline prices stay high and the Middle East is tense and unsettled, Congress can be expected to boost the priorities for biomass-to-energy technologies. As positive results appear, growing support can be expected from the Congress to expand research and production. The most likely areas where biomass legislation could be enacted are in the agriculture and transportation sectors, both of which are very important consumption areas in the United States.

2. State Ethanol/Biofuel Programs

Economics, environmental goals and energy independence have all pushed individual states to enact their own ethanol and biofuel programs. In some regards,

[2] A number of new biofuel and renewable energy bills have been introduced, reflecting the concern lawmakers have over the political fallout from high petroleum prices; perceived national and energy security threats; and growing reliance upon imported oil. One of the most recent examples of biofuel legislation is the Fuel Choices for American Security Act of 2005, introduced by Rep. Kingston (R-GA) and co-sponsored by more than 25 other House members and introduced by Senator Bayh (D-IN) and co-sponsored by nine other Senators. Another bill, the Health Care for Hybrids Act, introduced by Rep. Inslee (D-WA) on the House side (H.R. 4370, S.2045) and Senator Barak Obama (D-IL) on the Senate side, would provide incentives to the auto industry to accelerate efforts to develop more energy-efficient vehicles to lessen dependence on oil.
Other biopower and biofuels bills that were introduced in 2005 include: Representative Gil Gutknecht's (R-MN) '10 by10 Act'; Senator Maria Cantwell's (D-WA) 20/20 Biofuels Challenge Act of 2005; and Rep. Marcy Kaptur's (D-OH) National Defense Authorization Act for Fiscal Year 2006. Many of the bills proposed in Congress aim to reduce dependence on foreign oil, but also are designed to promote use of flex-fuel vehicles, research and development for biofuels, alternative fuel fueling stations and a wide variety of other biomass-related technologies.

states have outpaced the federal government in the development of ethanol and biofuel-related energy programs on a state level.

Currently, five states including California, Ohio, Hawaii, Minnesota and Montana have either a RFS or have passed legislation to promote use of biofuels.[3] Furthermore, many states provide biomass incentives to stimulate demand or to help new biofuels producers get established. For instance, Oklahoma has a tax credit, which will provide 20 cents/gallon of biodiesel, with a maximum annual payment of $5 million.

In the area of biopower (biomass for electricity production), 21 states have a Renewable Portfolio Standard—a requirement that a certain percent of a utility's overall energy capacity or energy sales must be derived from renewable resources, including biomass. For example, Iowa now has a program that provides two separate production tax credits for electricity generated by eligible renewable energy facilities, including solar thermal electric, photovoltaics, landfill gas, wind, biomass, hydrogen and anaerobic digestion.

The following are snapshots of the more significant programs.

Biodiesel Mandate – Minnesota: In March 2002, Minnesota enacted the nation's first biodiesel mandate that would require nearly all diesel fuel sold in the state contain at least 2 percent biodiesel by 2005 (earlier if certain conditions are met). Proponents of the biodiesel requirement argue it would be a boon for the state's farmers and improve the state's use of alternative fuels.

Biodiesel Use By School Districts – Missouri: In 2001 the state of Missouri passed a new law that gives school districts an incentive to purchase biodiesel fuel for their bus fleets. The law begins with the 2002-03 school year and lasts through the 2005-06 school year. Any school district may contract with an eligible new generation cooperative to purchase biodiesel fuel for its buses of a minimum of B-20 (20 percent biodiesel). The state will then reimburse the school district so that the net price to the contracting district for biodiesel will not exceed the rack price of regular diesel.

Ethanol and Biodiesel Incentives – Missouri: In 2002, Missouri enacted two incentive programs that will promote in-state, cooperatively-owned biofuel production. Targeted at increasing homegrown production of ethanol and biodiesel, the five-year incentive programs provide grants to producers that are at least fifty-one percent owned by agricultural producers actively engaged in agricultural production for commercial purposes in the state. Ethanol incentives include a payment of 20 cents/gallon for the first 12.5 million gallons and 5 cents/gallon for the next 12.5 million gallons. Biodiesel incentives are 30 cents/gallon for up to 15 million gallons of production.

[3] In addition, a number of states are currently considering state-level ethanol mandates, including Iowa, Illinois, Missouri, Nebraska, Washington, and Oregon.

Ethanol Production Incentives – North Dakota: In April 2003, North Dakota's Governor signed into law an Ethanol Production Incentive bill (Senate Bill 2222). The legislation implements the first program in the nation to create a market-based support system for the growing ethanol industry. The ethanol incentive operates on a counter cyclical feature that is market-based. It is not a fixed payment, but is provided to a facility when the price of ethanol drops or the price of corn increases to levels that make ethanol less profitable. Incentives are based on a combination of a $1.80/bushel price for corn and a $1.30/gallon rack price for ethanol (price at the terminal).

Hawaii Ethanol Investment Tax Credits: In early 2000, legislation passed in Hawaii to provide tax credits for the production of ethanol in the state. The new law will help sugar growers on Kauai and Maui by offering incentives to use molasses and other wastes as the feedstock for ethanol. Supporters also hope the possibility of using municipal solid waste, as a feedstock will cut down on the amount of waste being landfilled. In the fall of 2004, Hawaii passed a requirement that at least 85 percent of all gasoline in the state should contain 10 percent ethanol. The measure goes into effect in April 2006.

Minnesota Ethanol Program: To meet its goal of replacing 10 percent of its fuel needs with ethanol, in the late 1980s Minnesota instituted a producer payment program of 20¢/gallon on up to 15 million gallons of ethanol per year for a maximum of 10 years. The payment is limited to in-state producers, and the small scale requirement has resulted in the formation of more than a dozen farmer-owned ethanol processing cooperatives.

West Virginia Incentives for Schools to Use Biodiesel: West Virginia state law provides a financial incentive for schools to fuel their bus fleets with alternative fuels. Under the state school aid formula, counties receive about 85 cents for every dollar in transportation costs. By switching to alternative fuels like biodiesel blends or compressed natural gas [CNG], the reimbursement increases to 95 cents.

Wisconsin Ethanol Program: Wisconsin's Act 55 provides ethanol producers a credit much like Minnesota's - beginning July 1, 2000 it will provide 20 cents/gallon for no more than 15 million gallons of production. The feedstock must come from a "local" source, definition to be determined.

3. Overview of State Programs

Except for the District of Columbia, all states have at least one ethanol promotion programs in place, and most have several (Table 8). Additional detail regarding state ethanol incentives is in Table 9.

Table 8: State Ethanol Program Matrix (August 2005)

State	Producer Incentive Payments	Retailer Incentives for Ethanol Blends and E-85	State RFS	MTBE Ban Passed	Retail Pump Label Requirement	State Fleet Fuel Purchase Requirement	Winter Oxygenate Program
Alabama					X		
Alaska		X			X		
Arizona				X	X		
Arkansas					X		
California				X			
Colorado				X	X		
Connecticut				X	X		
Delaware					X		
District of Columbia							
Florida					X		
Georgia					X		
Hawaii		X	X				
Idaho		X			X		
Illinois		X		X	X		
Indiana	X			X		X	
Iowa		X		X	X	X	
Kansas	X			X		X	
Kentucky				X			
Louisiana							
Maine		X		X	X		
Maryland	X						
Massachusetts					X		
Michigan				X			
Minnesota	X	X	X	X			
Mississippi	X				X		
Missouri	X			X			

State	Producer Incentive Payments	Retailer Incentives for Ethanol Blends and E-85	State RFS	MTBE Ban Passed	Retail Pump Label Requirement	State Fleet Fuel Purchase Requirement	Winter Oxygenate Program
Montana	X		X	X	X		
Nebraska				X	X		
Nevada					X		X
New Hampshire				X	X		
New Jersey				X	X		X
New Mexico					X		X
New York				X	X		
North Carolina				X			
North Dakota	X	X			X		
Ohio				X			
Oklahoma	X	X					
Oregon					X		
Pennsylvania	X				X		
Rhode Island				X	X		
South Carolina					X		
South Dakota	X	X		X	X		
Tennessee					X		
Texas	X				X		
Utah					X		
Vermont				X	X		
Virginia					X		
Washington				X	X		
West Virginia					X		
Wisconsin	X			X	X		
Wyoming	X				X		

Source: RFA

Table 9: State Incentives for the Production and Use of Ethanol

State	State Excise Tax Exemption	State Producer Credits	Special Information
Alaska	$.06 per gallon tax exemption	No producer credit	Tax exemption applies only in Anchorage and only during the winter months. No sunset.
Connecticut	$.01 per gallon tax exemption	No producer credit	No sunset
Hawaii	4% tax exemption	No producer credit	No sunset -- Other: Administrative rules signed 9/20/04 require that beginning 4/06, 85% of all gasoline sold in the state must contain 10% ethanol. Implements the ethanol requirement originally included in legislation signed in 1994.
Idaho	Tax exemption is to equal the amount of ethanol blended in a gallon of gasoline – not to exceed 10%. Average exemption is $.023 per gallon.	No producer credit	No sunset
Illinois	2% sales tax exemption – average exemption is $.01 to $.015 per gallon. Extended in 2003 to include E85 and biodiesel.	No producer credit	A $15 million grant fund, the Renewable Fuels Development Program, was created in 2003 to support the construction of new ethanol/biodiesel plants and expansions; to qualify, a project must increase capacity by at least 30 million gallons per year (mgy). Sunsets in 2013; gradually reduces to zero after 12/31/2013.
Indiana	No tax exemption	$.125 per gallon producer credit	Credit applies to facilities that increase production by at least 40 mgy. Total per facility not to exceed $5 million for all taxable years. Total program not to exceed $10 million.
Iowa	$.01 tax exemption	No producer credit	Sunset 2007; Income tax credit available to retailers who sell more than 60% ethanol-blended fuel at their station, including E85. Other: State fleet vehicles shall operate on 10% ethanol blends when commercially available.
Kansas	No tax exemption	Average $.07 per gallon producer credit	Provides $.05 per gallon for producer in operation prior to July 1, 2001 during FY 2002-2004. Increased capacity of 5 mgy or more on-line on or after July 1, 2001 receives $.075 per gallon, limited to 15 mgy. Producers who begin production on or after July 1, 2001 are eligible for $.075 per gallon, limited to 15 mgy. Other: State's bulk fuel purchases for use in state motor fleet shall contain 10% ethanol, unless ethanol-blended fuel costs more than $.10 per gallon more than conventional fuel; same requirement for individual fuel purchases for fleet vehicles.

State	State Excise Tax Exemption	State Producer Credits	Special Information
Maine	Renewable fuels including ethanol and biodiesel produced in the state are exempt from state's motor fuel excise tax.		
Maryland		$.20 per gallon producer credit for ethanol produced from small grains (winter grain); $.05 per gallon producer credit for ethanol from other agricultural products.	Maximum total payment of $3 million/year for all ethanol produced. To reach maximum, would need at least 15 mgy of ethanol from small grains in a facility that began operating or expanded after 12/31/04. Sunsets 12/31/2017.
Minnesota	No tax exemption on 10% blend; $.058 tax exemption E85	$.20 per gallon producer credit; subject to reduction pending on state budget	Producer credit applies to the first 15 million gallons per plant per year. There is a $3 million annual cap per plant. Cap is 10 years from date of plant start-up. Other: statewide requirement to blend 10% ethanol in conventional gasoline sold in the state; legislation enacted in 2005 to increase blend requirement to 20% beginning in 2013 if waiver is received from US EPA.
Mississippi	No tax exemption	$.20 per gallon producer credit	Maximum payment of $6 million per producer of anhydrous ethanol and $37 million total per fiscal year. Provides formula for credit for production of "wet" alcohol. Sunset is June 30, 2015.
Missouri	No tax exemption	$.20 per gallon applies to the first 12.5 million gallons. $.05 per gallon to the next 12.5 million gallons produced.	Producer credit applies to the first 60 months of plant production
Montana	No tax exemption	$2 million per plant, per year producer incentive	To receive producer incentive, plant must use Montana produced grains: 20% in first year of production, 25% in 2nd year, 35% in 3rd year, and increasing by 10% per year until plant uses 65% Montana grains. Other: Provides for 10% ethanol mandate within 15 months of the state producing 40 mgy. Exempts 91 octane.
Nebraska	No tax exemption	No producer credit	$.18 producer incentive program expired in June, 2004.

State	State Excise Tax Exemption	State Producer Credits	Special Information
North Dakota	No tax exemption	$.40 per gallon producer credit	2005 legislation establishes producer payments for 2005-07 biennium (and not beyond) for plants that were in operation by 7/1/95 (less than 15 mgy = $900,000 and greater than 15 mgy = $400,000). Also provides incentives for increased production by the lesser of 10 mgy or 50%. Other: Exempts E85 from all but $.01 per gallon of state's fuel tax, up to 1.2 million gallons.
Oklahoma	No tax exemption	$.20 per gallon producer credit	For production in place between 12/31/03-12/31/06. Maximum of $25 million per facility per year, with total maximum per facility of $125 mil. Credit of $.075 for new production after 1/1/11, for up to 10 mgy per facility for 3 years.
Pennsylvania	No tax exemption	$.05 per gallon producer credit	Up to 12.5 million gallons of renewable fuel per calendar year produced by a qualified renewable fuels producer. Money provided from state Alternative Fuel Incentive Fund. (SB 255, signed into law 11/29/04.
South Dakota	$.02 tax exemption	$.20 per gallon producer credit	416,667 gallons per month maximum allowable to ensure equal distribution among all producers.
Texas		$.20 per gallon producer credit for ethanol and biodiesel	Credit applies to first 18 mgy of production per plant for ten years. Imposes fee on ethanol and biodiesel producers of 3.2 cents for each gallon produced up to 18 million gallons per facility.
Wisconsin	No tax exemption	$.20 per gallon producer credit	$3 million per year, per plant (limited to first 15 mgy)
Wyoming	No tax exemption	$.40 per gallon producer credit	Program has a $4 million per year cap. Plants constructed after 7/1/03 eligible for 15 years. Plants in existence prior to 7/1/03 eligible until 6/30/09, unless they expand by at least 25%, in which case they are eligible for 15 years following the date of expansion.

Source: RFA and National Conference of State Legislatures

C. Global Biofuel Policies

While clean air policies have been the main driver of biofuels policies in the United States (at least until passage of the Energy Policy Act of 2005), most other countries began their current biofuels programs later and have focused primarily on other objectives – primarily control of greenhouse gasses in efforts to control global warming.[4] Based on the potential for biofuels to remove carbon dioxide – the primary greenhouse gas – from the atmosphere, policies in the EU and other developed countries have sharply expanded production and use incentives in recent months.

Two countries in particular, the EU and Japan, have committed to significant, mandatory greenhouse gas emissions reductions following their ratification of the Kyoto Protocol, which came into effect in 2005.

1. Anti-Global Warming Policies and Programs – Background

Concern over emissions from use of fossil fuels have been growing for decades and by the 1980s, scientists around the world had begun to model the effect of increased pollution emissions on the global climate. Based on assumptions concerning economic activity and fossil fuel use, projections that growing concentrations of greenhouse gasses in the atmosphere could increase global temperatures and thereby adversely affect climatic patterns were increasingly accepted, although the debate regarding the origin and outcome of these trends continues. These concerns led to global efforts to control emissions of greenhouse gasses into the atmosphere.

The first effort came in the early 1990s came through the UN Framework Convention on Climate Change. Members adopted voluntary, non-binding measures to reduce greenhouse gas emissions, which proved ineffective as countries continued to miss their reduction targets. It was replaced by a second agreement negotiated in 1997 in Kyoto, Japan. Ratification by members was required for the Agreement's commitments to come into force, a process that took almost a decade. Before the Agreement was finally approved in 2005, the United States had withdrawn and is not committed to the emission reduction targets it contains.[5]

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[4] This is not to say that environmental policies are not important in many other counties, but that they have focused on other objectives than the development of alternative fuels.

[5] Nevertheless, the United States has a formal anti-global warming policy of its own. Its main goal is to reduce US greenhouse gas emission by 18% by 2012, reducing current emissions from 183 to 151 metric tons of carbon equivalent per million dollars of GDP, according to the "Global Climate Change Initiative" announced in 2002. Such a reduction would lead to a reduction in emissions of approximately 4.5% relative to "business as usual." However, this level would still be approximately 28% higher than the 1990 level defined by the UN commission on climate. In order to meet the administration's 18% intensity-reduction target, it proposed to:

- provide voluntary incentives for companies to cut emissions,
- diversify the energy supply to include cleaner fuels,
- increase conservation,
- increase research and development and provide tax incentives for energy efficiency and clean technologies
- increase carbon storage

If the policy targets are not met by 2012, and sound science justifies it, additional measures would be imposed, including broad based market programs as well as additional incentives and voluntary measures designed to accelerate technology development and deployment. The EPACT provided funding for some of the research initiatives, while the conservation and carbon storage goals are already part of existing environmental legislation.

By far the two largest sources of greenhouse gas emissions are the United States and the EU. Table 10 shows the carbon emission reduction targets for the main greenhouse gas emitters in the Kyoto Protocol, compared to their emission levels in 2003. Russia's emissions are currently 741 million metric tons lower than its target, while emissions from the EU and Japan are 573 million tons higher than their combined targets. The table also shows projected emissions in 2010, the deadline for countries to meet their commitments. By 2010, both Japan and the EU must make significant reduction commitments, although Russia, the Eastern European countries (Poland, Hungary, and East Germany) and Ukraine likely will have surplus emissions credits, which they may sell to countries that have not met their targets. China and India, two of the world's largest emitters of greenhouse gases, were not required to reduce their emissions under the Protocol, although high oil prices are providing incentives there for some biofuel consumption. The United States did not ratify the protocol and is not bound by its reduction targets.

Table 10: Carbon Emissions and Kyoto Protocol Reduction Commitments

	Emissions Target	Emissions, 2003	Trend Emissions, 2010	Difference from target
	million metric tons of carbon emissions			
Australia	284	377	520	236
Canada	450	600	681	231
EU-25	3831	4149	4,513	682
Japan	950	1206	1,211	261
Russia	2347	1606	1,732	-615
United States	4651	5802	6,561	1,910

Source: US Department of Energy, Energy Information Administration

There are a number of proposals for legislation that would impose much stricter controls on U.S. greenhouse gas emissions, which would likely add momentum to policies encouraging biofuels use. Concerns about global warming are increasing around the world and support for these proposals will likely grow. However, they currently face strong opposition from industries that would be affected by the emissions reduction requirements.

D. Energy and Environmental Policy in Canada

Canada currently produces relatively low volumes of biofuels with 2004 production estimated at 66 million gallons. However, a number of provincial governments have introduced biofuels programmes and both major parties have pledged to raise the 2010 federal renewable fuels target incorporation rate to 5% (from the current 3.5%). The effect of these measures, if they are agreed and implemented, would be to raise Canada's production of renewable fuels to 370 million gallons by 2007 and 820 million gallons by 2010.

In 2003 the federal government announced the Ethanol Expansion Program. The program is intended to expand fuel ethanol production and use in Canada and reduce transportation-related greenhouse gas (GHG) emissions that contribute to climate change. Under the first round, C$72 million in contributions has been allocated to six projects across Canada. This second round invests an additional C$46 million.

The Ethanol Expansion Program builds on the Future Fuels Initiative that was announced under the Action Plan 2000 on Climate Change. The Future Fuels Initiative provides up to C$140 million in contingent loan guarantees to encourage investment in new ethanol production facilities, funds for analytical research and public awareness activities.

The funding under the Ethanol Expansion Program is part of a larger bio-fuels strategy that also includes the extension of the National Biomass Ethanol Program, research and development under the biotechnology component of the Technology and Innovation Strategy, and an investment in biodiesel.

In 2005, Ontario approved a 5% ethanol mandate for all gasoline fuel by 2007, despite strong objections from the major oil companies in Canada. Ontario believes this commitment would more than triple the market for renewable fuels in Ontario to 793 million liters by 2007. The main constraint to Ontario's plan is the concern that much of this demand would initially be met with imports from the United States and Brazil, rather than domestic production.

E. Energy and Environmental Policy in the EU

The EU has implemented a number of policies to expand bio-based fuels use, including a non-binding target for a 5.75% biofuel share of total gasoline and diesel consumption by 2010—targets it is considering making mandatory. Total EU gasoline and diesel consumption for transportation purposes in 2010 is projected to be 389 million tons, so such a target for 2010 biofuels consumption would be 22.4 million tons, about 7.5 billion gallons of ethanol, or 6.7 billion gallons of biodiesel (80% of biofuel production in the EU is of biodiesel). The EU produced about 1.9

million tons of biodiesel in 2004 or about 574 million gallons, a 27% increase from 2003. Ethanol production was about 130 million gallons.

While the EU has moved strongly in recent months to support biofuel production, its policies have been evolving over a considerable period of time. For example, the main drivers for fuel ethanol and biodiesel production in the EU in recent months have been two EC biofuel directives adopted in 2003, the ‘promotional’ Directive and the Directive on the Taxation of Energy Products. These followed the Green Paper ‘Towards a European strategy for energy supply’ published by the EC in 2000. This paper highlighted the fact that the EU will become increasingly dependent on external energy sources and that eastward expansion will worsen the situation (import dependence was expected to reach 70% in 2030, compared to 50% in 2000).

The Commission also emphasized the need to comply with emissions reductions commitments in the Kyoto Protocol. At present, greenhouse gas emissions in the European Union are rising, making it difficult to respond to the challenge of climate change and to comply with Kyoto objectives. In addition, although not explicitly mentioned in the Green Paper, the EU’s biofuels policy aims at creating a new stimulus for the rural economy.

Under the ‘promotional’ Directive, which entered into force in May 2003, Member States shall achieve a 2% share of renewable fuels (pure biofuels, blended fuel or ETBE[6]) by the end of 2005 and a 5.75% share by end 2010. These are indicative rather than mandatory targets based on the energy content of all petrol and diesel for transport purposes placed on the market.

The Directive on the Taxation of Energy Products, in force since October 2003, allows Member States to exempt, in full or in part, products that contain renewable substances (such as bioethanol or biodiesel). In some Member States, including Spain, France and Sweden, there has already been a tax exemption or reduction for biofuels in place since before the EU directive entered into force.

There is also support from the European Union for research projects on biofuels, e.g. for a 4-year project to develop cost-effective and environmentally friendly methods to mass produce ethanol as fuel for motor vehicles, which is being funded with 12.8 million Euros and conducted by 21 universities, research institutes, and companies.

In addition, the latest reform of the EU Common Agricultural Policy in June 2003 maintained/introduced financial support to farmers growing energy crops as feedstocks for biofuel production:

[6] Ethyl Tertiary Butyl Ether, an oxygenated additive for petrol.

- The provision to allow the production of energy crops on set aside land was maintained. In the case of sugar beet however, no payments are made for set aside land grown with beet for non-food use.

- A 'carbon credit' payment of 45/hectare was introduced for land grown with 'energy crops' (excluding sugar beet) that are processed to fuel or gas, on condition that the farmer concludes a contract with a processor. Payments are subject to an upper limit of 1.5 million ha. The provision for an exclusion of sugar beet grown for bioethanol production from the 'carbon credit' and set aside payment will most likely change once the reform of the sugar market organization has been implemented.

The combination of high oil prices and the ratification of the Kyoto Protocol in 2005 provided the incentive necessary for the EU to begin a push for more biofuel production. In early 2006, the EU adopted a formal biofuels strategy, specifically based on its need to substitute biofuels for oil imports and to comply with the Kyoto Protocol.

The strategy also has the potential to help reduce pressure on EU internal grain markets as it eliminates agricultural export subsidies reforms its sugar policies.

The European Union has both a Biomass Action Plan and an overall Strategy for Biofuels, both very new policy commitments developed in the last three months.

1. Action Plan.

The European Commission completed its *Biomass Action Plan* in December 2005, heralding the use of biomass as a key part of the EU's future energy strategy, although the Commission said that any use of agriculture to increase renewable energy would be done in a sustainable manner. The action plan set out around 20 actions that would attempt to increase the use of energy from forestry, agriculture and waste materials. The Commission's aim is to double the share of renewable energy sources in the EU in the next five years, from 6% today to 12% by 2010. Within this objective, it believes that the action plan has the potential to increase the use of biomass to around 150 mtoe[7] tons by 2010 - compared with 69 mtoe in 2003 - thereby reducing emissions of CO2 by 209 million tons/year and reducing reliance on imported energy. It also aims to reduce crude oil imports by 8% and create between 250,000 to 300,000 new jobs in the agriculture and forestry sector.

2. Biomass Strategy.

The EU implemented its *Strategy for Biofuels* in February 2006, including a range of potential market-based, legislative and research measures to boost production of fuels from agricultural raw materials. The paper sets out three main aims: 1) to promote biofuels in both the EU and developing countries; 2) to prepare for large-

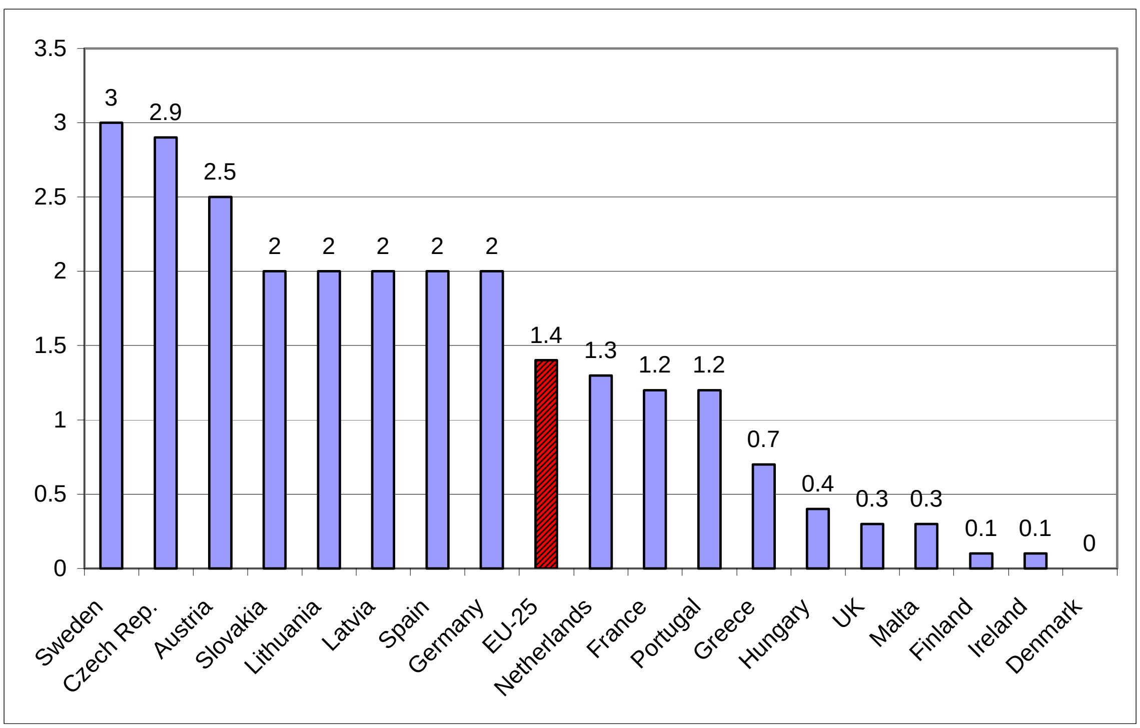
[7] Million tons of oil equivalent

scale use of biofuels by improving their cost-competitiveness and increasing research into 'second generation' fuels; and 3) to support developing countries where biofuel production could stimulate sustainable economic growth. The plan claims the use of biofuels will bring numerous benefits to the EU, by reducing Europe's dependence on fossil fuel imports, reducing greenhouse gas emissions, providing new outlets for farmers, and opening up new economic possibilities in several developing countries.

One of the key actions in the plan is the promotion of biofuels to fulfill the Commission aim to see all diesel and petrol gasoline contain 2% of biofuel by the end of 2005, rising to 5.75% by 2010. Based on Member States' reports on national biofuels plans submitted to the European Commission by November 2005, the EU would only reach a 1.4% share of renewable fuels by end 2005, thereby missing its 2% target.

Figure 17 shows biofuel targets for each member state, based on plans developed by the national governments. The targets are not mandatory, so the actual share of biofuels likely will be somewhat lower than the 1.4% since most member states are still far from reaching a 2% share of renewable fuels, including Denmark which does not use any biofuels at all, and Ireland and Finland which both have a 0.1% target for 2005.

Figure 17: EU Biofuel Market Share Targets. 2005 Percent of Fuel Consumption



Source: F.O. Licht

Some market experts are skeptical that EU will have the feedstocks necessary to meet its biofuels targets. Nevertheless, biofuel production has increased significantly over the last ten years (Figure 18), especially for biodiesel—a market that is continuing to grow, while the gasoline market is contracting. Annual biodiesel output is now close to two million tons per year, while production capacity in 2004 was about 2.4 million tons. Germany, France, and Italy are the main producers of biodiesel, while Spain and France are the largest ethanol producers (Table 11).

In addition, air quality standards in European legislation include criteria concerning volatility (evaporation) on fuels that bioethanol-based mixes (up to 5%) cannot meet. This suggests that its greenhouse gas emission goals will require either changes in European standards that increase acceptable fuel volatility levels, or use of ethanol mixes that do meet standards for evaporation. Oil companies in the EU have objected to being forced to incorporate ethanol in their gasoline supplies, preferring to use ethanol to produce ETBE composed of 50% ethanol and 50% isobutylene, a gasoline derivative.

Figure 18: EU Biofuel Production

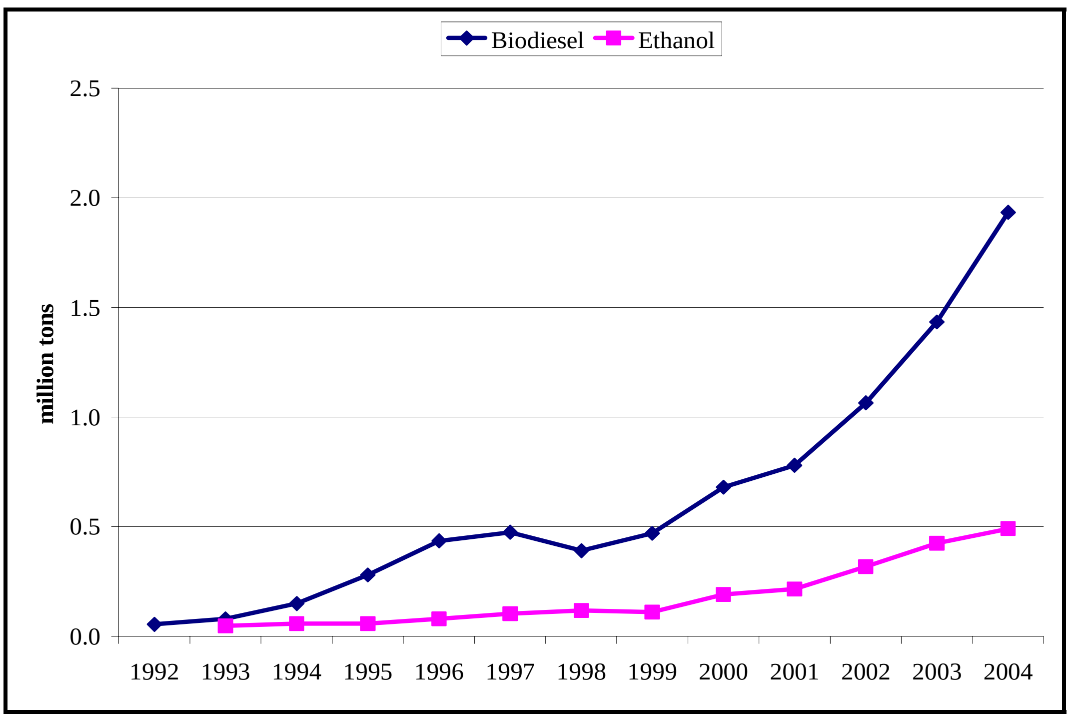


Table 11: EU Biodiesel Production

	2002	2003	2004
	tons		
Germany	450,000	715,000	1,035,000
France	366,000	357,000	348,000
Italy	210,000	273,000	320,000
Czech Republic	-	74,861	82,698
Denmark	10,000	41,000	70,000
Austria	25,000	32,000	57,000
Slovak Rep.	-	-	15,000
Spain	-	6,000	13,000
United Kingdom	3,000	9,000	9,000
Lithuania	-	-	5,000
Sweden	1,000	1,000	1,400
Total EU-25:	**1,065,000**	**1,508,861**	**1,956,098**

Source: EurObserv'ER

Table 12: EU Ethanol and ETBE Production

	2003		2004	
	Ethanol	ETBE	Ethanol	ETBE
	tons			
Spain	160,000	340,800	194,000	413,200
France	82,000	164,250	102,000	170,600
Sweden	52,000	-	52,000	-
Poland	60,430	67,000	35,840	n.a.
Germany			20,000	42,500
European Commission	70,320		87,200	n.a.
Total EU-25:	**424,750**	**572,050**	**491,040**	**626,300**

Source: EurObserv'ER

3. EU Member-States Biofuels Programs

Germany

The development, use, and support of biofuels, namely biodiesel, in Germany have a history of more than 15 years. The aim is to make use of their environmental benefits, in order to become less dependent on fossil fuels, and to generate additional income for farmers. With the Green Party gaining more influence in the German government and at the EU level, environmental benefits are playing a greater role in determining policy for biofuels.

Since January 1st, 2004, the mineral oils tax law that governs fuel taxation allows for a total tax exemption for biofuels, whether in pure form or mixed with fossil fuels.

Germany's new coalition government says the special tax exemption for biodiesel will be replaced by compulsory blending with conventional diesel in oil refineries. German oil refineries will be compelled to blend a maximum 5% biodiesel content into conventional diesel fuels. Biodiesel is more costly to produce than conventional fuels and without a tax break would be more expensive than mineral diesel. Biofuel industry and farm associations are lobbying hard to retain some form of tax break and the actual scope of the coalition's plans is currently unclear. But Germany's Finance Ministry said biodiesel taxes would be raised in some form. Surging oil prices meant German biodiesel consumption shot up in 2005 to an estimated 1.8 million to 2 million tons from 1.1 million tons in 2004. About half of consumption is sold at petrol pumps and half is blended with conventional fuel by oil refineries.

France

France has promoted and used biofuels for over ten years. It is the second biggest fuel ethanol producer in the EU (27 million gallons in 2004, and probably 60 million gallons in 2005), and also comes second in EU biodiesel production (approximately 103 million gallons in 2004).

In France, fuel ethanol is not used in its pure form but is converted into ETBE. The most important instrument for supporting the use of bioethanol in transport fuel is an excise tax reduction. It currently amounts to 38/hl for ethanol used in the form of ETBE[8], i.e. a reduction of 60% of the normal tax level[9]. The tax exemption is only valid for a limited volume of ethanol (and therefore ETBE). The government fixes quotas for distinct periods of time on an irregular basis. Between 2004 and 2005, the quota was doubled and for 2005 amounts to approximately 66 million gallons of ethanol, corresponding to roughly 445,000 tons of ETBE.

Similarly, there is a limited quota of biodiesel, which is eligible for a mineral oil tax reduction of 33/hl of biodiesel[10]. In 2005, the quota amounts to 145 million gallons.

[8] The tax reduction only applies to the ethanol component in the fuel. It can be calculated on the basis of the ETBE-petrol blending ratio, and taking into account the fact that ETBE consists of 45% of ethanol and 55% of iso-butylene.
[9] In early 2003, the French government reduced the excise tax break from 80% (50.23/hl) to 60% (38/hl) due to shortages in the state budget. Currently, the French Finance Ministry seeks to further reduce the tax reduction bioethanol by 5 Euro-cent to 33 Euro-cent a liter.
[10] It is however reported that the French Ministry of Finance plans to reduce the tax incentive for biodiesel by 8 Euro-cent to 25 Euro-cent a liter.

Biodiesel production in France has decreased continually since 2001. Although biodiesel enjoyed a 33 euro per hectoliter tax break for 387,500 tons of biodiesel in 2004, biodiesel production was only 348,000 tons. In order to encourage distributors to put the totality of the authorized quantities (biodiesel, ETBE or pure bioethanol) onto the market, the 2005 Finance Law introduced a 'new' tax called the TGAP ('General Tax on Polluting Activities')[11] for those cases where biofuels are not made available for consumption. This has been applied since 1st January 2005 for all transport fuel sold. Every distributor is liable to pay a tax of 1.2% of the value of the fuel product in 2005. This is lower or even nil for fuels containing renewable components, depending on the share of the biofuel in the final product. The 1.2% rate corresponds to the desired percentage of biofuels incorporation in fuels in 2005. In this manner, the incorporation percentage was scheduled to increase each year to reach 5.75% in 2010 (in line with the European Commission's target).

In autumn 2005, France announced plans to respond to current high oil prices by increasing its target of incorporating biofuels in other fuels to 5.75% by end 2008[12], rising to 7% by end 2010 and 10% by end 2015. This would go beyond the EU objective of a 5.75% market share for biofuels by 2010. According to Prime Minister Dominique de Villepin, this target will be complemented with a policy of boosting production of agriculture-based biofuels, including an increase of the ethanol and biodiesel quotas eligible for the tax reduction (plus 260 million gallons for fuel ethanol, and plus 530 million gallons for biodiesel for the period 2005-08).

Spain

In its *Renewable Energy Plan* for 2005-2010, the Spanish government earmarks EUR2.85 billion of sales tax breaks for bioethanol and biodiesel producers over the five-year period, in order to reach a total share of 5.83% of biodiesel and bioethanol in the total consumption of diesel and petrol in Spain by 2010. As a result the use of biofuels is to more than quadruple by 2010, when it will reach 2.2 million tons of oil equivalent against 500,000 tons at present.

Spain is the biggest fuel ethanol producer in the EU. In 2004, approximately 67 million gallons of fuel ethanol were manufactured in Spain. Current ethanol production capacity of approximately 86 million gallons will be expanded by 50 million gallons in 2006 when a new big plant is expected to start production.

In Spain, a limited volume (quota) of ethanol is eligible for a full exemption from the mineral oil tax of 37/hectolitre (hl). This tax incentive expires in 2012.

[11] In fact, the tax is not really new, because it has been in place since 1st January 1999, but it did not apply to transport fuel before 2005.
[12] The previous target was 5.75% by end 2010.

Spain started up its biggest biodiesel production unit (74 million gallons) in May 2004 in the region of Cartagena. Total biodiesel production amounted to approximately 3.7 million gallons in 2004. Biodiesel is also fully exempt from the hydrocarbon tax.

Sweden

Although not a large biofuels producer, Sweden is the biggest user of biofuels in relative terms. It is expected to achieve a 3% share of renewable fuels in the transport fuel sector in 2005. Domestic production of biofuels amounted to 18.8 million gallons of fuel ethanol and 400,000 gallons of biodiesel in 2004. However, fuel ethanol consumption is much higher, in the region of 68.7 million gallons. Most of the fuel ethanol used in Sweden is imported, originating from Brazil (sugar cane ethanol) and Italy (wine alcohol). However, imports from outside the EU may decrease from 2006 onwards because of a change in the tax rule for fuel ethanol

So far, Sweden is the only EU Member State, which uses direct blending to a significant degree and which runs flexible fuel vehicles, e.g. the 'Ford Focus'. There are several incentives to use such cars, including free parking in city centers and an exemption from the city "congestion tax." Sweden applies both low (E-5, accounts for approximately 85% of total fuel ethanol use) and high blending (E-85, accounts for approximately 15% of total fuel ethanol use). Currently, all Swedish petrol stations are offering E-5 blends, and 160 of the 4,000 existing stations are also selling E-85 blends. There is a tax exemption of 100% (52.5/hl), enabling petrol stations to offer ethanol-blended fuel at the same price as pure petrol. In 2004, the average gasoline blend contained 5.5% ethanol. By 2009, at least 2,400 gas stations around Sweden will have to feature at least one kind of biofuel. There are now more than 300 E-85 fuel stations in Sweden.

In its latest budget proposal the Swedish government indicates it wants to extend the tax exemption on fuel ethanol until 2013. Under existing regulations this exemption is due to end in 2009.

In 2005, the government in Sweden decided to close an import tax loophole of ethanol that has been mixed with ordinary petrol, so called denaturated ethanol. The new rules will come into effect from January 2006. The decision will mainly hurt Brazilian imports, which have ousted Swedish ethanol imports from other EU countries such as France and threatened the aspiring domestic ethanol production.

Effective on January 1, 2006, exporters to Sweden will have to show that they have paid the standard EU import charge of 0.192/liter paid for non-denaturated ethanol in order to get access to the tax exemption. The new rules apply only to ethanol used in gasoline with a 5% mix with ethanol, the suggested EU formula. However, the new rules do not apply to the E-85 mix that some cars now run on, with 85% ethanol and 15% ordinary petrol and bus ethanol.

Poland

Poland is the only country among the new EU Member States to have developed a significant fuel ethanol sector. Fuel ethanol is mainly added to petrol in the form of ETBE. Bioethanol production decreased sharply in 2004 by more than 40% to approximately 48 million liters. This situation can be explained by the fact that in 2004 the Polish Constitutional Court did not ratify the Biofuels Law that had been previously adopted by Parliament in November 2003. This law provides for a tax exemption for the production of ethanol mixed with petrol, the final percentages and the amount of the exemption are to be determined on a yearly basis after approval of the annual budget. The Biofuels Law is presently still under revision.

The country only produces limited amounts of biodiesel to date. The first industrial scale biodiesel plant with a capacity to produce 110 million liters/year[13] came online in December 2004 in Trzebinia (Southern Poland). Most of its output is exported to Germany, however, since May 2005, part of the biodiesel produced is being sold on the Polish market as B-20 (a blend of 20% biodiesel and 80% conventional diesel). The 20% biodiesel blend benefits from a full excise tax exemption of PLN2.2 (ca. US$0.66) per liter. In addition, the company Elstar Oils S.A., Elblag, plans to start construction of a 14.5 million gallon[14] biodiesel plant in Poland in the 2006.

According to the National Statistical Office (GUS), the share of liquid biofuels in the transportation sector (in calorific values) amounted to only 0.3% in 2004. This share is expected to increase to 0.5% in 2005 and 1.5% in 2006.

Netherlands

So far, the Netherlands has only produced minor volumes of fuel ethanol (14 million liters in 2004) and no biodiesel at industrial scale, because there is no support program for biofuels yet. However, in autumn 2005, the government announced plans to introduce a blending obligation for biofuels. In 2007, petrol and diesel sold in the Netherlands will have to contain 2% biofuel (either bioethanol or biodiesel). This will rise to 5% in 2010 and 20% in 2020. In addition, the government plans to introduce a duty exemption of 0.5 per liter for bioethanol and biodiesel for 2006. The money to be spent on this measure shall be limited at EUR50 million. This is equivalent to a market share of 1.5% for ethanol by energy content. The Netherlands aims to stimulate the use of biofuels after warnings from the European Commission on the risk of non-compliance with the indicative targets for biofuels usage. A final decision on the obligation will be taken by January 1, 2007. By 2007 the use of fuel ethanol in the Netherlands could rise to 26 million gallons if the 2% mandate is approved.

Several plans to construct biofuel plants have been announced recently, mainly for the production of biodiesel from rapeseed. In July 2005, Solar Oil Systems opened

[13] However, annual production capacity can easily be increased to 170 million liters.
[14] Later on capacity is to rise to 29 million gallons.

the Netherlands' first biofuel plant, producing pure rapeseed oil and having an annual production capacity of 3.5 million liters. In Northern Netherlands, the country's first biodiesel plant with an annual capacity of 33 million liters is currently under construction and expected to start production in spring 2006. On 1 November 2005, the country's first commercial bio-ethanol pump was opened in Gorinchem.

Italy

Italy is the third biggest producer of biodiesel in the EU, manufacturing approximately 95 million gallons in 2004, up 17% from 2003. More than 90% of this production was intended for the fuels market, with the rest being destined for building heating applications. As in the case of fuel ethanol, a limited amount of biodiesel is eligible for a mineral oil tax reduction each year. In contrast to France and Germany, the biodiesel situation will probably deteriorate in Italy in 2005, because the volume of biodiesel benefiting from the tax incentive decreased by 29 million gallons to 58 million gallons in 2005. This decrease in quotas is due to the introduction of tax break quotas for ethanol in 2005. This decision is justified by the fact that biodiesel is mainly produced using imported vegetal oils while Italy possesses a sizeable capacity for producing its own alcohol of cereal and wine origin.

United Kingdom

Until recently the UK had shown little interest in biofuels. However, as with other EU member states the UK is moving to address the objectives of the Biofuel Directive. The government, through its white paper on energy in 2003, acknowledged that biofuels were an important potential route for achieving the goal of zero carbon transport, noting they could account for some 5% of road transport fuels by 2020. The UK's main support has been through fuel duty incentives—a 20 pence per liter duty incentive on both biodiesel and ethanol. This represents a 40% reduction until 2008. Other measures are under consideration. At current levels of support, the industry view is that biofuel use may stabilize at less than 1% of road fuel use, well below the EU target, as the duty differential rate of 20 p/L for biofuels is considered insufficient to stimulate production.

Under the renewable transport fuels obligation (RTFO), the government requires that 5% of all fuel sold in the UK should come from renewable sources by 2010. The RTFO has only been officially announced in November 2005 and is not expected to be implemented before April 2008. It will work through a system of certification. Oil companies will receive certificates from an administrator to demonstrate how much biofuel they have sold. If a company sells more than its 5% obligation, it would then be able to sell those certificates to other companies who need more to meet the obligation.

Fuel ethanol requirements are exclusively being covered through imports from Brazil. In the first three quarters of 2005, total Brazilian ethanol imports into the UK amounted to 24.4 million gallons against negligible amounts the previous year.

There are also government subsidies available for the construction of biofuel plants. The first large-scale biodiesel plant with a capacity to produce 13.2 million gallons/year started production in March 2005, and a second plant is currently under construction. In late December 2005 construction work started on Britain's first ethanol plant, owned by British Sugar, and another plant owned by Wessex grain is in the planning stage. The combined production capacity of the two plants would be 50 million gallons.

F. Bio-based Fuel Demand—South America and Asia

Developing countries frequently lack the resources to provide subsidies and other tax incentives to produce biofuels. Consequently, the "bio-based product" strategy in many of the larger biofuel producing developing countries like China, India, and Malaysia are often small and poorly funded. Virtually all of the projects for producing biofuels in these countries are a result of investors taking advantage of opportunities created by high petroleum prices and low feedstock production costs in countries like Brazil and Malaysia.

None of the developed countries in Asia (Japan, South Korea, Taiwan) has a full-blown biofuels strategy. And, most Asian developed countries do not have surplus production of subsidized feedstocks, so biofuels policies are more dependent on their cost competitiveness.

The Asian biofuels became more active in 2005, although feedstock shortages remain a key issue. In India, the fuel ethanol program is starting to take off, buoyed by a bumper sugarcane crop, initially in the southern state of Tamil Nadu, although supply problems are still being seen in states such as Andhra Pradesh. India's 2005/06 sugar production could reach 18.0 million tons, up 47% from last season owing to good rainfall in sugar producing states. China has now mandated the use of ethanol-doped petrol in several provinces and the program is being rolled out further, as concerns about urban pollution and growing oil demand coupled with fuel shortages escalate. China also plans to build four biodiesel plants, using Malaysian palm oil as feedstock. Japan is conducting some tests using a 3% ethanol mix (E-3), but it looks as though it will be some time before biofuels demand takes hold in that potential key market. Taiwan is already conducting tests with a 20% biodiesel mix (B-20), while South Korea started some biodiesel trials in January 2006.

1. Developing Countries

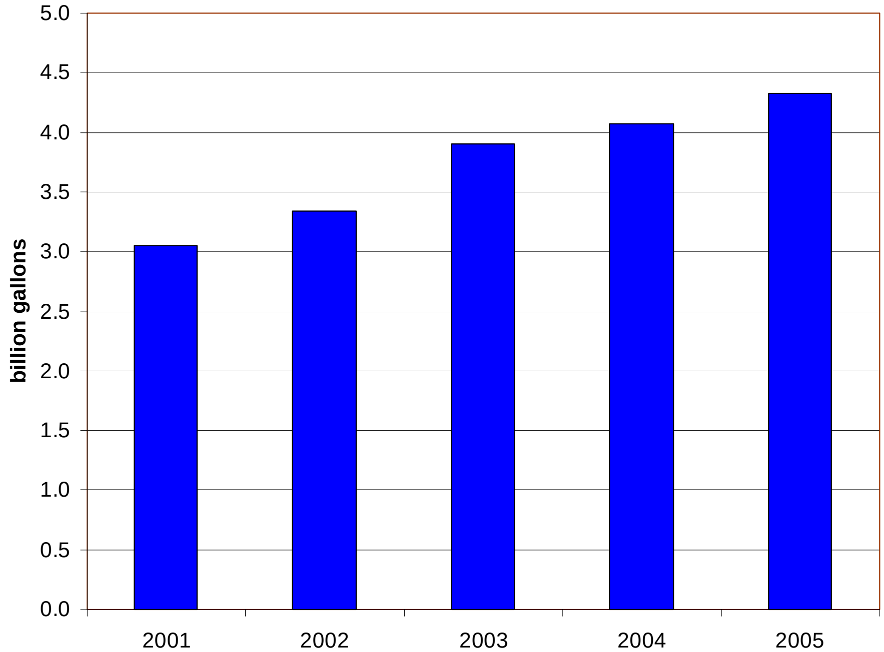
Brazil

By far the largest producer of biofuels, Brazil uses abundant and cheap sugarcane feedstock to produce 3.9 billion gallons of ethanol (2004) of which it exported 613 million gallons. While the ethanol industry in Brazil was started with significant government intervention, direct subsidies for ethanol production were removed in the 1990s. Brazilian environmental policies require gasoline to contain specific amounts of alcohol, with the amount established each year. Currently ethanol production and exports are almost entirely market driven.

After the oil shocks of the 1970s, Brazil implemented an aggressive strategy to encourage the use of ethanol in domestic transportation fuels (PROALCOOL), mainly by funding investments in ethanol distilleries, regulating the price of ethanol relative to gasoline, and increasing the capacity of the vehicle fleet to consume ethanol by subsidizing production of “flexifuel” cars. In the late 1980s, sugar prices rose and oil prices fell, making the PROALCOOL program prohibitively expensive. In 1998 the price of ethanol was liberalized and all subsidies associated with the program were gradually eliminated.

The high oil prices of 2005 have brought about a renaissance in ethanol production in Brazil (Figure 19). Brazil has several advantages in ethanol production resulting from the infrastructure and knowledge accumulated during the PROALCOOL program and from the relatively low cost and high efficiency of ethanol production from sugarcane stock. Brazil’s ethanol exports grew by 8% from 2004 to 2005, mostly from increased exports to Japan and the EU (Table 13).

Figure 19: Brazil Ethanol Production



Source: F.O. Licht

Table 13: Brazil's Alcohol Exports*

Country	2003	2004	2005
	million gallons		
India	6.3	126.1	108.5
Japan	15.0	58.1	83.3
United States	14.7	112.3	68.9
Netherlands	16.9	42.7	68.5
Sweden	16.5	51.4	65.0
South Korea	12.3	63.3	57.2
El Salvador	4.0	6.7	41.7
Jamaica	26.9	35.1	35.2
Costa Rica	8.4	28.2	33.5
Nigeria	12.5	27.8	31.3
Mexico	10.6	22.9	26.4
Other	29.3	38.7	65.4
Total	**173.4**	**613.4**	**684.9**

* HS Code 2207Ethyl alcohol, undenatured and >80%, or denatured
Source: SECEX - Foreign Trade Secretariat

China

The world's second-largest oil consumer, China, launched its fuel ethanol program in 2000 in order to improve the fuel supply situation in view of rapidly growing demand for transportation fuels, to tackle the surplus grain stocks accumulated in the late 1990s, to reduce air pollution in big cities, and to support the rural economy. It began blending gasoline with ethanol for use in automobiles in 2001 and invested the equivalent of more than $620 million that year to set up four ethanol plants with a capacity to process 3 million tons of corn, producing 1 million tons (1.3 billion liters) of ethanol in the process. China has set a target of producing 15% of its energy from renewable sources by 2020, up from around 7% currently.

Fuel ethanol is exempt from consumption tax (5%) and value-added tax (17%). Biofuel producers have priority in obtaining feedstock released from the State grain reserves at competitive prices. Currently, five provinces blend 10% of ethanol into all their petrol throughout their whole territory (Jilin, Heilongjiang, Liaoning, Henan and Anhui), and four provinces sell E-10 blend in part of their territory (Shandong, Jiangsu, Hebei and Hubei). Over 20 cities across the country are also pioneering E-10. According to a researcher from Tsinghua University in Beijing, total E-10 consumption will reach more than 10 million tons by the end of 2005, which equals about ¼ of total current petrol consumption.

However, fuel use of grain faces competition from food uses that could limit the growth of China's biofuels industry. China has long been concerned about its food security, and the top priority for land use is food crops. Because of serious sugar shortages in the country, a plan for substituting vehicle fuel with ethyl alcohol refined from sugarcane has been stalled for the time being in August 2005.

In contrast to bioethanol, the biodiesel program is not as developed. A few small plants with a capacity of 0.5 to 6.6 million gallons/year are in operation, using mainly waste cooking oil but also oilseeds as feedstock. China, which is already Malaysia's top palm oil buyer plans to build four biodiesel plants with combined production capacity of 400,000 tons of biodiesel/year, likely using palm oil as their feedstock due to the commodity's competitive price compared with soybean oil.

Under China's Renewable Energy Plan, the government set a target of 11 million tons of biofuels (bioethanol and biodiesel) production by 2020. According to Tsinghua University in Beijing, total transport fuel (petrol and diesel) consumption is expected to reach 228 million tons in 2020, so that a production level of 11 million tons of biofuels would mean an average share of 5% of renewable fuels in 2020. Fuel ethanol demand will continue to expand in China, as more provinces will introduce the compulsory use of ethanol-blended petrol.

India

The second largest producer of ethanol in Asia, India also is one of the world's largest sugar producers. Installed ethanol production capacity amounts to approximately 700 million gallons but capacity utilization rates are low (total ethanol production in 2004 amounted to 450 million gallons). In 2004, only approximately 26 million gallons of ethanol were used for blending with gasoline. Assuming that the ethanol program will be implemented in those States and Union territories originally envisaged by the government, the projected demand for fuel ethanol will be 396 million gallons in 2010 if E-10 is sold, as is now planned.

A fuel ethanol program was introduced in India in 2003. Measures currently in place include an excise tax reduction for E-5, the obligation[15] to blend all petrol with 5% ethanol in certain regions since January 2003 and government regulation of the ethanol selling price on the basis of ethanol production costs. Currently, 5% ethanol blends are used[16] in 10 sugar producing States and 3 contiguous Union Territories[17]. In addition to the federal moves, several Indian States have also attempted to support local ethanol production through the use of additional fiscal measures.

However, recently, the Indian fuel ethanol program suffered from a crisis. Following a drought, the 2003/04 and 2004/05 sugar crop and therefore also molasses output was unusually low, which resulted in sharply increased feedstock prices for ethanol production. As a result, local producers in India's Southern States concentrated on production of industrial and potable alcohol. The ethanol blending obligation was temporarily suspended in the autumn 2004. In the meantime, India has become increasingly dependent on molasses and ethanol imports to meet its ethanol requirements. However, it is likely that the molasses supply will increase substantially over the coming years with the recovery of cane production.

The government is currently developing a new biodiesel support program for the country. According to Petroleum Ministry officials, biodiesel is likely to be fully exempt for excise duty in the 2006 budget year. Under the government's new biodiesel (vegetable oil) purchasing policy, public sector oil firms will purchase straight vegetable oil extracted from plants, such as jatropha, pongamia etc. for mixing in diesel at INR25 (ca. US$0.55) a liter beginning January 2006. In a first step, 5% straight vegetable oil will be mixed with diesel during trial runs and will be increased to 20% in phases. In 2003, the country's Planning Commission had drafted plans to encourage the widespread planting of Jatropha curcas trees and use the oil produced for blending with conventional diesel. It set a target of a 'vegetable oil for fuel use' output of 13 million tones/year. In Bangalore, there are plans to transform a plant producing straight vegetable oil from Karanjia and Jatropha into a biodiesel production unit.

[15] However, due to supply problems, this 'obligation' was suspended in 2004.
[16] Under normal conditions, the blending of 5% ethanol is mandatory, however, the blending obligation was suspended in late 2004.
[17] Andhra Pradesh, Damman and Diu, Goa, Dadra and Nagar Haveli, Gujrat, Chandigarh, Haryana, Pondicherry, Karnataka, Maharashtra, Punjab, Tamilnadu, Uttar Pradesh.

In November 2005, Petroleum Ministry officials were quoted saying that under the next State budget, the excise duty on both biodiesel and ethanol would be likely go to zero and states would be asked to have a favorable sales tax regime. The government plans to achieve a countrywide ethanol-petrol blending rate of 5% in the near future, which would require 132 million gallons of ethanol. Later on, it plans to increase the ethanol content in petrol to 10% and to blend conventional diesel with 5% ethanol. The country's Planning Commission proposes increasing the proportion of biofuels used in India from 5% to 20% by 2012.

Malaysia

A low-cost producer of palm oil, Malaysia expects that its oil will be a primary feedstock for a number of biofuel projects in Asia. In the meantime, the government in Malaysia government said late last year that it has approved at least 12 licenses to build biodiesel plants. It also is working on a National Biofuel Policy encompassing the formulation of the Biofuel Act and its provisions to encourage biofuel production and usage. Government vehicles will start using the fuel in trials from January 2006, to be followed by a wider program from 2007.

Global demand for biodiesel is expected to touch 10.5 million tons in the next few years and Malaysia says it has the potential to capture at least 10% of the total market. The first three plants costing a combined MYR120 million were announced in Putrajaya on December 12, 2005.

Malaysia and South Korea have signed a Memorandum of Understanding (MoU) for collaboration in research and development (R&D) relating to biofuels, particularly biodiesel.

Another memorandum of understanding was signed between Ecosolution Co. Ltd Korea and POIC Sabah Sdn Bhd towards joint ventures in the production of biodiesel. A 300,000 ton biodiesel plant will be built in Sabah by Palm Oil Biodiesel International Sdn Bhd, with most of its output destined for South Korea.

Thailand

A new policy will mandate the use of 10% ethanol in gasoline with 95-octane rating by 2007 and in gasoline products with 91-octane by 2011. However, Thailand's ambitious fuel ethanol policy has been stymied by a tight domestic sugar market, leading to significant feedstock imports over recent months to satisfy growing demand. In the meantime, the Thai Energy Ministry has announced it would accelerate plans to introduce biodiesel nationwide to follow the King of Thailand's call for more promotion of alternative fuels. The plan calls for the use of 2.2 million gallons of biodiesel/day by 2010.

The focus initially will be on a mixture of 5% refined palm oil and 95% diesel. The use of palm oil, a major crop in Thailand, will be increased to 10% under a B-10 blend in 2012. However, as with fuel ethanol production, palm oil feedstock imports may be necessary to plug any supply gaps in the short term.

Several Thai plants have already begun biodiesel production. Viset said around 130,000 gallons of palm oil/day were currently available after domestic use and export, which is insufficient to meet future biodiesel requirements. As a result, he was considering a plan to waive some taxes on biodiesel production to help lower the cost to attract consumers.

At present, Bangchak Petroleum Plc is the only distributor of B-5 fuel, which is available at 14 gasoline stations. Ministers have as a consequence agreed to expand palm plantation areas to help boost market supplies, and no doubt sugarcane and cassava (tapioca) production will be expanded to meet growing ethanol demand.

Philippines

The use of a 1% (B-1) biodiesel blend will be required, and a new Biofuels Act presented to the Senate in late 2005 is looking to promote the production of ethanol from sugarcane as a fuel and bioelectricity feedstock. The bill would require 5% ethanol content in gasoline two years after the bill is signed into law, growing to a 10% mandate after another two years.

2. Developed Countries

Japan

Under pressure to meet its Kyoto targets, Japan has proposed a target of 500 megaliters (132 million gallons) of biomass derived fuels by 2010. This would equate to about 1% of projected fuel use. To encourage the uptake of ethanol, the government proposed an E3 standard in 2004 as a prelude to a national E10 blend standard by 2010. An E3 standard would imply a market of about 470 million gallons. Currently legislators are discussing whether to increase the cap to 10%. In mid 2005, Reuters reported that Japan was considering a 7% ETBE standard rather than E3 after strong industry opposition to costs and concerns about health impacts. Industry claims that ethanol would require blending at the service station while ETBE would reportedly be made using idle facilities previously being used to make MTBE. The ETBE would be blended with gasoline at the refinery. The Brazilian company Petrobras has started a joint venture to produce ethanol for the Japanese market.

South Korea

A Memorandum of Understanding for collaboration in research and development relating to biofuels, particularly biodiesel has been signed with Malaysia. During January 2006, South Korea started its own biodiesel trials to better evaluate its potential

Australia

During September 2005, the Australian government finally set a target of 92.4 million gallons of biofuel use by 2010. Australian car manufacturers have agreed to start putting labels on gasoline caps of new cars stating E-10 is acceptable for use, after earlier bad publicity for the fuel, which arose from a higher percentage in some tanks. The New South Wales (NSW) state government's announcement that its fleet of more than 3,000 vehicles will use biofuels has raised the hopes of businesses looking to build ethanol plants in rural NSW.

3. Background on the Kyoto Protocol

The world's primary emitters of greenhouse gases are the United States, the EU, China, Russia, and Japan (Table 14). However, recent growth in emissions has taken place mainly in the United States, China and other developing countries in Asia such as Indonesia, Taiwan, Thailand, Malaysia, and Pakistan. US carbon dioxide emissions have grown 16% since 1990, from 5 to 5.8 billion metric tons. China's emissions grew 58% over the same period, from 2.2 to 3.5 billion metric tons.

Although the EU-25 is the world's second largest emitter of carbon dioxide, its emissions growth has declined since 1990. The collapse of the Soviet Union led to a steep decline in industrial output in the East European countries and the closure of large numbers of old, poorly designed and inefficient plants in Poland, Hungary, and the Czech Republic, among others—a shift that reduced emissions for the region in spite of economic growth in the EU. Even in Western Europe CO2 emissions have only grown by 6% since 1990.

In the early 1990s a coalition of UN countries concerned about climate changed associated with greenhouse gas emissions agreed on the United Nations' Framework Convention on Climate Change. Members were asked to adopt voluntary, non-binding measures to reduce greenhouse gas emissions. The first Bush administration concluded that pre-existing EPA regulations mandating cleaner air and some fairly inexpensive research incentives would be accomplish the US reduction target. The Clinton administration initially embraced the same approach, but by 1995 it had become apparent that the United States was not going to meet its target and coalition members began negotiating legally binding emissions reduction commitments, but only for developed countries – meaning the United States, the EU, and Japan would bear the main costs of reducing global greenhouse gas emissions. Although Russia is also bound by the agreement to reduce emissions, its reduction commitments are not binding—in addition, its emissions fell dramatically after the collapse of the USSR.

When the current administration took office, it withdrew from the Kyoto Protocol negotiations, in part because of expected compliance costs—estimated to be $400 billion and 4.9 million jobs—and, because of the lack of compliance requirements for developing countries. Instead, it formed a coalition of like-minded economies, – Australia, China, India, Japan, South Korea, and the United States – to pursue less costly emissions reductions measures.

The Asia-Pacific Partnership on Clean Development and Climate

The six members of the Asia Pacific Partnership Clean Development and Climate – Australia, China, India, Japan, South Korea, and the United States – collectively account for 54% of global economic output, 45% of global population, 48% of global energy use and 50% of global greenhouse gas emissions. The main purpose of the partnership is to facilitate the development, deployment, and transfer of more energy efficient and cleaner technologies to allow emissions to be reduced without undue cost to the member countries' economic growth. The partnership has not yet agreed to any binding greenhouse gas reduction commitments, nor is it likely to do so.

A study commissioned by APPCDC from Australia's Bureau of Agricultural and Resource Economics estimated that technology transfer could result in a 23 – 24% reduction from the baseline in oil production in the partnership countries by 2050, while global greenhouse gas emissions could be lowered by 23% by 2050 from the baseline scenario.

The report concludes that both technology 'push' and emissions trading 'pull' will be required to bring about significant greenhouse gas reductions. However, the emissions trading would have to wait until technology for significantly reducing emissions actually exists.

Table 14: World Carbon Dioxide Emissions by Region

Region/Country	History			Projections			
	1990	2001	2002	2010	2015	2020	2025
	Million metric tons of carbon dioxide						
Mature Market Economies							
North America	5,769	6,624	6,701	7,674	8,204	8,759	9,379
United States a/	4,989	5,692	5,751	6,561	6,988	7,461	7,981
Canada	473	573	588	681	726	757	807
Mexico	308	359	363	432	490	541	591
Western Europe	3,413	3,585	3,549	3,674	3,761	3,812	3,952
Mature Market Asia	1,284	1,610	1,627	1,731	1,780	1,822	1,852
Japan	990	1,182	1,179	1,211	1,232	1,240	1,242
Australia/New Zealand	294	429	448	520	548	582	610
Total Mature Market	10,465	11,819	11,877	13,080	13,745	14,392	15,183
Transitional Economies							
Former Soviet Union	3,798	2,393	2,399	2,804	3,040	3,201	3,379
Russia	2,347	1,553	1,522	1,732	1,857	1,971	2,063
Other FSU	1,452	840	877	1,072	1,183	1,230	1,317
Eastern Europe	1,095	744	726	839	898	951	1,006
Total Transitional	4,894	3,137	3,124	3,643	3,937	4,151	4,386
Emerging Economies							
Emerging Asia	3,890	5,967	6,205	9,306	10,863	12,263	13,540
China	2,262	3,176	3,322	5,536	6,506	7,373	8,133
India	583	1,009	1,025	1,369	1,581	1,786	1,994
South Korea	234	431	451	549	623	676	723
Other Asia	811	1,351	1,407	1,853	2,154	2,428	2,689
Middle East	845	1,311	1,361	1,761	1,975	2,163	2,352
Africa	655	840	854	1,122	1,283	1,415	1,524
Central and South America	711	998	988	1,289	1,480	1,639	1,806
Brazil	250	343	342	433	502	583	679
Other Central/South America	461	655	646	856	979	1,056	1,128
Total Emerging	6,101	9,116	9,408	13,478	15,602	17,480	19,222
Total World	**21,460**	**24,072**	**24,409**	**30,201**	**33,284**	**36,023**	**38,790**

Source: US Department of Energy, Energy Information Administration

G. Survey of Corporate Sustainable Development and Environmental Stewardship Policies – Selected Companies

1. Introduction

- While many public institutions have taken the lead regarding the advancement of environmental initiatives, many private sector firms have made headlines recently by adopting and engaging in “green” oriented practices. This section explores how and what these companies are doing to become the new breed of conservationists in pin stripe suits. It should be noted that this section details four companies and their green initiatives: General Electric, Toyota, Whole Foods and Johnson & Johnson, also within the Appendix there are additional company overviews.

- The five broad reasons why a company would enter into a green initiative are environmental regulations, cheaper electricity, public relations, the company is in the environmental field, and the company is owned by an individual who is willing to sacrifice short-term profits for some type of longer term benefits.

- The best example of an environmental regulation is minivans that can run on ethanol. Since minivans that can run on ethanol are not counted in the national fuel mileage standard, car companies are able to produce more vehicles that are larger and more profitable than the smaller gas efficient vehicles.

- Several manufacturing and utility companies know the environmental regulations are going to force a change in their operations. In order to meet the existing regulations, the companies must act now. By being part of EPA programs the company is able to get credit for the antipollution steps that have been taken.

- In several locations in the US, the impact of higher fossil fuel costs and the availability of a cheaper local renewable energy source have led companies to expand into new renewable energy inputs. In Austin TX, many local operations of a national company will be green to save money.

- High-end specialty companies view green initiatives as a way to cement their relationship with their customers. Whole Foods Market customers are higher income individuals who believe in green policies and are willing to pay more money for goods. Expensive coffee shops have customers that greatly appreciate environmental friendly policies.

- As the amount of money in the environmental sector field grows, there are more companies that are obligated to support green causes. The commercials for hybrid vehicles during the Super Bowl are an example of a traditional industry being pulled into the environmental sector. Previously, the new environmentally friendly vehicles were viewed by the industry as “concept cars” produced for a niche market. Now, automobile manufacturers are beginning to view environmentally friendly vehicles, such as hybrids, as a real opportunity to make money.

- The general method for a company to enter into a green initiative is to form a government / company partnership. A government / company policy is the easiest way for a company to participate in a green initiative because the criteria is defined and independently monitored. Developing a comprehensive green program for a single company is difficult to define, implement, verify, and enforce. For this reason, the EPA programs where companies are partners must be reviewed. Most companies will join EPA programs for the reasons stated earlier.

2. Green Power Partnership

- Green Power Partnership is an arrangement between the Environmental Protection Agency (EPA) and organizations to promote the use of renewable fuels for electricity consumption. The Green Power Partnership is a voluntary Partnership between the US Environmental Protection Agency (EPA) and organizations that are interested in buying green power. Through this program, the EPA supports organizations that are buying or planning to buy green power. As a Green Power Partner, an organization pledges to replace a portion of its electricity consumption with green power within a year of joining the Partnership. The EPA offers credible benchmarks for green power purchases, market information, and opportunities for recognition and promotion of leading purchasers.

- The Top 25 Partners are Partners whose annual green power purchase is the largest, and whose green power purchase has been completed. Their actions are increasing demand for new renewable energy sources for electricity generation, which in turn should result in more renewable energy electricity generation plants. Combined, their purchases amount to 3.3 million megawatt-hours (MWH) annually, which is approximately 75 percent of the green power commitments made by all Partners. For the Partners, the EPA will monitor the Green Power Partnership.

- Table 15 is a list of the Top 10 Retail Partners in the Green Power Partnership. These Partners have the largest completed annual green power purchases of all Partners within this sector. Their purchases are helping to drive the development of new renewable energy sources. Combined, these leaders' purchases amount to almost 878,000 megawatt-hours (MWH) annually, which is equivalent to the power required by more than 82,000 homes every year.

Table 15: Top 10 Corporate Renewable Energy Consumers

Green Power Usage (MWH)	% of Total Electricity	Resources	Provider
1. Whole Foods Market			
463,128	100%	Biomass, Geothermal, Hydro, Solar, Wind	Austin Energy, Community Energy, PNM, Renewable Choice Energy, Sky Energy
2. Starbucks			
150,000	20%	Wind	3 Phases
3. Safeway Inc.			
87,000	2%	Wind	3 Phases
4. Staples			
49,457	10%	Biogas, Biomass, Solar, Wind	Avista Utilities, Pacificorp, Portland General Electric, Sterling Planet, Tennessee Valley Authority
5. FedEx Kinko's			
40,600	15%	Various	Various
6. HEB Grocery Company/Austin Region Operations			
27,600	26%	Biogas, Wind	Austin Energy
7. Liz Claiborne, Inc./NJ Corporate Headquarters			
25,000	100%	Wind	3 Phases
8. prAna			
16,500	100%	Wind	3 Phases
9. Lowe's Home Centers in NC, NM, SC, TN, TX			
16,473	4%	Biogas, Solar, Wind	GT Energy, NC GreenPower, Palmetto Electric Co-op, PNM, Santee Cooper, Tennessee Valley Authority
10. Shaw's Supermarkets in Rhode Island			
2,000	6%	Biogas, Solar	Sun Power Electric

Sources: World Resources Institute, U.S. Environmental Protection Agency

3. EPA's Combined Heat and Power Partnership

- Combined Heat and Power (CHP) is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. By installing a CHP system designed to meet the thermal and electrical base loads of a facility, CHP can increase operational efficiency and decrease energy costs, while reducing emissions of greenhouse gases that contribute to the risks of climate change.

- The CHP Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. The Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new projects and promote their energy, environmental, and economic benefits.

- The goal of the 175 partners is to reduce the environmental impact of power generation by building cooperative relationships with the CHP industry, state and local governments, and other stakeholders to expand the use of CHP. The Partnership assisted over 160 projects representing 3460 Megawatts of new CHP capacity. On an annual basis, these projects will prevent the emissions of over 2.5 million metric tons of carbon dioxide equivalent. This is equivalent to the annual emissions of over 1.6 million cars, or the sequestration from over 2.5 million acres of forest.

- Industry Partners includes facilities in the industrial, commercial, district energy, and institutional sectors, as well as project developers and equipment suppliers.

- State and Local Partners include state, local, and tribal energy, environmental and economic development agencies.

4. Climate Leaders

- Climate Leaders is an EPA industry-government partnership that works with companies to develop long-term comprehensive climate change strategies. Partners set a corporate-wide greenhouse gas (GHG) reduction goal and inventory their emissions to measure progress. By reporting inventory data to EPA, Partners create a lasting record of their accomplishments. Partners also identify themselves as corporate environmental leaders and strategically position themselves as climate change policy continues to unfold.

- Climate Leaders Partners come from a variety of sectors, from heavy manufacturing to banking and retail. These companies all strive to set the standard for GHG management. Table 16 is a list of companies that have committed to lowering the level of greenhouse gasses produced by the company.

Table 16: List of Companies That Are Reducing Green House Gasses

Name	Industry	Name	Industry
3M	Manufacturing	IBM Corporation	Hardware Manufacturing
Advanced Micro Devices, Inc.	Semiconductor	Interface, Inc.	Manufacturing
American Electric Power	Utilities	International Paper	Manufacturing
Ball Corporation	Manufacturing	Johnson & Johnson	Pharmaceutical
Baltimore Aircoil Company	Manufacturing	Lockheed Martin Corporation	Engineering
Bank of America Corporation	Financial Services	Mack Trucks, Inc.	Automotive
Baxter International Inc.	Health Services	Marriott International, Inc.	Hotel Services
Calpine	Utilities	Melaver, Inc.	Real Estate
Caterpillar Inc.	Manufacturing	Miller Brewing Company	Manufacturing
Cinergy Corp.	Utilities	National Renewable Energy Laboratory	Federal Government
Eastman Kodak Company	Manufacturing	Oracle Corporation	Software Manufacturing
EMC Corporation	Software Manufacturing	Pfizer Inc.	Pharmaceutical
Exelon Corporation	Utilities	PSEG	Utilities
First Environment, Inc.	Consulting	Roche Group U.S. Affiliates	Health Services
FPL Group, Inc.	Utilities	SC Johnson	Retail
Frito-Lay, Inc.	Food Services	Shaklee Corporation	Manufacturing
GAP Inc.	Retail	St. Lawrence Cement	Manufacturing
General Electric Company	Manufacturing	Staples, Inc.	Retail
General Motors Corporation	Automotive	STMicroelectronics	Semiconductor
Green Mountain Energy Company	Utilities	Sun Microsystems, Inc.	Software Manufacturing
Hasbro, Inc.	Marketing	The Collins Companies	Manufacturing
Haworth, Inc.	Manufacturing	United Technologies Corporation	Manufacturing
Holcim (US) Inc.	Manufacturing	Volvo Trucks North America, Inc.	Automotive
		Xerox Corporation	Hardware Manufacturing

Source: EPA

5. Energy Star

- ENERGY STAR is a government/industry partnership that offers businesses and consumers energy-efficient solutions, with the objective being to save money while protecting the environment for future generations.

- In 1992 the US Environmental Protection Agency (EPA) introduced ENERGY STAR as a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. Computers and monitors were the first labeled products. Through 1995, EPA expanded the label to additional office equipment products and residential heating and cooling equipment. In 1996, EPA partnered with the US Department of Energy for particular product categories. The ENERGY STAR label is now on major appliances, office equipment, lighting, home electronics, and more. EPA has also extended the label to cover new homes and commercial and industrial buildings.

- Through its partnerships with more than 8,000 private and public sector organizations, ENERGY STAR delivers the technical information and tools that organizations and consumers need to choose energy-efficient solutions and best management practices. ENERGY STAR claims to have successfully delivered energy and cost savings across the country, saving businesses, organizations, and consumers about $10 billion in 2004 alone. Over the past decade, ENERGY STAR has been a driving force behind the more widespread use of such technological innovations as LED traffic lights, efficient fluorescent lighting, power management systems for office equipment, and low standby energy use.

- ENERGY STAR provides a trustworthy label on over 40 product categories (and thousands of models) for the home and office. These products deliver the same or better performance as comparable models while using less energy and saving money. ENERGY STAR also provides home and building assessment tools so that homeowners and building managers can start down the path to greater efficiency and cost savings.

6. The Natural Gas STAR Program

- The Natural Gas STAR Program is a flexible, voluntary partnership between EPA and the oil and natural gas industry. Through the Program, EPA works with companies that produce, process, and transmit and distribute natural gas to identify and promote the implementation of cost-effective technologies and practices to reduce emissions of methane, a potent greenhouse gas.

- EPA and the natural gas industry hope to protect the environment and improving profitability. Participation in Natural Gas STAR cuts across all of the major industry sectors, including gas production, processing, transmission and distribution. As of 2004, the 110 companies participating in Natural Gas STAR represent nearly 70% of the natural gas industry in the US.

- Since the Program began in 1993, Natural Gas STAR partners have eliminated 338 billion cubic feet (Bcf) of methane emissions through the implementation of the Program's core Best Management Practices (BMPs), as well other activities identified by partner companies (referred to as Partner Reported Opportunities - or PROs) (see chart below). This is the equivalent of removing more than 30 million cars from the road for one year or planting more than 41 million acres of trees. At the same time, these companies have saved over a $1 billion by keeping more gas in their systems for sale in the market.

7. Overview of Corporate Initiatives and Case Studies

- This section describes companies that have done the best job of cutting GHG according to Climate Group. Climate Group, and a panel of judges compiled this ranking based on total reduction of GHG, results relative to company revenues, and management's leadership on environmental issues over the past ten years.

Table 17: Top 10 Companies in Reducing Greenhouse Gases (10 Year)

Company	2004 Sales $ Billions	Metric Tons	% Reduction
1 DuPont	$27.5	65 million	72
Reduced energy consumption 7% below 1990 levels, saving more than $2 billion -- including at least $10 million a year by using renewable sources			
2 BP	$285.1	12.8 million	10
Reached its 2010 GHG reduction target in 2001. Increased valuation by $650 million through improvements in operating efficiency and energy management			
3 Bayer	$36.7	4.9 million	63
Boosting energy efficiency also avoided $850 million in investments that otherwise would have been required, because production grew 22%			
4 BT	$18.5	1.6 million	71
Low-carbon and renewable sources provide 98% of its electricity in Britain, saving $1.1 billion. Adding 38% reduction in vehicle emissions almost doubles savings			
5 Alcoa	$23.5	8.9 million	26
Slashed emissions of perfluorocarbon (PFC) gas from aluminum smelters by 80%. Expects annual cost savings to reach $100 million next year			
6 IBM	$96.3	1.7 million	38
Tonnage cuts are from just higher energy efficiency. The reduction triples if other CO2 and PFC cleaning-solvent emissions are included. Total savings: $791 million			
7 Catalyst Paper	$1.9	280,000	61
Substantially lower CO2 emissions stem from efficiency initiatives that have netted savings of more than $17 million over the past 10 years			
8 STMicroelectronics	$9.5	850,000	50
Since 1994, CO2 emissions have been progressively curtailed with better energy practices. Efficiency savings now exceed $100 million a year			
9 3M	$20.0	1.85 million	12.8
By cutting energy consumption, 3M has saved more than $190 million since 1990			
10 Iberdrola	$12.0	3.9 million	n.a.
Tonnage was avoided with renewable fuels, but total emissions grew in 2004. Biomass investments -- $12.7 billion since 2001 -- will yield 5,500 megawatts in 2008			

Source: Climate Group, Innovate, Panel of Judges, BW

Table 18: Top 10 Companies for a Single Year

Rank	Entity	2004 Sales $ Billions	1-Year Cut in GHGs (Tons of CO2e)	1-Year % Cut in GHGs
1	Johnson & Johnson	$47.30	140,091	14.85%

Johnson & Johnson's greenhouse gas reduction program includes on-site renewable energy projects using solar panels and windmills, purchasing green energy, and carbon capture and storage. J&J is No.2 in photovoltaics installations in the U.S., according to the World Resources Institute

2	IBM	$96.30	257,716	10.70%

By installing high-efficiency lighting and variable frequency drives on pumps and motors, IBM has lowered its emissions by 10%

3	UBS	$59.70	27,596	10.50%

In 2004, 26% of UBS's electricity came from renewable sources and direct heating. Other contributors are lighting and cooling controls with sensors that detect the presence of people, as well as variable-speed pumps and drives

4	Unilever	$48.40	362,306	10.20%

Since 1997, Unilever has set annual greenhouse gas reduction targets. They are part of a company-wide conservation program that not only promotes renewable resources but also calls for refrigerants that don't emit chlorofluorocarbons, a potent GHG

5	Credit Suisse Group	$58.80	40,850	9.75%

The world's first bank to implement an environmental management system, Credit Suisse has reduced emissions by relying on movement-sensitive lighting, solar power, and general energy conservation

6	Diageo	$11.90	74,443	9.50%

The spirits company has lowered emissions by capturing and storing the methane released in the distilling process, and using low-emission refrigeration technologies

7	International Paper	$25.50	900,000	6.50%

International Paper cut its carbon footprint by boosting the use of its own forest waste as a fuel. Because trees convert carbon dioxide to oxygen, burning waste wood is considered to be carbon neutral

8	Sony	$64.20	91,251	4.40%

Despite the price premium, Sony signed on with Japan's National Energy Co. for lots of wind power -- 4.5 million kilowatt-hours a year

9	Entergy	$10.10	1,138,400	3.20%

Entergy is a pioneer in GHG reduction. Aside from generating power with nuclear plants and wind turbines, it minimizes CO2 emissions from its natural-gas-fired generators by capturing the gas for underground sequestration at a number of sites

10	Novartis	$30.70	13,800	3.00%

Novartis has improved its overall energy efficiency through the use of renewable energy sources, including biomass, along with an emphasis on energy conservation

Data: Climate Group, Innovest, Panel of Judges, BW

a) General Electric

- Historically, General Electric (GE) has been focused on its fossil fuel power plants or nuclear energy. GE's interest in nuclear power was driven by defense contracts and had nothing to do with the environment. Ecomagination is a huge reversal concerning the environment. So far, the environmentalist view it as "green wash", a public ploy to confuse the public about the true nature of its business, and GE's industrial customers are fearful ecomagination will increase public pressure to change its operations. The fears from traditional industrial companies are not unfounded. If CEO Jeffery Immelt is correct and "green is green", then they will have to follow in one form or another. Likewise, if Mr. Immelt is wrong, the damage done to GE will be significant and might destroy a needed partner.

- In ecomagination, GE is committing itself to more than double its research investment in cleaner technologies, from $700 million in 2004 to $1.5 billion in 2010; introduce more clean-tech products annually, doubling its current $10 billion in annual revenues from ecomagination products and services to at least $20 billion by 2010. In addition, GE has joined the EPA Climate Leaders program and pledged to improve its own environmental performance by reducing its greenhouse gas emissions (GHG) 1% by 2012. Without any action, GE claims its emissions would have risen 40% by 2012. GE promises to cut the intensity of its GHG emissions by 30% by 2008. Intensity is the amount of GHG emitted in terms of its economic activity. By comparison, the UN's Kyoto Protocol calls for Europe to reduce its GHG emissions by 2012 to 8% below the 1990 level.

- What's driving GE to do this? It's a huge business opportunity. The profits being realized by green operations, such as an ethanol plant, are extremely impressive. The global markets for wind power, solar power, and fuel cells are forecasted to grow from $16 billion to $100 billion by 2015. In addition, clean-water technologies are expected to be a $35 billion market by 2007 and the energy efficiency technologies are considered to be the largest opportunity. CEO Jeffery Immelt thinks by viewing the environment as a no-win situation companies are hurting themselves. By embracing the realities of the environmental situation, companies can invest in creating new markets for cleaner fuels and technologies.

- Everybody does not agree that some of the technologies GE classifies as "clean" are really "clean". For example, GE manufactures nuclear power plants, which are very clean but not part of its ecomagination goals and "cleaner coal" technologies, which is a vital part of its ecomagination goals. Critics can disagree on the different technologies but GE's goal is to aggressively pursue all the technologies.

- Like BP and Dupont, GE has made a strategic move to make environmental technologies a priority. Ecomagination is GE's venture into creating new revenue streams. Obliviously, GE's success level in creating these new revenue streams will determine how sustainable ecomagination is within the company. CEO Immelt is totally committed to ecomagination. Immelt has staked his professional reputation on ecomagination. For any environmental initiative, having upper management committed to the process is extremely important.

- Ecomagination combines strategy with goals and timetables. Often times, a program will have either the strategy or the goals and timetables, as with any project, without both the program will likely fail. GE has signaled its intention to be an environmental and clean-technology leader, and knows how they plan to achieve their goal.

- GE has identified 17 products (ranging from renewable energy and hydrogen fuel cells, to water filtration and purification systems, to cleaner aircraft and locomotive engines) representing about $10 billion in annual sales as part of the ecomagination platform on which it plans to build. GE benchmarked its products to the competitions best products, regulatory standards, and historical performance. For each ecomagination product, GE created an extensive "scorecard" quantifying the product's environmental attributes, impacts, and benefits relative to comparable products. The scorecards were used to create the ecomagination brand.

- The ecomagination brand will be integrated into its marketing efforts. This has a high risk because if the claims are not met, it can become a public relations nightmare. GE's leaders are willing to take the risk because they're making specific claims they are confident they can confirm. In addition, ecomagination is not a short-term proposition, but a long-term commitment. GE's goal is for ecomagination to become part of its corporate identity.

- GE's new position on climate change is very significant. Many of the coal burning utilities are opposed to any new regulations on GHG. By proclaiming global warming is real and calling for the US government to take action, could cause a serious backlash from its traditional client base. On the other hand, if the US government enacts stricter GHG regulations, which would provide a real opportunity for a company that is positioned to exploit the situation. In addition, ecomagination puts real pressure on utilities to change. Since GE sells the infrastructure, change is profitable. American Electric Power (AEP), the largest coal user in the world, opposes GHG regulations but after ecomagination was announced, agreed to a joint venture to test a clean coal technology that GE is pioneering. AEP testing the clean coal technology is in-turn forcing smaller utilities to make decisions. Furthermore, if GHG regulations are enacted within the next 5 years, GE's profits from its wind-turbine business and nuclear business could greatly increased. Although the reasons for the environmental policy shift seem smart, it is always a risky proposition to upset your client base.

- The five largest problems facing ecomagination are possible lower energy prices, slow adoption rates in the energy sector, no new environmental regulations, low profit margins and a GE's workforce that changes slowly.

- High-energy prices spur investment in alternative energies and traditional fossil fuels. Any major technological breakthrough in fossil fuel recovery could send the price of petroleum back to historical lows. High-energy prices in the early 1980's resulted in a huge breakthrough in petroleum drilling. This resulted in alternative energies getting crushed by low petroleum prices.

- Refineries and coal plants last for 40 or 50 years. Change comes slowly in the energy sector because it is very difficult to compete on price with a baseline coal utility and since the population located near the plant is dependent on it for cheap power, the plant will be grandfathered or exempted from many of the regulations. In addition, even if the utility is out of compliance, no politician will close the plant if it will result in blackouts or brownouts. For example, in 1999, the Environmental Protection Agency sued Cinergy after it refused to fit some of its older plants with "scrubbers" that remove sulfur dioxide and ozone. In 2000, Cinergy agreed to pay $1.4 billion and make necessary upgrades. But since Bush took office in 2001, the settlement has fallen by the wayside. Cinergy hasn't paid the money, and not all of the agreed-to improvements have yet taken place. "In general, Cinergy's stance has been to resist letting the EPA push cleanup programs to their limit," says Ken Waltzer, a Clean Air Strategy Specialist with the Ohio Environmental Council. Another example is GE's reluctance to clean the Hudson River of PCPs. Major policy initiatives like GHG regulations take a long time to be fully enacted.

- Like any manufactured product, countries such as China and India will quickly enter into businesses that have high profits. So, although the profits might be large for a short period of time, economics will work and lower the profit margins.

- The biggest challenge for ecomagination is GE's workforce. Mr. Walsh, the previous CEO, thrived on the "Six Sigma", which is why GE managers are extremely good at delivering exactly what, is ordered. The "Six Sigma" is a statistically based quality control program. GE is famous for its emphasis on execution and desire for change. Change hurt productivity and increased the chance the wrong product would be delivered. The goal is to produce the right product at the lowest possible price. Innovations require freethinking and new approaches. For employees who have spent their entire professional career under the "Six Sigma", being innovative does not come naturally.

b) Whole Foods Market Inc.

- Whole Foods is the biggest corporate user of wind power in the country. Whole Foods will buy 458,000 megawatt-hours of the wind energy credits from Boulder, Colo.-based Renewable Choice Energy Inc., which is enough wind power credits to cover energy use at all of its US stores, bakeries, distribution centers, regional offices and its Austin headquarters.

- Whole Foods Market sets itself apart from others in the grocery industry with its fervent dedication to its mission: “Whole Foods, Whole People, Whole Planet”. Whole Foods Market's core values reflect its care and concern for the environment. A key aspect of its mission is to be a leader in environmental stewardship. The nation's leading natural and organic supermarket has an ongoing commitment to green power. Currently, Whole Foods Market is purchasing or generating 100 percent of its total national power load from green power sources. Whole Foods reason for going green is to improve public relations with their customers. Andrew Aulisi, senior associate at the nonprofit World Resources Institute said, "For a company like Whole Foods, which has a particular kind of clientele, I can imagine this is an important way they relate to their customers."

- Whole Foods Market's strategy to invest in green power is based on decisions made at the store or regional level. The regional-based decisions empower Whole Foods Market's team members to make decisions locally for their own stores or regions and also stay in tune with the environment of each particular community served by Whole Foods Market. Publicity of Whole Foods Market green power purchases has been undertaken at the regional level. For example, in Colorado and New Mexico, Whole Foods Market's commitment has included in-store educational information about wind energy.

c) Toyota

- Toyota Motor Sales was a 2001 and 2003 Green Power Leadership Award winner. From its first large green power purchase (40,000 MWh/year) in 1998 to installing one of the world’s largest commercial solar rooftop electric systems, Toyota demonstrates a firm commitment to environmental stewardship and energy improvement. Toyota’s 536 kW solar rooftop system, completed in February 2003, shows Toyota’s initiative in improving the environment as well as company operations. The system was installed on site at the company’s headquarters in Torrance, California, on the world’s largest Gold-certified Leadership in Energy and Environmental Design (LEED) project and is part of the company's larger 17-state strategy to use renewable energy at all its facilities. Toyota’s Earth Charter guidelines, established in 1992, direct the company to reduce its impact on the environment in every aspect of its business. Toyota’s photovoltaic (PV) system consists of five arrays, one on each of the five buildings of the new headquarters campus. The system generates enough electricity for approximately 20 percent of the needs of the campus.

- Toyota has had great success with its Prius gasoline/electric hybrid. Toyota has sold over 400,000 of these fuel-sippers and is now expanding its hybrid lineup by at least 10 other vehicles.

- Less well known are Toyota's efforts to reduce emissions from smokestacks as well as tailpipes. In the past 15 years, Toyota has cut its carbon-dioxide emissions in Japan to 1.78 million tons annually, from 2.12 million tons, while globally; C02 emissions per car produced are down 15% since 2002.

- This year, it announced that it plans to cut emissions per unit worldwide by 20% from 2001 levels by 2010. "We're very much focused on energy efficiency and global warming," says Kiyoshi Masuda, senior general manager in Toyota's environmental-affairs division in Tokyo.

- Toyota is way ahead of the targets established in the Kyoto Protocol. The treaty, which was agreed to in 1997 but didn't come into effect until this year, calls for Japan and most other developed countries to cut emissions of CO_2 and other greenhouse gases by an average of 6% from 1990 levels by 2012. In addition, Tokyo has told companies that they must reduce their emissions by 8.6% from 1990 levels. By comparison, Japan's Environment Ministry projects that by the deadline, the country will actually emit 4.8% more greenhouse gases, rather than 6% less.

- By replacing multiple production lines with single lines capable of producing different vehicles, Toyota has decreased energy usage by as much as 40%, Masuda says. Similarly, a welding system that Toyota began rolling out to plants globally in 2003 helped speed up production, cut costs, and also led to a 50% reduction in C02 emissions by using less electricity.

- Toyota's has large profits that are being invested in newer, cleaner factories. By contrast, the latest restructuring plans of General Motors involve reducing capacity but not increasing investment in new production technologies.

- Environmentalist complain that Toyota's hybrids don't have much better fuel economy than regular gasoline engines and that Toyota's fuel economy per vehicle has worsened as the company has increased the proportion of larger vehicles it sells in the US. In addition, Toyota has opposed tougher fuel-mileage standards in the US. Furthermore, while Toyota may be a leader in cutting emissions from production, Toyota's worldwide CO_2 emissions have climbed as Toyota makes more cars. Last year it emitted 6.4 million tons of CO_2 equivalent, up from 5.9 million tons in 2001. Toyota acknowledges that plants in developing markets will continue to spit out more pollutants than those in Japan, Europe, or the US.

d) Johnson & Johnson

- Johnson & Johnson has committed to reduce its carbon dioxide emissions seven percent below 1990 levels by 2010 in its quest to become a corporate leader in addressing the challenge of climate change. To achieve this goal, Johnson & Johnson is investing in green power as an alternative to fossil fuel energy. Johnson & Johnson's green power use in 2004 equaled 18 percent of their worldwide electricity use and included the direct purchases of low-impact hydro and wind power, on-site solar PV, and the purchase of renewable energy certificates from wind power and biomass facilities. Johnson & Johnson believes that the investment in green power not only benefits the environment, but is also a good business decision because it provides the company with a reliable and stable supply of energy. The extraordinary size of the company's green power purchase, along with its willingness to share its experiences, has made Johnson & Johnson a leader in green power procurement.

- The existence of a "core" group of large corporations that are committed to "green" products and policies, coupled with on-going government programs and high-energy prices should create an environment favorable to the development of biomass products and practices. While the companies described in this section are the current visible leaders in this area, it is believed that others, large and small, are soon to follow into this space.

IV. Product/Technology Assessment

A. Introduction

The depletion of oil reserves for fuels and chemicals is occurring at an ever-increasing rate. Failure to discover new and significant oil reserves and the increased energy usage in China and India are major contributors to a projected increase in energy demand during the next decade.[18] The consequence of increased energy demand will result in higher energy costs e.g. oil and natural gas. The location and availability of oil and gas reserves is generally not coincident with the location of the major energy consumers.

The United States Department of Energy (USDOE) and Department of Agriculture (USDA) have identified energy security as a national priority and have established the "Vision for Bioenergy and Biobased Products in the United States" which establishes goals that by 2030 biomass will supply 5% of the nation's power, 20% of the transportation fuels and 25% of the chemicals. These combined goals are approximately equivalent to 30% of the current petroleum consumption.[19]

Recent advances in biotechnology have eliminated many technical hurdles in the translation of lab scale research into production scale commercial ventures. Research that was once slow and expensive has been accelerated through the use of molecular biology, genomics, proteomics and metabolomics. Stability of the biocatalysts has been improved by genetic modification of more robust microorganisms and more finely tuned fermentation processes. Yield of product in aqueous solution has also been improved using advanced molecular biological techniques and the recovery of these products has been enhanced through the development of new aqueous separations systems and solvent extraction.[20,21]

Industrial biotechnology has been projected by the management consulting firm, McKinsey and Company, to be the major driver for growth in the chemical industry from 2000 to 2010.[22] Growth in the chemical industry during that time is expected to be $400 billion, with biotechnology estimated to contribute $280 billion or 70% of the industry's growth. The McKinsey study suggests that growth is expected in all chemical industry sectors: fine, polymers, bulk and specialties where biotechnology is projected to account for upwards of 60% of the share of fine chemicals market; 10-15% of the polymer and bulk chemicals market and as much 50% of the specialty chemical uses. The primary value drivers are new

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product/business opportunities, value added processes, risk reduction, process cost reductions and lower feedstock costs.

B. Fermentation Technology

1. Fermentation Systems

Fermentation is the core process technology for the production of biobased products including ethanol. Fermentation is the use of microorganisms to produce products that are metabolites of the organism's physiological activity. Fermentation processes can usually be classified into three types of systems: 1) batch; 2) fed-batch; and 3) continuous. Batch fermentation is the production of a product in a single stage fermentation where all feedstocks and growth supplements are added in one step prior to the fermentation. This fermentation is inoculated with the desired organism and operated at specified conditions for a specified length of time. Optional control systems may include temperature, pH, and dissolved oxygen. Advantages of this system are: 1) simple, well tested design; 2) easy to operate; and 3) relatively easy to prevent contamination. The disadvantages are: 1) the growth cycle can be inefficient (if product is formed only in one growth phase, others phases do not contribute to the productivity); 2) requires a large volume of prepared medium; and 3) cleaning and sterilization time. Production of ethanol is currently accomplished using batch fermentations. Development of either fed-batch or continuous fermentations could improve the efficiency and productivity of corn to ethanol production where product inhibition could be a problem, especially in high density fermentations with increased starch loading.[23]

Fed-batch fermentations utilize the controlled feeding of a nutrient to precisely control fermentation conditions and the metabolic state of the production organism. This type of fermentation is widely used in biotechnological applications, particularly for recombinant organisms with engineered expression systems that achieve optimal production at low concentrations of a particular nutrient. It is also used when high substrate concentration may be inhibitory, such as in production of the enzyme amylase (high starch concentration increases the medium viscosity and decreases mass transfer rates) or in the production of acetic acid from ethanol.

Continuous fermentations are fed as in fed-batch fermentations; however, unlike fed-batch, cells and spent medium are continuously removed at the same rate of nutrient input. This allows the use of smaller bioreactors than with batch or fed-batch. Downtime is reduced and continuous fermentations yield more uniform product due to the fact that the production organism is kept at the same physiological state during production. This is often referred to as a chemostat fermentation and is also advantageous for studying metabolic behavior under specific conditions (e.g. pH, cell density, substrate concentration, product concentration, specific growth rate, etc.). Chemostat fermentations are often used in the development of production

[23] Taylor, F., et al., 1995. Biotechnol. Prog. 11 (6): 693-698

organisms for improved efficiency.[24,25] Disadvantages of continuous fermentations include: 1) difficulty maintaining sterile conditions; 2) genetic instability of the production organism; 3) cell dilution or washout. Continuous fermentations are not typically suitable for production of recombinant products (potential back mutation to the parent strain) or for the production of metabolites that are produced in stationary phase.

2. Process Metrics

The use of biological methods in industrial processes is not a new concept; such processes have a long history that is overlooked in the current enthusiasm for industrial biotechnology. The brewing, baking, and dairy industries all use biological methods to produce high volume low price, commodity products. Similarly, the production of food and feed ingredients such as amino acids and acidulants are commodity products produced at large volumes using fermentation.

Recently, the tools and methods developed initially for the production of recombinant therapeutics and the elucidation of cellular process (for understanding diseases and identifying drug targets) have been applied to production of commodity fuels and chemicals from biomass feedstock. The difference between the biotechnology industry and the biocommodity (biorefinery) industry is not in the technology, but in its application to problems posed by very different economic forces and requirements of the chemistry of the molecules produced.

The needs of bioprocesses applied to fuels, chemicals and materials are different than those used in the biopharmaceutical industry. The biopharmaceutical industry was created with a focus on therapeutics. These products are expensive to develop and are priced based on market need and the immense risk associated with product development. Efficiencies of scale and manufacturing, cost of starting materials and competition in an established product marketplace are not necessarily primary considerations.

This is completely opposite to the forces affecting commodity manufacturing. Commodities are long established, high-volume products with well-known market requirements with easily measured competition and cost/price considerations. Success in this market requires efficient production processes from low-cost feedstocks. For the commodities industry the technical and economic forces are: [26,27,28]

- Yield – the conversion of feedstock to product on a molecular basis
- Productivity – the optimum use of equipment and avoidance of idle-time
- Downstream processing - best summarized as purity and concentration

[24] Weusthuis, R.A., et al., 1994. Microbiol. Rev. 58(4): 616-630
[25] Rossa, C.A., et al.,. 2002. Metabolic Engineering. 4: 138-150
[26] Lynd, L.R., C.E. Wyman, and T.U. Gerngross. 1999. Biotechnol. Prog. 15: 777-793
[27] Cameron, D.C, and J. Lievense. 2004. Appl. Biochem. Biotech. 113-116: 805-806
[28] Pierce, J. Metab. Eng. V, Squaw Valley, Sept. 2004

While any manufacturing plant will be concerned about these points, they are essential for success in the production of commodities. The price of the final product in the market is well known, and the competition is obvious and easily measured. A further distinction is that pharmaceutical processes are run as single batches. While this is primarily for regulatory reasons, the result has been the development of biotechnology and fermentation batch process. Processes for the production of commodity chemicals are often run as continuous processes, and the adaptation of batch-process biotechnology to continuous production processes remains a challenge.

3. Limitations

Despite the use of molecular biology and microbiology to over-produce protein therapeutics, metabolic engineering (the use of molecular biological tools to manipulate the metabolic processes of an organism) for fuel and chemical production must address very different metabolic issues than pharmaceutically-based biotechnology. Production of recombinant proteins generally requires the cell to produce very large amounts of ATP that is used to run the synthesis of the protein for which a heterologous gene has been inserted. The consideration of metabolic pathways in the fermentation is limited to this single purpose (and possibly the need for post-translational processing, such as glycosylation). The production of small molecules requires consideration of energy efficiency and minimizing the production of ATP to only what the cell needs to live, the redox balance, and carbon flux within the available metabolic pathways. The balance of these concerns with that of the cell's own metabolism is the art of metabolic engineering.[29]

Redox balance is an important chemical design issue, especially when starting from carbohydrates, which are approximately in the middle of the redox range available to carbon. Consider the single carbon atom case; the simplest carbohydrate is formally formaldehyde, CH_2O, while the most reduced form of carbon (as a compound with a single carbon atom) would be methane, CH_4, and the most oxidized form would be carbon dioxide CO_2. If a molecule with a redox potential lower (i.e. more reduced) than that of carbohydrates is desired then some other carbon atoms must undergo oxidation, likely to CO_2. Petroleum is highly reduced relative to carbohydrates. To directly compete with commodity chemicals that are produced from petroleum feedstocks, a net reduction of carbon is required relative to carbohydrates, and this requires the cell to expend energy producing a pool of reducing equivalents rather than ATP, which would be required for synthesis of a recombinant protein. A net de-oxygenation of the carbohydrate starting material is required to reach the equivalent redox potential of hydrocarbon compounds. This is the central chemical issue in producing commodity chemicals from biomass, whether by biological methods or conventional chemical processes.[30] For example, ethanol is more reduced than carbohydrates, so to provide the electron source for the net chemical reduction needed to produce ethanol from carbohydrates, some of the carbohydrate molecules

[29] Sanchez, S., and A.L. Demain. 2002. Enz. Microbial Technol. 2002. 31: 895-906
[30] Schlaf, M. Canadian Chemical News Feb. 2005, 15-17

are oxidized, and the fermentation produces CO_2. This is of particular concern for both biocatalysis (the use of single enzyme reactions) and metabolic engineering, as other cellular mechanisms are required to supply and remove the electrons needed to perform reductions or oxidations.

Adjusting the oxidation state of carbon always adds value in industrial chemistry. It is easy to oxidize in our oxygen atmosphere, so it is not surprising that of the 14 target molecules identified in the USDOE Energy Efficiency and Renewable Energy (EERE) program, eight are more oxidized with respect to carbohydrate redox potential, while six are more reduced .[31] None have the same redox potential as the starting carbohydrate.

4. Traditional Products

The brewing, baking and dairy industries (cheese-making) have employed microbial cultures exclusively for centuries, if not millennia, to make commercially valuable products that cannot be produced by any other method. Similarly, the commercial, large-scale use of fermentation by bacteria and fungi originally isolated from the environment to manufacture therapeutic molecules (that would be prohibitively expensive if produced by classical organic chemistry) has been practiced since the middle of the twentieth century. The beta-lactam antibiotics penicillin and cephalosporin are both produced exclusively by fermentation, with annual global volumes of approximately 50 million kgs and 15 million kgs respectively[32]. Other widely used antibiotics such as tetracycline, erythromycin, and gentamycin are all produced by fermentation and used directly as therapeutics, or as the essential starting material for improved therapeutics. These products are all made by biological processes, which work so well that the bulk pricing of these important medicinal molecules does not allow any non-biological process to compete commercially. For example, the price of Penicillin G is now approximately $10/kg while the price of 6-aminopenicillinic acid (the penicillin nucleus from which all therapeutic penicillins are derived) is currently at $35 to $40/kg.[32] While pharmaceutical examples are of easily recognized value, less appreciated are the fermentation processes for the production of much more basic chemicals; mono-sodium glutamate (approx. 1 billion kgs/yr - $1 billion/yr), citric acid (approx. 1.5 billion kgs/yr, $2 billion/yr), and lysine (approx. 0.75 billion kg/yr, $1.5 billion/yr).

Historically, commodity or industrial biotechnology has been applied to the production of solvents. Microbial acetone production was discovered in 1905 by Shardinger and organisms producing acetone and butanol were isolated independently by Fernbach and Weizmann. Their processes were patented in 1912 and 1915 respectively, and the Weizmann process dominated the industrial production of acetone and butanol until 1936. Between 1945 and 1950, 66% of the n-butanol (over 45 million pounds) and 10% of the acetone in the US were produced

[31] Top Value Added Chemicals from Biomass. Vol 1. 2004. U.S. DOE, EERE

[32] The World Antibiotics Market 2002-2009. 2004. Visiongain; www.visiongain.com

by fermentation of molasses and starch. Other commodity products produced by fermentation in the first half of the 20th century include acetic acid, citric acid, lactic acid, itaconic acid, and dextrans, plus vitamins and antibiotics.[33] Increased prices of the sugar feedstock and decreased prices of petrochemical feedstock ended the fermentive production of these solvents. With the current reversal of these trends, the development of these processes by classical methods continues today.[34]

The following list is an overview of the many types of products produced by microorganisms in fermentation systems.[35]

Products Produced by Microorganisms in Fermentation Systems

- Pharmaceuticals
  - Antibiotics
  - Steroids
  - Human proteins
  - Vaccines
  - Vitamins
- Amino acids and other organic acids
  - Lysine
  - Glutamic acid
  - Gluconic acid
  - Citric acid
  - Itaconic acid
  - Gibberellic acid
  - Lactic acid
- Enzymes
  - Proteases
  - Amylases
  - Cellulases
- Solvents
- Fuels
  - Ethanol
  - Methane
- Food
  - Diary products
    - Buttermilk, Sour Cream, Yogurt, Cheese
  - Fermented meats
  - Bread
  - Beverages
    - Beer & Ale, Wine, Distilled liquors
  - Vinegar

[33] Perlman, L.D., W.E. Brown, and S.B. Lee. 1952. Industrial and Engineering Chemistry. 44(9): 1996-2012
[34] Qureshi, N., and H.P. Blaschek. 2001. Journal of Industrial Microbiology & Biotechnology. 27: 287–291
[35] Atlas, R.M. In: Principles of Microbiology. 1995. Mosby-Year Book, Inc., St. Louis, Missouri

- Fermented Vegetables
  - Sauerkraut
  - Pickles
  - Olives
  - Soy Sauce
  - Tempeh
  - Tofu
  - Natto
  - Poi

C. Biocatalysts

1. Definitions

In the biological production of industrial products biocatalysts are utilized to manufacture products through the use of whole cell microorganisms or specific enzymes derived from microorganisms. The use of microbial cultures to produce wine, cheese, bread and other products has been practiced for centuries. The biochemical pathways utilized by the organism for production of needed metabolites for its own survival is exploited to make products for human use. These biochemical pathways consist of a series of enzymatically catalyzed steps. The use of microorganisms to produce enzymes of specific interest, and the subsequent use of these enzymes to effect conversion of feedstock chemicals to desired products is a modern twist on classic fermentation systems.

2. Production Strains and Strain Improvement

Industrial production strains must be capable of providing consistent production of product over long periods of time. Microbial strains used for the production of industrial products should have the following characteristics:

1) Genetic Stability
2) Limited or no need for vitamins and additional growth factors
3) Efficient production of the target product
4) Known route of biosynthesis of the target product
5) Utilization of a low-cost and readily available carbon source
6) Amenability to genetic manipulation
7) Non-pathogenic and no production of toxic agents
8) Production of limited byproducts to ease subsequent purification

Once a production strain has been selected, a cell banking system is usually established to ensure stability of the strain.

Isolation of naturally occurring strains and the use of classical mutagenesis have been used extensively for the improvement of microbial strains capable of producing compounds of interest.[36] Organisms can be isolated from the environment using a technique known as enrichment. This utilizes isolation conditions that are selective

[36] Steele, D.B. and M.D. Stowers. 1991. Ann. Rev. Microbiol. 45: 89-106

for organisms with the desired metabolic activity. An example is the use of a growth medium that contains only protein as a carbon source, a pH of 10.5, and an incubation temperature of 60^o C to isolate an organism that produces a thermostable protease that functions at high pH. The environmental source may be a highly alkaline hot spring to further increase the chances of isolating the desired organism.

Most natural isolates will not have the desirable characteristics of a production strain listed above; therefore, it is usually necessary to improve the productivity of a natural isolate before it can be used for the economic production of a desired product. Mutagenesis, or the use of a mutagen to effect a change in genotype, has been widely used for strain improvement. Mutagens can cause mutation directly as a result of damaging DNA (pairing errors) and indirectly as a result of errors during the normal DNA repair process. Typical techniques include use of radiation (short and long wavelength ultraviolet, and ionizing gamma radiation) and chemical mutagens (ethidium bromide, mitomycin c, nitrosoguanidine, etc.). Organisms are then screened for the selection of desirable traits.

3. Enzymes

The field of biocatalysis is differentiated from fermentation by the use of isolated, single enzymes in non-physiological conditions to catalyze desired chemical reactions that are unrelated to physiological processes. The application of this field and its acceptance by industry has been pioneered by Jones, Whitesides, Sih, and Yamada in the 1970s and 1980s. The use of isolated enzymes as chemical reagents to perform reactions in otherwise classical chemical processes has been firmly established in the chemical industry and heavily reviewed.[37,38,39,40,41,42] A very useful extension of this field into non-aqueous systems more familiar to industrial chemists was made by Zaks and Klibanov in 1985.[43]
Initially this field was exclusively driven by the ability of enzymes to control chirality (and stereochemistry generally). This in turn was most applicable to molecules with biological activity. Thus, much of the early application of biocatalysis was in the pharmaceutical industry but today is applied more broadly across the chemical industry.[44,45] While most of the applications of enzymes lie in the field of specialty and fine chemical production several examples of very large volume applications of these biological reagents are known.

- Acrylonitrile to Acrylamide: hydrolysis of acrylonitirile by *Rhodococcus* sp. nitrile hydratase at about 5 million kg/yr

[37] Davis, B.G., and V. Boyer, 2001. Nat. Prod. Rep. 18: 618-640
[38] Whitesides, G.M., and C.-H. Wong. 1985. Angew. Chem. Int. Ed Engl. 24: 617-638
[39] Jones, J.B. 1986. Tetrahedron, 42(13): 3351-3403
[40] Chen, C-S., et al., 1982. J. Am. Chem. Soc., 104: 7294-7299
[41] Huisman, G.W. and D. Gray. 2002. Current Opinion in Biotech., 13: 352-358
[42] Bommarius, A.S. and B.R. Riebel. 2004. Biocatalysis, Wiley-VCH, Weinheim, ISBN 3527 30344 8
[43] Zaks, A. and A. M. Klibanov. 1985.Proc. Nat. Acad. Sci., 82: 3192-3196
[44] Zaks, A. and D.R. Dodds. 1998. Current Opinions in Drug Discovery & Development, 1(3): 290-303
[45] Dodds, D.R. and A. Zaks. 1997. Drug Discov. Today, 2(12): 513-531

- High-Fructose Corn Syrup: two-enzyme hydrolysis of starch (debranching with alpha-amylase, hydrolyze dextrins with glucoamylase), followed by a third enzyme step to isomerize glucose to fructose with glucose isomerase
- Penicillin and Cephalosporin: enzymes are used to remove the sidechain of the naturally produced beta-lactam to give the commercial products 6-APA, 7-ACA, and 7-ADCA[46,47,48,49]

Today the production of enzymes as catalysts for a wide range of applications is approximately $2 billion annually. Of recent interest is the large scale effort to develop commercial catalysts for direct application to the biorefinery concept; these are the cellulases and xylanses developed by Novozyme, Genencor and others.[50]

Distribution of Enzyme Use by Industry

o Textile processing	10%
o Grain processing	12% HFCS
o Food processing	18%
o Cleaning	44%
o Cattle feed	4% (cellulase, xylanase, phytase)
o Waste treatment	4%
o Specialty chem	4% (diagnostic, chiral)
o Other	4%

Once the utility of enzymes as individual catalysts was proven in industry, it was logical to extend this to a sequence of reactions. Combined with the capabilities of molecular biology, the concept of constructing reaction pathways by expressing a series of enzymes was the next step.

4. New Technologies

Molecular Biology & Genetic Engineering

The mention of "molecular biology" or "biotechnology" today immediately brings to mind the recombinant protein therapeutics, and historically this technology was first applied to very high valued therapeutic materials that were known (or presumed to be known) targets with utility in healthcare; for example tumor necrosis factor (TNF),[51,52] alpha-interferon,[53] and insulin.[54]

[46] Patel, R.N. 1998. Ann. Rev. Microbiol., 52: 361-95
[47] Tabata, H. 2004. Adv. Biochem. Eng. Biotechnol., 87: 1-23
[48] Pestchanker, L.J., S.C. Roberts, and M.L Shuler. 1996. Enzyme Microb. Technol. 9(4): 256-60
[49] Bringi, V., et al., patent WO97/444476, Phyton, Inc., filed May 27, 1997
[50] Current Opinion in Biotechnology 2002, 13:338–344
[51] Larsen, G.R. US patent 5002887, Genetics Inst. Inc., March 26, 1991
[52] Pennica, D. et al. 1983. Nature 301: 214
[53] Weismann, C. US patent 4530901, Biogen B.V., July 23, 1985
[54] Goeddel, et al. 1979. Proc. Nat. Acad. Sci., 76: 106-110

With the founding of Genentech in 1976, the tools of molecular biology moved from an academic to an industrial setting where they have developed and matured into off-the-shelf items that can be purchased from a catalogue and used immediately. This has greatly reduced the need to "invent a new tool" to perform basic gene manipulation in a large variety of microorganisms. Today, it is not unusual that a microorganism with suitable characteristics for large-scale fermentation can be ordered from a list, the DNA sequence of desired genes can be found in a database and the actual gene synthesized chemically, and the tools for inserting and expressing genes in that organism can all be purchased from a catalog or provided as an over-the-counter contract service. Companies such as InvitroGen, Stratagene, and New England BioLabs, are examples. Further, if a microorganism is found with a desired metabolic activity but that organism has not previously been studied it is now possible to obtain the sequence of the genome in 3 to 4 days within one's own lab.[55] One can also use off-the-shelf software to search and annotate this information, and have not only the desired genes but the entire expression vector synthesized as a fee-for-service after which the completed construct is ready for use in the lab.[56]

The initial application of biotechnology to the chemical industry was analogous to recombinant therapeutics; the use of (now conventional) techniques allowing the heterologous over-expression of enzymes one at a time, plus the ability to perform site-directed mutagenesis in attempts to alter the catalytic activity of the given enzyme. The enzymes expressed could either be isolated and used as discrete reagents, or simply left within the microorganism and the entire biomass used to catalyze the desired chemical reaction. Since the single enzyme of interest is usually so highly over-expressed and composes such a large amount of the cell mass, potential interference of naturally occurring enzymes is not a major practical problem. This may actually be considered an example of "metabolic pathway deconstruction" since the desired single enzyme activity is arranged to overwhelm existing metabolic routes in the cell.

Generally, enzymes such as lipases, esterases, and proteases are isolated as purified or partially purified preparations of the single protein molecule, again using the techniques applied in conventional biotechnology for protein purification. Enzymes that perform redox reactions are more generally used as preparations of intact cells, since the additional cellular components needed to provide or remove electrons during the redox reaction are already present in the cell. Usually in such cases two enzymes are over expressed; one to catalyze the reaction of interest and a second to catalyze the redox reaction of another chemical to provide the corresponding source, or sink, of the electrons. For example, the reduction of a ketone to a secondary alcohol requires the addition of two electrons (a net reduction, provided formally as a full molecule of hydrogen). These electrons (formally as a molecule of hydrogen and most generally termed a "reducing equivalent") are provided by the oxidation of another molecule, preferably a commonly available and

[55] www.454.com
[56] www.ndatwopointo.com

very inexpensive one such as glucose. Glucose dehydrogenase catalyzes the oxidation of glucose to gluconolactone and provides the necessary reducing equivalent through the existing cellular machinery. This allows the over-expressed enzyme to perform the desired redox reaction. Many dehydrogenases are known, and such reaction systems well established industrially.[57,58,59]

The over-expression of heterologous enzymes must also satisfy requirements of yield and productivity in order for the reaction to be of economic utility, and must also satisfy any particular requirements of the downstream processing necessary to isolate the desired reaction product. Here too, the now conventional biotechnology tools of site-directed mutagenesis, for altering and improving specific properties of enzymes, are used. For single enzymes, such properties are:

- Thermal stability and the ability to operate outside the range of normal physiological conditions
- Ability to operate in non-aqueous environments, extremes of pH, or salinity
- Alteration of catalytic activity

It became clear that the expansion of industrial biocatalysis would be driven by the isolation of new enzymes. Classical microbiology, that had been the source for natural products in the pharmaceutical industry, was now pressed into service to find new enzymatic activities. Companies such as Novozymes and Genencor exploited the search for new enzyme activities and have become successful producers of industrial enzymes.

But a problem in the search for new enzymatic activities from microbial sources was “culturing the unculturable”. Microbiologists had realized for many years that simply taking an environmental sample (e.g. a spoonful of dirt) and placing it in an environment rich in nutrients did not produce a population that included members of all of the flora present in the original sample. Many organisms simply resisted the standard techniques of culturing; this was especially true for environmental samples that were being brought back from extreme environments, such as deep sea hydrothermal vents, where it had not previously been thought that any life could exist. Such “exotic” organisms were prime candidates to screen for novel, and presumably useful, enzymatic activities.

A now standard tool of biotechnology, the polymerase chain reaction (PCR) was invented in 1985. PCR allowed the amplification of any existing piece of DNA in a given physical sample.[60] The concept that one did not have to grow the organism in order to gain access to its genes, and the presumably valuable enzymatic activities encoded by these genes, was now realizable by using PCR and related techniques

[57] Homann, M.J., et al., 2004. Tetrahedron, 60: 789-797
[58] Liese, A. 2nd ed. Enzyme Catalysis in Organic Synthesis 2002; Vol. 3. pp 1419–1459
[59] Patel, R.N. 2002. Enzyme Microb. Technol. 31: 804–826
[60] Mullis, K.B., et al., US patent 4683195, Cetus Corp., July 28, 1987

directly on the environmental sample. This made it not only possible but reasonable to assemble very large collections of genes isolated from both unculturable and culturable organisms, express them in conventional biotechnology platforms, and screen them for useful activities. Further, it was possible to generate and screen massive numbers of mutants of these genes by the same techniques. The best known commercial enterprise in this endeavor is Diversa Corporation and the evolution of the names of this company are representative of the evolution of the field itself. Diversa began as Industrial Biocatalysis Inc. in 1992, became Recombinant Biocatalysis in 1995, and then Diversa in 1997. A number of technologies developed and patented by Diversa have essentially made access to enzymes from microorganisms a "solved problem", limited only by the mundane although very real issues of cost and time. The same techniques are directly applicable to the exhaustive generation and screening of mutants produced from the naturally occurring genes.[61,62,63]

The ability to build and manipulate genes allowed the development of other techniques which directly lead to metabolic engineering. One of these is the group of shuffling techniques for the generation of mutants in an adaptive and evolutionary manner.[64,65,66] This provided access to mutant enzymatic activities, and provided a mechanism by which the desired catalytic property actually drove the iterative mutation of the given enzyme until a desired outcome was reached. The commercial utility of this particular technology was recognized and manifested by the establishment of Maxygen, and the application of the technology specifically to the chemical industry rather than the pharmaceutical industry. However, this was still a one enzyme/one reaction endeavor, not the construction of a synthetic pathway that would lead to a given molecule by a series of enzymatic reactions contained entirely within a single cell.

The application of shuffling to a group of enzymes, or even the entire genome of an organism is a form of metabolic pathway engineering.[67,68] This could theoretically create a novel pathway, but it is intended only to improve an organism's existing capabilities. Codexis has a very useful example on their website illustrating how their technology is used to rapidly improve the production of doramectin.[69]

The technologies described above are not an exhaustive review of molecular biology, but they are examples of the commercial applications of molecular biology that makes metabolic engineering practical commercially. In addition to the creation

[61] Short, J.M. US patent 5958672, Diversa Corp., September 28, 1999
[62] Short, J.M. US patent 6057103, Diversa Corp., May 2, 2000
[63] Short, J.M. and M. Keller, US patent 6806048, Diversa Corp., October 19, 2004
[64] Stemmer, W.P.C. 2004. Nature, 389-391
[65] Minshull, J. and W.P.C. Stemmer. 1999. Current Opinion in Chemical Biology, 3: 284-290
[66] Stemmer, W.P.C. US patent 5605793, Affymax Technologies N.V., Feb 25, 1997
[67] Zhang, Y.-X., et al., 2002. Nature, 415: 644-646
[68] Stemmer W.P.C., 2002. Biotechnology and Bioprocess Engineering, 7: 121-129
[69] Stutzman-Engwall K., et al., 2005. Metabolic Engineering, 7: 27-37

of powerful tools, the pursuit of basic cellular physiology and genetics has allowed the establishment of metabolic pathway databases that show the chemical reactions, the enzyme and biological source, and the gene sequence. The collation of physiological pathway data is not new. The pathways of central carbon metabolism, the Krebs Cycle, was proposed by Sir Hans Adolf Krebs in 1937, and acceptance of this pathway formalized by the Nobel Prize in Medicine in 1953. Over the past 50 years, most of the basic metabolic pathways of microbial, plant, and animal cells have been elucidated, and are readily available through internet-based databases. Several websites which are freely accessible and have all of the metabolic pathways annotated are:

- The University of Minnesota Biocatalysis/Biodegradation Database (umbbd.ahc.umn.edu)
- KEGG from Kyoto (www.genome.ad.jp/kegg/kegg2.html)
- ExPASy (www.expasy.org/cgi-bin/search-biochem-index) which presents the Boehringer-Mannheim (now Roche) pathway chart
- The MPW and EMP Databases by Integrated Genomics (igweb.integratedgenomics.com).

This is not an exhaustive listing, but sufficient to make it clear that there is now enough information to rationally plan and construct metabolic pathways to build molecules of commercial interest.

Metabolic flux analysis

The simplest form of metabolic engineering is to block existing metabolic pathways so that certain intermediates accumulate in the cell, or to block branching of a given pathway that normally leads to multiple metabolic products so that only a single product is produced instead. This includes the over-expression of enzymes already present in existing metabolic pathways to remove bottlenecks in the flow of molecules through the pathway.

The most topical example of this work in the biorefinery industry is the manipulation of the metabolism of both bacteria and yeast to enhance ethanol production.[70,71,72] Also in the biorefinery industry is the production of succinic acid, a commodity chemical itself and a replacement for maleic anhydride in multiple industrial processes. Of additional interest today is the work by Professor John Frost to produce shikimic acid, a starting material for the antiviral drug TamiFlu™.[73] In this last example, the existing pathway leading from glucose ultimately to the aromatic amino acids is blocked to force the accumulation of shikimic acid.[74,75]

[70] Ingram, L.O. and M.D.F. Barbosa-Alleyne, US patent 6849434 B2, University of Florida, February 1, 2005
[71] Karhumaa, K. and M-F. Gorwa-Grauslund, patent application WO2005/108552 A1, filed May 4, 2005
[72] Ho, N.W.Y., and G.T. Tsao, US patent 5789210, Prude Research Foundation, August 4, 1998
[73] Bischofberger, N.W. et al., patent EP0976734 B1, Gilead Sciences Inc., September 28, 2005
[74] Frost, J.W., K.M. Frost, and D.R. Knop, US patent 6472169 B1, Michigan State Univ., October 29, 2002
[75] Frost, J.W., K.M. Frost, and D.R. Knop, US patent 6613552 B1, Michigan State Univ., September 2, 2003

The central challenge in the field of metabolic engineering is to use the tools of molecular biology to assemble a series of chemical reactions to produce a molecule that is not made by any existing, naturally occurring metabolic pathways. That is, to perform synthetic organic reactions in series entirely within a microbial cell, and produce a molecule that would normally require an organic chemistry lab. New metabolic pathways that do not exist naturally are now able to be constructed thanks to the various techniques summarized previously. Several examples show the history and breadth of this field.

A useful, novel metabolic pathway can be constructed by the insertion of a single heterologous gene, the activity of which allows an existing metabolic pathway to be diverted. In 1982, Amgen filed a patent for the production of indigo by *E.coli* that involved inserting the gene for naphthalene dioxygenase.[76] In the resulting construct, the indole produced in the naturally occurring pathway for the degradation of tryptophan is oxidized by the naphthalene dioxygenase to produce indigo. In 2002, Genencor published work showing that this pathway could be extended by the addition of a second gene, isatin hydrolase. This allows an intermediate on the indigo pathway to be re-routed to another product, isatic acid.[77]

An early example the construction of a multi-enzyme pathway can be found in the production of therapeutic steroids. As steroids were of tremendous commercial value to the pharmaceutical industry in the 1950s, the cellular physiology surrounding them was well studied, and the metabolic pathways were deduced over the next two decades. The central target in steroid synthesis is hydrocortisone. Decades of work by the pharmaceutical industry, as well as academic labs, produced elegant chemical syntheses. Eventually none could compete commercially with the isolation of steroid precursors coupled with the single biologically catalyzed hydroxylation at the 11-position on the steroid skeleton; a single, essential biological step in a multi-step chemical synthesis.[78]

The commercial value of cortico-steroids remains high and even today extraction of plant materials as a starting point for commercial production is practiced. In 1989, Gist-Brocades filed a patent application in which a novel steroid pathway had been constructed by inserting multiple genes, known to catalyze certain steroid reactions, into a single organism.[79] The result was a microorganism (*Saccharomyces*, *Kluyveromyces*, and *Bacillus* are generally claimed in the patent) that was able to transform cholesterol into hydrocortisone. Five enzymes not normally present in the selected microorganism were assembled and inserted by classical molecular biology. As the chemistry of these multiple transformations involves redox reaction at each step, the attendant proteins for electron transport were also part of the metabolic pathway construction. Taking this a step further, in 2003 Aventis published an improved version of this construct, in which cholesterol (which had to

[76] Ensley, B.D. US patent 4520103, Amgen, May 28, 1985

[77] Chotani, G., et al., 2000. Biochimica et Biophysica Acta, 1543: 434-455

[78] Murray, H.C. and D.H. Peterson, US patent 2602769, Upjohn Co., July 8, 1952

[79] Slijhuis, H., G.C.M. Selten, and E.B. Smaal, patent application 0360361 A1, Gist-Brocades N.V., filed September 25, 1989

be fed to the organism) is replaced by pulling ergosterol out of the microorganism's own pathways (ergosterol is synthesized as part of the cell's membrane requirements). The overall result of this work was a *Saccharomyces cerevisiae* which produced hydrocortisone from glucose.[80,81]

Manipulating the shikimic acid pathway work mentioned earlier, Frost blocked the added genes that diverted the carbon flow from shikimic acid towards protocatechuic acid and then to catechol, a commodity chemical currently produced by the chemical oxidation of phenol.[82] Adding a third gene, a dioxygenase, Frost was further able to transform the catechol to cis, cis-muconic acid[83] which can be hydrogenated chemically to give adipic acid[84], one of the two components in Nylon™ 6,6.

Likely the best known industrial example of metabolic engineering for the production of commodity chemicals from glucose is DuPont's process for the synthesis of 1,3-propanediol (1,3-PDO). This is one of two components for the polyester Sorona™, and DuPont has announced the construction of a fermentation facility in Loudon, TN that will produce 100 million lbs of 1,3-PDO/yr. Formally, only two enzymes are needed to transform glycerol to 1,3-PDO; glycerol dehydratase, and 1,3-propanediol dehydrogenase. Practically however, the engineering is more complicated. A re-activation factor is required to make the dehydratase useful, and since *E.coli* does not produce glycerol metabolically from glucose, two additional genes had to be inserted, and three potential pathway branch points blocked. The resulting *E.coli* construct is reported to be capable of producing 120 g/L 1,3-PDO in the final fermentation broth in 36-40 hours, using only glucose as the carbon source.[85,86]

D. Thermochemical Conversion

While ethanol and biodiesel are established technologies, another approach to biofuels production is the use of thermochemical conversion of biomass to liquid fuels such as di-methyl ether, diesel, methanol and hydrogen. This envisions the modification of existing gas-to-liquids (GTL) processes (Fischer-Tropsch) to create a biomass to liquids (BTL) technology. It is expected that these processes will produce a very clean fuel that is essentially sulfur free and rich in hydrogen for use in fuel cell applications. This approach is being pursued in Europe by companies such as Choren Industries, Daimler-Chrysler and Volkswagen.[87]

The existing gasification industry produces greater than 45,000 megawatts thermal (MW_{th}) of syngas. There are approximately 117 operating gasification plants in 24

[80] Duport, C., et al., 1998. Nature Biotechnology, 16: 186-189
[81] R. Spagnoli, et al., 2003. Nature Biotechnology, 21: 143-149
[82] Frost, J.W. and K.M. Draths, US patent 5629181, Purdue Research Foundation, May 13, 1997
[83] Frost, J.W. and K.M. Draths, US patent 5616496, Purdue Research Foundation, April 1, 1997
[84] Frost, J.W. and K.M. Draths, US patent 5487987, Purdue Research Foundation, January 30, 1996
[85] Laffend, L.A. and C.E. Nakamura, US patent 5686276, E.I. Du Pont de Nemours, November 11, 1997
[86] Emptage, M., et al., European patent application 1586647A1, E.I. du Pont de Nemours, filed August 18, 2000
[87] Multi Year Program Plan 2007-2012. August 31, 2005. Office of the Biomass Program, Energy Efficiency and Renewable Energy; US Department of Energy

countries. The Africa/Middle East region account for over 1/3 of the total output. Coal accounts for 49% of the syngas produced and petroleum 37%. The remaining syngas is produced from natural gas, petcoke and biomass/wastes. Biomass feedstock accounts for approximately 2% of current syngas production. Approximately 37% of the syngas is used to produce chemicals; 36% for Fischer Tropsch fuels; 19% for power; and 8% for gaseous fuels.[88]

Thermochemical conversion uses elevated temperatures to convert biomass to compounds that may be used as fuels or products; in some cases as direct replacements for existing products. Pyrolysis (absence of oxygen), gasification and hydrothermal processing are thermochemical conversion technologies with the potential for conversion of biomass to direct replacements for petroleum-based fuels and chemicals. The difference between pyrolysis and gasification is primarily in the temperature at which each process operates. Pyrolysis takes place at temperatures of 400-650^{o}C and results in the formation of a liquid (pyrolysis oil), while gasification involves temperatures of 650-900^{o}C and results in the formation of the permanent gases (H_2, CO, CO_2, and CH_4). Hydrothermal processing uses organic solvents or water at temperatures of 300-350^{o} C and pressure (2,300 psia) to produce hydrocarbon liquids (aliphatic chains, carboxylic acid groups, ether linkages). Wet gasification is a form of hydrothermal processing that utilizes a catalyst, such as Ni-Ru, to produce methane or hydrogen.

Biomass gasification has the potential to be an important source of heat and electrical production in a biorefinery. Waste streams from other processes can be used as feedstock for thermochemical conversion to improve power efficiencies. Another advantage of thermochemical conversion is that all major components of biomass, including lignin, can be converted to intermediate compounds. Lignin can represent as much as 30% of biomass and is recalcitrant to biological conversion. Once the gaseous products of thermochemical conversion have been cleaned they can be used directly in existing petrochemical facilities to produce fuels and chemicals.

From a technical perspective the conversion of biomass to synthesis gas (syn-gas) is similar to the process currently used for conversion of coal to syngas. Biomass thermochemical conversion will compete directly with coal-syngas as well as products derived from natural gas. Biomass presents unique problems in handling and feeding when compared with petroleum-based materials (i.e. coal). While the processes are similar for both biomass and petroleum-based thermochemical conversion, current processing facilities are too large to be economically feasible for biomass conversion. Other barriers include the geographic distribution of biobased feedstocks when compared to fossil fuel feedstocks and the higher content of particulates and tars in biomass-derived syngas. Analysis indicates that for thermochemical conversion to reach economic feasibility the technology must be integrated into a larger biorefinery.[87] To date, finding a cost-effective all-

[88] Current Industry Perspective: Gasification; 2004 World Survey Results; US Department of Energy/National Energy Technology Laboratory

thermochemical process has proven difficult.[89] Pending development of integrated biorefineries, transition scenarios include the possibility of integrating some level of biomass thermochemical conversion into existing petroleum refineries.

E. Feedstocks

1. Glucose

Glucose can be considered the universal feedstock source for microbial conversion to industrial products. Almost all microorganisms are capable of utilizing this simple six carbon sugar as a carbon source. Glucose is produced commercially via the enzymatic hydrolysis of starch. Many crops can be used as the source of starch. Corn, rice, wheat, potato, cassava, arrowroot, and sago are all used in various parts of the world. In the United States, cornstarch (from maize) is used almost exclusively.

This enzymatic process has two stages. Over the course of 1-2 hours near 100°C, these enzymes hydrolyze starch into smaller carbohydrates containing on average 5-10 glucose units each. Some variations on this process briefly heat the starch mixture to 130°C or hotter one or more times. This heat treatment improves the solubility of starch in water, but deactivates the enzyme, and fresh enzyme must be added to the mixture after each heating.

In the second step, saccharification, the partially hydrolyzed starch is completely hydrolyzed to glucose using the glucoamylase enzyme from the fungus *Aspergillus niger*. Typical reaction conditions are pH 4.0–4.5, 60°C, and a carbohydrate concentration of 30–35% by weight. Under these conditions, starch can be converted to glucose at 96% yield after 1–4 days. Still higher yields can be obtained using more dilute solutions, but this approach requires larger reactors and processing a greater volume of water, and is not generally economical. The resulting glucose solution is then purified by filtration and concentrated in a multiple-effect evaporator. Solid D-glucose is then produced by repeated crystallizations.

2. Starch

Starch is a combination of two polymeric carbohydrates (polysaccharides) called amylose and amylopectin. Amylose is constituted by glucose monomer units joined to one another head-to-tail via alpha-1,4 linkages. Amylopectin differs from amylose in that branching occurs, with an alpha-1,6 linkage every 24-30 glucose monomer units. The overall structure of amylopectin is not that of a linear polysaccharide chain since two glucose units frequently form a branch point, so the result is the coiled molecule most suitable for storage in starch grains. Both amylopectin and amylose are polymers of glucose, and a typical starch polymer chain consists of around 2500 glucose molecules in their varied forms of polymerization. In general,

[89] Badger, P.C. 2002. Ethanol from cellulose: A general review. pp. 17-21. *In*: Trends in New Crops and New Uses. J. Janick and A. Whipkey (eds.), ASHS Press, Alexandria, VA.

starches have the formula $(C6H10O5)_n$, where "n" denotes the total number of glucose monomer units.

Structurally, the starch forms clusters of linked linear polymers, where the alpha-1,4 linked chains form columns of glucose units which branch regularly at the alpha-1,6 links. The relative content of amylose and amylopectin varies between species, and between different cultivars of the same species. For example, high-amylose corn (maize) has starch consisting of about 85% amylose, which is the linear constituent of starch, while waxy corn starch is more than 99% amylopectin, or branched starch. The primary function of starch in plants is to act as an energy storage molecule for the organism.

Starches are insoluble in water. They can be digested by hydrolysis, catalyzed by enzymes called amylases, which can break the glycosidic bonds in the alpha-1,4 linkages of the starch polysaccharide. Hydrolysis of starches consists of the process of the cleavage of the starch molecules back into their constituent simple sugar units by the action of the amylases. The resulting sugars are then processed by further enzymes (such as maltase) in the body, in the same manner as other sugars in the diet. A second enzyme, glucoamylase, catalyzes the hydrolysis of the 1,6-linkages.

3. Cellulose: Definition and Availability

Cellulose is a common material in plant cell walls and was first noted as such in 1838. It occurs naturally in almost pure form only in cotton fiber. In combination with lignin and hemicellulose, it is found in all plant material. Cellulose is the most abundant form of terrestrial biomass.[90] Some animals, particularly ruminants and termites, can digest cellulose with the help of symbiotic microorganisms. Cellulose is processed to make cellophane and rayon, and more recently Modal, a textile derived from beech wood cellulose. Cellulose is the major constituent of paper. Cellulose monomers (beta-glucose) are linked together through ß-1,4 glycosidic bonds by condensation. Cellulose is a straight chain (no coiling occurs). In microfibrils, the multiple hydroxide groups hydrogen bond with each other, holding the chains firmly together and contributing to their high tensile strength. This strength is important in cell walls, where they are meshed into a carbohydrate matrix, helping keep plants rigid.

Biomass is a very broad term which is used to describe material of recent biological origin that can be used either as a source of energy or for its chemical components. It is derived from numerous sources including trees, crops, algae and other plants, as well as agricultural and forest residues. Materials that are considered as wastes including food and drink manufacturing effluents, sludges, manures, industrial (organic) by-products and municipal solid waste are also considered biomass. The primary components of most plant materials are commonly described as lignocellulosic biomass. The biomass is principally composed of three major compounds; cellulose, hemicellulose, and lignin. Cellulose, the primary component,

[90] Crawford, R. L. (1981). Lignin biodegradation and transformation, John Wiley and Sons, New York. ISBN 0471057436

is an insoluble and unbranched, linear polymer of glucose that is connected with a β-1,4 glycosidic linkage and arranged in bundles. In the plant cell wall, the cellulose molecules are interlinked by another molecule, hemicellulose. The hemicellulose is a branched polymer of glucose or xylose, substituted with arabinose, xylose, galactose, fucose, or glucuronic acid. Unlike cellulose, which is crystalline, strong, and resistant to hydrolysis, hemicellulose has an amorphous structure with little physical strength. Lignin is also present in significant amounts and gives the plant its structural strength. Lignin is essentially a three-dimensional phenylpropane with phenylpropane units held together by ether and carbon-carbon bonds. The extensive cross linking among these components comprise the very rigid cell wall matrix of plants.[91] Table 19 shows the composition of several different lignocellulosic feedstocks. The composition ranges are both species and tissue specific, thus plant selection for feedstock requires prior knowledge of the composition.

Table 19: Composition of different lignocellulosic biomass based on dry weight[92]

Biomass	Cellulose%	Hemicellulose %	Lignin%
Corn stover	37.5	22.4	17.6
Corn Fiber	14.28	16.8	8.4
Pine wood	46.4	8.8	29.4
Poplar	49.9	17.4	18.1
Wheat straw	38.2	21.2	23.4
Switchgrass	31.0	20.4	17.6
Bagasse *	34.57	19.44	20

- MBI unpublished data

Every year approximately 100 billion tons of new plant biomass is produced worldwide.[93,94] This amount of renewable biomass has an energy content roughly 10 times the energy value of all petroleum used worldwide.[95] Feedstock costs are absolutely critical to the economy of commodity chemicals and fuels. Previous studies have shown that raw material cost accounts for 60-70% of commodity manufacturing costs.[96,97] Biomass feedstocks are less expensive than petroleum on both mass and energy bases. Therefore with efficient and economically viable technologies to convert biomass to fuels, chemicals, and other products there is

[91] Tarchevsky, I. A. and G.N. Marchenko . 1991, "Cellulose: Biosynthesis and structure" Springer-Verlag New York, NY, pp 9-31

[92]Mosier N., Wyman Ch., Dale B., Elander R., Lee Y.Y., Holtzapple M., Ladisch M., 2005, "Features of promising technologies for pretreatment of lignocellulosic biomass" Bioresource Technology, 96, pp 673-686

[94] Graboski M. and R. Bain, 1981. *In* Biomass gasification: principles and Technology, T. B. Reed (Ed.), Noyes Data Corporation, USA, pp 41-71

http://www.eia.doe.gov/pub/international/iealf/table18.xls

ample reason to believe that biomass has significant potential to compete with petroleum-derived technologies.

The three major markets envisioned for biomass derived technologies are: fuels, organic chemicals and materials, and electricity. The most promising route to these markets is a biobased industrial biorefinery. The biorefinery concept is similar to conventional petroleum refineries, which produce multiple fuels and products from petroleum.

The USDOE and the USDA jointly conducted research to determine if the land resources of the United States are sufficient to support a large-scale biorefinery industry capable of replacing a significant portion of the US petroleum consumption.[98] Target dates were set at the mid-21st century when large-scale biorefinery industries are likely to exist. This work showed that the combined forest and agriculture land resources are capable of sustainably replacing more than one-third of the nation's current petroleum consumption. The forest resources include logging residues, fuel treatment thinning and fuelwood extracted from forestland. The agricultural resources include grains used for biofuel production, animal manures and residues, and crop residues derived primarily from corn and small grains such as wheat straw. Residues from sugarcane, rice, fruit and nut can also be used.

The summary of this study estimates that agricultural lands can provide nearly 1 billion dry tons of sustainably collectable biomass while continuing to meet food, feed and export demands. This estimate includes timber and forest residues, crop residues, perennial crops, grains used for biofuels, animal manures, process residues, and other residues generated in the consumption food products. The study predicts that this will require increasing yields of corn, wheat, and other small grains by 50 percent, developing much more efficient residue harvesting equipment, growing perennial crops primarily dedicated for bioenergy; and using a larger fraction of other secondary and tertiary residues for bioenergy. It is estimated that this level of biomass production can be achieved in the next 15-20 years.

F. Pretreatments

1. The Need for Pretreatment

The complex structure of lignocellulosic biomass, the crystalline structure of cellulose and the physical protection provided by hemicellulose and lignin, prevent efficient hydrolysis and subsequent release of fermentable sugars by hydrolytic enzymes. Therefore, pretreatment is required to alter the structure of cellulosic biomass. In general, an effective pretreatment enhances the susceptibility of biomass to enzymatic hydrolysis by disruption or removal of barriers such as lignin

[98] United States Department of Energy and Department of Agriculture, April 2005, Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a Billion-ton annual supply

and hemicellulose so that more surface area is available for the enzyme; and/or by decreasing the crystallinity of the cellulose structure.

Lignocellulosic biomass treatment can be classified as: 1) physical; 2) chemical; or 3) physiochemical, which incorporates both physical and chemical effects.[99,100] The most common physical treatment is comminution or pulverization which provides a dramatic increase in hydrolysis rate but demands extensive energy, a major drawback for these treatments.[101] Chemical treatments with strong acid or base effectively increase the hydrolysis of cellulose. These chemicals are generally quite corrosive and expensive and are often toxic or inhibitory to microorganisms, requiring the removal of any residue prior to further processing. These treatments, while effective, are often expensive. In physicochemical treatments both physical and chemical aspects are involved. These techniques have the advantage of physical treatment without the expense of high energy use.

2. Examples of Pretreament and their Applicability

Several pretreatment technologies were evaluated by the Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI) group. A team of researchers from Auburn University, Dartmouth College, Michigan State University, The National Renewable Energy Laboratory (NREL), Purdue University and Texas A&M University coordinated this project to develop comparative information on the performance of leading pretreatment techniques. This work was performed by using a single feedstock (corn stover), common analytical methods, and a consistent approach to data interpretation. This evaluation showed that all of the evaluated pretreatment methods have potential as cost-effective technologies.[92,102] The evaluated pretreatments were: dilute sulfuric acid cocurrent, flowthrough pretreatment, pH controlled water treatment, ammonia fiber explosion (AFEX), ammonia recycle percolation (ARP) and lime treatment. Table 20 and Table 21 summarize the favorable processing conditions and the hydrolysis yields of each process in treatment of corn stover, respectively. Table 22 summarizes the major chemical and physical effects of the different biomass pretreatments.

[99] McMillan, J.D., 1994, “Pretreatment of lignocellulosic biomass. *In*: Enzymatic conversion of biomass for fuels production, ACS symposium series, vol. 566. ACS , Himmel, M.E., Baker, J.O., Overend, R.P. (Eds), Washington DC. pp.292-324

[100] Hsu, T.A., 1996, “ Pretreatment of biomass. *In*: Handbook on bioethanol, production and utilization. Wyman C.E. (Ed.), Taylor & Francis, Washington DC

[101] Holtzapple M.T., et al., 1991. Appl. Biochem. Biotech. 28/29: 59-74

[102] Wyman, C.E., et al., 2005. Bioresource Technology 96: 1959-1966

Table 20: Favorable processing conditions for biomass pretreatments[102]

Pretreatment	Chemical used	Temperature, °C	Pressure, atm absolute	Reaction time, min	Concentration of solid, wt%
Dilute sulfuric acid cocurrent	0.5-3% sulfuric acid	130-200	3-15	2-30	10-40
Flowthrough pretreatment	0.0-0.1% sulfuric acid	190-200	20-24	12-24	2-4
pH controlled water pretreatment	water or stillage	160-190	6-14	10-30	5-30
AFEX	100%(1:1) anhydrous ammonia	70-90	15-20	<5	60-90
ARP	10-15 wt% ammonia	150-170	9-17	10-20	15-30
Lime	0.05-0.15g Ca(OH)2/g biomass	70-130	1-6	1-6h	5-20
Lime + air	0.05-0.15g Ca(OH)2/g biomass	25-60	1	2 weeks-2months	10-20

Table 21: Sugar yields for each pretreatment followed by enzyme hydrolysis with 15 FPU/ g glucan in the original corn stover[102]

	Xylose yield			Glucose yield			Total sugar		
Pretreatment	**Stage 1**	**Stage 2**	**Total yields**	**Stage 1**	**Stage 2**	**Total yields**	**Stage 1**	**Stage2**	**Combined (Glucose + xylose) sugars**
Dilute acid	32.1/31.2	3.2	35.3/34.4	3.9	53.2	57.1	36.0/35.1	56.4	92.4/91.5
Flowthrough	36.3/1.7	0.6/0.5	36.9/2.2	4.5/4.4	55.2	59.7/59.6	40.8/6.1	55.8/55.7	96.6/61.8
pH controlled	21.8/0.9	9	30.8/9.9	3.5/0.2	52.9	56.4/53.1	25.3/1.1	61.9	87.2/63.0
AFEX		34.6/29.3	34.6/29.3		59.8	59.8		94.4/89.1	94.4/89.1
ARP	17.8/0	15.5	33.3/15.5	0	56.1	56.1	17.8/0	71.6	89.4/71.6
Lime	9.2/0.3	19.6	28.8/19.9	1.0/0.3	57	58.0/57.3	10.2/0.6	76.6	86.8/77.2

Stage 1 refers to pretreatment and stage 2 to the enzymatic hydrolysis of solids generated after each pretreatment. The first value in each column represents total sugars released into solution and the second is for the monomers. A single value indicates release of only monomers. Yields are defined based on the maximum potential sugars released from the corn stover used of 64.4 g per 100g of dry solids with maximum potential xylose being 37.7% and the maximum potential yield of glucose being 62.3% on this basis.

Table 22: Chemical and physical effects of the different biomass pretreatments on the structure of the biomass[92]

Pretreatment	Increase Surface area	Cellulose crystallinity	Removes hemicellulose	Removes lignin	Alter lignin structure
Steam explosion	++	Increases[103]	++		+
Dilute acid	++	Increases[104]	++		++
Flowthrough acid	++	ND	++	+	++
Flowthrough hot water	++	ND	++	+	+
pH controlled	++	ND	++		ND
AFEX	++	Decreases	+		++
ARP	++	Decreases	+	++	++
Lime	++	ND	+	++	++

++: Major effect

+: Minor effect

ND: Not determined

[103] Tanahashi, M., et al., 1983, Wood Research 69: 36-51

[104] Laureano-Perez, L., et al., 2005. Applied Biochemistry and Biotechnology, 121-124: 1081-1100

Following is a summary of the key features of these treatments with respect to pretreatment of corn stover.

Steam explosion

Steam explosion was not included in the CAFI study, however a great deal of research has been conducted on this treatment[99,100,105] and it is used commercially in the Masonite process for the manufacture of fiberboard and other products.[106] No chemical is involved in this treatment. Biomass is rapidly heated with high pressure steam for a specific amount of time followed by quick release of the pressure. Removing hemicellulose is one of the major effects of this process. This makes the cellulosic portion of biomass more available to cellulose, which subsequently increases the digestibility of the biomass. It has been suggested that acetic acid and other acids released during the pretreatment may be the major cause for hemicellulose removal. Terminating the process with rapid release of pressure disrupts and opens up the cell wall structure of the biomass and increases the accessible surface area, enhancing the digestibility. Due to the high temperature (~235°C) some of the biomass is degraded during the process.

Flowthrough hot water treatment

Flowthrough technologies pass hot water at 180-220°C and 350-400 psig pressure for 12-24 minutes over a stationary bed of biomass. In this process there is no need for additional chemicals or neutralization. With this treatment a significant portion of lignin is removed and the solid left behind is highly digestible. Up to 96% overall sugar yield is achievable, however, the process suffers from low concentration of sugars (due to dilution) and requires significant energy for product recovery.[92]

Acid pretreatment

Dilute sulfuric acid is used commercially to produce furfural from cellulosic materials.[107,108] The US DOE has spent much of the last two decades in developing the dilute acid technology as a pretreatment for lignocellulosic biomass, and at this time is funding major efforts to position this technology in emerging biorefineries. In this process a mixture of biomass and acid is heated indirectly through the reactor vessel walls, or by direct steam injection. The dilute acid is percolated through a bed and sprayed onto the biomass after which the agitated and/or heated in a reactor. Acid pretreatment with dilute sulfuric acid (0.5-3%) at temperatures of 130-200°C, effectively removes hemicellulose, which results in high digestibility of the cellulose present in the residual solids. In this process lignin is not dissolved; however, data suggests that lignin is disrupted, increasing cellulose susceptibility to enzyme[92]. With this treatment up to 90% hemicellulose yields are achieved and enzymatic hydrolysis yields of glucose can be over 90%.[100] Dilute acid treatment has

105 Saddler, J.N., L.P. Ramos, and C. Breuil. 1993. Steam pretreatment of lignocellulosic residues. *In* Bioconversion of forest and agricultural plant wastes. Saddler, J.N. (Ed.), C.A.B. International, Wallingford, UK, pp 73-92

106 DeLong, E.A. 1981. Method of rendering lignin separable form cellulose and hemicellulose in lignocellulosic material and the products so produced. Canadian Patent 1,096,374

107 Root, D.F., et at., 1959. Forest Prod. Journal 9(5): 158-164

108 Zeitsch, K.J. 2000. *In*: The Chemistry and Technology of Furfural and Its Many By-Products, Sugar Series, vol 13, Elsevier, New York.

some limitations including: costly materials of construction, high pressure, neutralization, formation of degradation products, and release of fermentation inhibitors.

Flow-through acid pretreatment
Addition of very dilute sulfuric acid (about 0.07%-0.1% vs the 0.5-3% typical dilute acid technology) in a flow-through reactor is very effective in pretreatment of biomass. Despite achieving high hemicellulose sugar yields and highly digestible cellulose the generated products are very dilute. The large amount of water used in this process results in high energy requirements for pretreatment and product recovery.

Controlled pH pretreatment
Controlled pH pretreatment using potassium hydroxide (KOH) is based on the properties of water under pressure and elevated temperature (160-190°C). Temperature affects the pK_a of water; the pH of pure water at 200° C is almost 5.0.[109] Water with high dielectric constant is able to dissociate ionic substances such as hemicellulose and lignin. One half to two thirds of lignin dissolves from most biomass treated at 220°C for 2min. In this process water under pressure (6-14 atm) penetrates the cell structure of biomass, hydrates cellulose, and removes hemicellulose so that the treated biomass is highly reactive. In this pretreatment KOH is not used as a catalyst in chemical pretreatment; its function is simply to maintain the pH between 5 and 7 to prevent the hydrolysis of monosaccharides.[109]

Lime pretreatment
In lime pretreatment biomass materials are sprayed with a slurry of lime (calcium hydroxide) and water (typical loading of 0.05%-0.15g $Ca(OH)_2$/g biomass) and stored in a pile for a period of days to weeks at temperatures of 25-60°C. Addition of air/oxygen to the reaction mixture (oxidative lime treatment) improves the delignification of the biomass. Removal of lignin (typically 33%), acetyl and various uranic acid substitutions from hemicellulose are the major effects of lime pretreatment, which results in a very reactive biomass. Due to the low process temperature there is no need for a pressure vessel, thus reducing the overall capital cost of this process.[110] The logistics of handling and storage of large amounts of biomass is a major drawback.

Ammonia treatments
Ammonia Fiber Explosion (AFEX) is a physiochemical pretreatment. In AFEX pretreatment biomass is treated with liquid anhydrous ammonia at moderate temperatures (60-100°C) and a pressure of 250-300 psi for 5 min. The pressure is then rapidly released. In this process the combined chemical and physical effects of modifying or altering hemicellulose and lignin structure, cellulose decrystallization, and increased surface area, enables near complete enzymatic conversion of

[109] Weil, J.R., et al., 1998. Appl. Biochem. Biotech. 70/72: 99-111
[110] Eggeman, T. and R.T. Elander. 2005. Bioresource Technology, 96: 2019-2025

cellulose and hemicellulose to fermentable sugars.[111] AFEX can be performed in lower cost vessels compared to acid pretreatment, the hydrolysate is compatible with fermentation organisms without conditioning, ammonia can be recovered and reused and any residual ammonia serves as a nitrogen source for microbial production of products from this feedstock. Efficient ammonia recovery is critical to the economics of this pretreatment. With the use of moderate temperatures and high pH the formation of sugar degradation products is minimal while the sugar yield is high.

Another ammonia process is ammonia recycled percolation (ARP). In this process aqueous ammonia (10-15 wt%) at elevated temperature (150-170°C) passes through biomass and then is then recovered for recycle.[112] ARP is highly effective in delignifying biomass and increasing the enzymatic digestibility. The ARP process removes about 70-85% of lignin. The crystalline structure of cellulose is not altered by the ARP process. This process also suffers from the high energy requirement for pretreatment and product recovery due to the relatively high amount of water used in the process.

G. Products in the Emerging Bioeconomy

The production of industrial and consumer products from biomass is not a new idea. Over $400 billion in products are currently produced from biomass in conventional manufacturing.[113] These products include inorganic and organic chemicals, pharmaceuticals, soaps and detergents, pulp and paper, fuels, lubricants and greases, adhesives and paints. The emerging bioeconomy will drive the production of non-traditional products from biomass, such as fuels, chemicals and materials currently produced from petroleum feedstocks. Prior to 1920 a large proportion of chemicals were alcohols derived from wood and grain. Most polymers were derived from cotton and a majority of the US energy was derived from wood. The introduction of inexpensive and abundant fossil energy displaced this carbohydrate-based economy during the remainder of the twentieth century. With the increasing cost and diminishing supplies of fossil fuels, the economy is set to swing back toward a carbohydrate base.

An example of a new biobased technology that is competing directly with fossil fuel derived products is the installation of a 300 million pound/year plant by Cargill to produce polylactic acid. Other examples are DuPont's 1,3 propanediol (a polymer precursor), Dow Chemical's venture into soy-based polymers for carpet manufacture, and Vertec BioSolvents' production of environmentally friendly solvents from soybeans and corn.

[111] Teymouri F., et al., 2004, Appl. Biochem. Biotech. 113-116: 951-963
[112] Kim, T.H., et al.,. 2003. Bioresource Technology. 90: 39-47
[113] Industrial Bioproducts: Today and Tomorrow; July 2003; Energetics, Inc/US Department of Energy

Estimates of industrial bioproducts produced today in the US utilize approximately 12 billion pounds of biomass/year[113] and fall into four main categories:

- Cellulose derivatives, fibers and plastics
    - Primarily derived from wood pulp and cotton linters; products include cellulose acetate, cellulose nitrate and regenerated cellulose
    - Major producers include: Dow Chemical, Celanese, DuPont

- Oil and lipid-based products
    - Primarily derived from soybean and oilseeds; products include oils, fatty acids, and glycerine.
    - Major producers include: Cambrex, Vertec Biosolvents, AG Environmental Products LLC, West Central Soy, and Lonza

- Sugar and starch products
    - Primarily derived from corn, sugar cane, sugar beets, wheat, rice, potatoes, barley, sorghum grain and wood; products include alcohols, starch, acids, xanthan gum, and industrial enzymes used in laundry detergents, textile sizing as well as production of starch, sugar, alcohols and oils.
    - Major producers include: ADM, Arkenol, Cargill, Minnesota Corn Processors, DuPont, Grain Processing Corporation, Tate & Lyle, Williams Bio-Energy, Genencor, Novozymes

- Gum and wood chemicals
    - Primarily derived from trees; products include resins, tall oil, pitch, fatty acids and turpentine.
    - Major Producers include: Westvaco, Hercules, Norit America, Arizona Chemical, Georgia Pacific, and Akzo Nobel Resins

Conventional uses of biomass to produce products for the food, textile, paper and building materials industries constitutes a $400 billion/year market. Emerging technologies could further expand the market for biobased products into the areas of fuels, chemicals, and materials.

1. Biofuels

An extensive analyses of the ethanol and biodiesel industries is presented beginning on page 110 for the ethanol section and page 130 for the biodiesel section in the following chapter.

2. Chemicals

The USDOE has identified several leading chemicals that can be produced from sugars via chemical or biological conversions[31]. The chemicals are 1,4-diacids (succinic, fumaric and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hjydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol. These chemicals represent building blocks from which numerous high-value, biobased chemicals or materials can be made. The production of such platform chemicals from biomass could offer direct replacement of major chemicals currently produced from petroleum feedstocks.

3. Biobased Materials

During the last five years there have been major advances in the production of biobased polymers. These include Cargill's production of polylactic acid polymers, DuPont's Sorona® polymer precursor, 1,3 propanediol, and Dow Chemical's BIOBALANCE™ soy-based polymer used in carpet manufacture. These bioplastics are useful for many materials; however, they are marginal structural materials. Addition of reinforcing fibers can improve thermal, moisture and mechanical durability. An example of such biocomposite materials is a moldable board material under development by the United States Department of Agriculture Forest Service Laboratory that is composed of 70-80% wood flour combined with a conventional plastic. Another example is a soy-based composite used by John Deere in the manufacture of their tractors. The reinforcing fiber is fiberglass. Research at Michigan State University and other institutions is directed at use of natural fibers from biomass as direct replacements of fiberglass in biocomposites.[114]

The European Union has set stringent guidelines for recycle of materials used in cars. Starting this year 80% of a vehicle must be reused or recycled at the end of its life. This increases to 85% by 2015. Japan already requires that 88% of vehicles must be recycled and will implement a 95% recycle requirement by 2015. The use of natural and biobased fibers have great appeal from a lifecycle standpoint.[115]

New developments in the automobile industry are showing biobased materials to be as good, or better, than the petrochemical-based materials they are replacing. Goodyear has developed corn infused tires that have a lower rolling resistance.[116] Honda is experimenting with wood fiber-reinforced floor panels that exhibit better dimensional stability than current materials. DaimlerChrysler and BMW Group have made the use of biobased materials a key part of their overall environmental strategy.[115]

[114] Knudson, W.A. and H.C. Peterson. 2005. The market potential of biobased fibers and nano-fibers in the auto industry. The Strategic Marketing Institute Working Paper. Michigan State University Product Center for Agriculture and Natural Resources.
[115] Elliot-Sink, S. Special Report: Cars made of plants. April 12, 2005. www.edmunds.com
[116] News release. February 28, 2001. Goodyear. www.goodyear.com

V. Overview of Major Biobased Products and Markets (existing and emerging) with a Focus on Chemicals, Plastics, Packaging and Related Products

A. Commodity Chemicals/Biofuel: __Ethanol__

1. Background

- The modern US ethanol industry has its origins in the economic and political shocks of the 1973 and 1979 oil embargoes by the Organization of Petroleum Exporting Countries (OPEC), which generated widespread political pressure to reduce dependence on imported petroleum. Concerns about exploitation by the petroleum cartel led to the creation of federal programs that provided support for a wide variety of regional and state projects, as well as for research initiatives. While petroleum costs were high in the 1970s and early 1980s, enthusiasm for programs to find and develop new energy sources was high; however, as petroleum prices declined during the remainder of the 1980s and 1990s and OPEC lost much of its impact, public support for alternative energy receded. Against this trend, the funding of ethanol incentives and implementation of demand-enhancing programs continued, mainly through support from the agricultural lobby, environmentally oriented legislators and organizations promoting alternative fuels.

2. The Clean Air Act Amendments of 1990

- In 1990, a new source of demand for ethanol was created when the US Congress passed amendments to the Clean Air Act (referred to as CAA90), establishing two programs to reduce automotive pollution by mandating specifications for “cleaner” fuel. The Oxygenated Fuels Program (OXY Program) was targeted at reducing carbon monoxide emissions, while the Reformulated Gasoline Program (RFG Program) was intended to reduce smog-forming emissions. The reformulated gasoline market, the oxygenated fuels market, and the conventional gasoline market comprised the three major segments of the overall US ethanol market over the last 15 years.

- In contrast to the previous legislative and administrative approaches in which pollution-control programs focused mainly on increasing automobile fuel efficiency, the CAA90 focused on the composition of automotive fuel. Ethanol and methyl tertiary butyl ether (MTBE) were the two main oxygenates (i.e., additives that increase the oxygen content in fuel) used to meet the requirements of these programs. The RFG Program took effect in early 1995 and targets ground-level ozone pollution (i.e., smog) by lowering levels of toxic and aromatic substances in gasoline. The program originally was required in nine metropolitan areas, including Los Angeles, New York, Chicago, Houston, Milwaukee, Baltimore, San Diego, Philadelphia, Hartford, and Washington, DC. Sacramento and the San Joaquin Valley in California were subsequently required to join. In addition, other areas designated as serious, moderate or marginal ozone non-attainment areas were allowed to opt into the program, and several states in the Northeast and cities in the Midwest participated in the program under that provision. Atlanta and Baton Rouge were designated as being in severe non-attainment early in 2004, but the implementation of the RFG Program in these areas was put on hold pending administrative and legal appeals.

3. The Energy Policy Act of 2005

- In response to high energy prices in recent years, the US Congress considered comprehensive legislation that would spur energy production, streamline electricity transmission procedures and contain other initiatives affecting a broad swath of the US energy complex. Congress failed to pass a bill despite legislative efforts from 2002 through 2004, but legislators finally succeeded in late July 2005, and President George W. Bush signed the Energy Policy Act of 2005 (the 2005 Energy Bill) into law on August 8, 2005.

- Passage was facilitated by the elimination of provisions that had undermined the bill in previous legislative sessions. Key members of the House of Representatives had insisted during the 2004 debate that the bill contain a so-called "safe-harbor" provision to shield MTBE manufacturers from defective product liability suits. A major breakthrough occurred in the 2005 process when House negotiators in the House-Senate Conference Committee agreed to delete the MTBE provision from the conference version of the bill.

- The most important provision for ethanol in the 2005 Energy Bill is a new Renewable Fuels Standard (RFS) that would require motor fuels sold in the US to contain at least the following volumes of renewables in future years:

    - In 2006: 4.0 billion gallons;
    - In 2007: 4.7 billion gallons;
    - In 2008: 5.4 billion gallons;
    - In 2009: 6.1 billion gallons;
    - In 2010: 6.8 billion gallons;
    - In 2011: 7.4 billion gallons; and
    - In 2012: 7.5 billion gallons.

- Starting in 2013, the share of the motor fuels market accounted for by renewable fuels in 2012 will have to be maintained, and a minimum of 250 million gallons derived from cellulosic biomass will have to be used. Through 2012, each physical gallon of cellulosic biomass or waste-derived renewable fuel will count as 2.5 gallons toward the RFS.

- A trading system will also be designed by the EPA that will allow refiners and blenders in areas with little renewable fuels production or constraints on usage to buy credits from areas where it is used widely. The credits would be valid for 12 months. The exact method of trading is not yet known, however, as the EPA is not expected to issue the implementing rules until at least late 2006. It should be noted that not only ethanol but also biodiesel counts toward the RFS. However, it appears that biodiesel will represent only a small minority of the renewable fuels used in the US.

- It should be mentioned that a waiver of the RFS volume requirements is provided for in the 2005 Energy Bill, in two cases: (1) if the federal government determines that implementation would "harm the economy or environment of a State, a region, or the United States" or (2) if "there is inadequate domestic supply." Based on the current capacity and ongoing construction in the ethanol industry, the latter condition is unlikely to be a problem during the next few years, if ever during the timeframe of the 2005 Energy Bill.

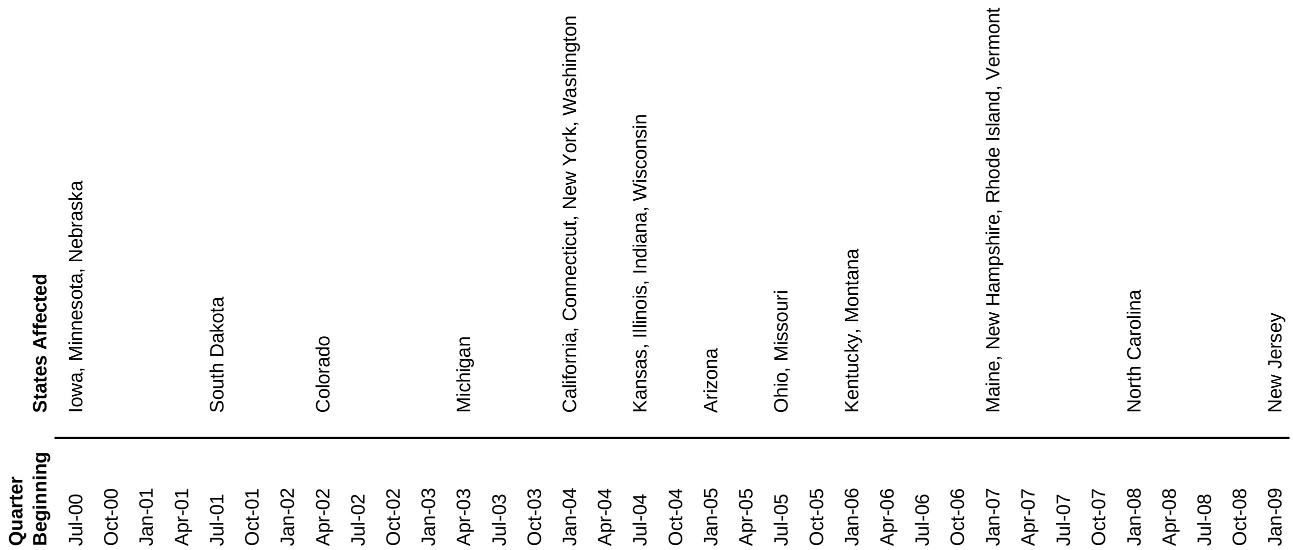
- Interestingly, the 2005 Energy Bill does not include a nationwide ban on the use of MTBE. However, the oxygenate requirement in the RFG Program is scheduled to be removed in May 2006, with removal in California approximately one month earlier. The lack of a nationwide MTBE ban, which had been a provision in versions of the bill that had previously been considered, likely moves the venue to state administrations and legislatures for further MTBE bans.

4. State Bans of Methyl Tertiary Butyl Ether

- MTBE was the predominant oxygenate used in the RFG Program prior to 2003. However, MTBE makes its way into groundwater from leaking underground storage tanks and has contaminated water supplies in a number of locations around the country, particularly in metropolitan areas participating in the RFG Program. The health effects of low levels of MTBE in water are subject to debate, but it has been found to be carcinogenic when inhaled at high doses.

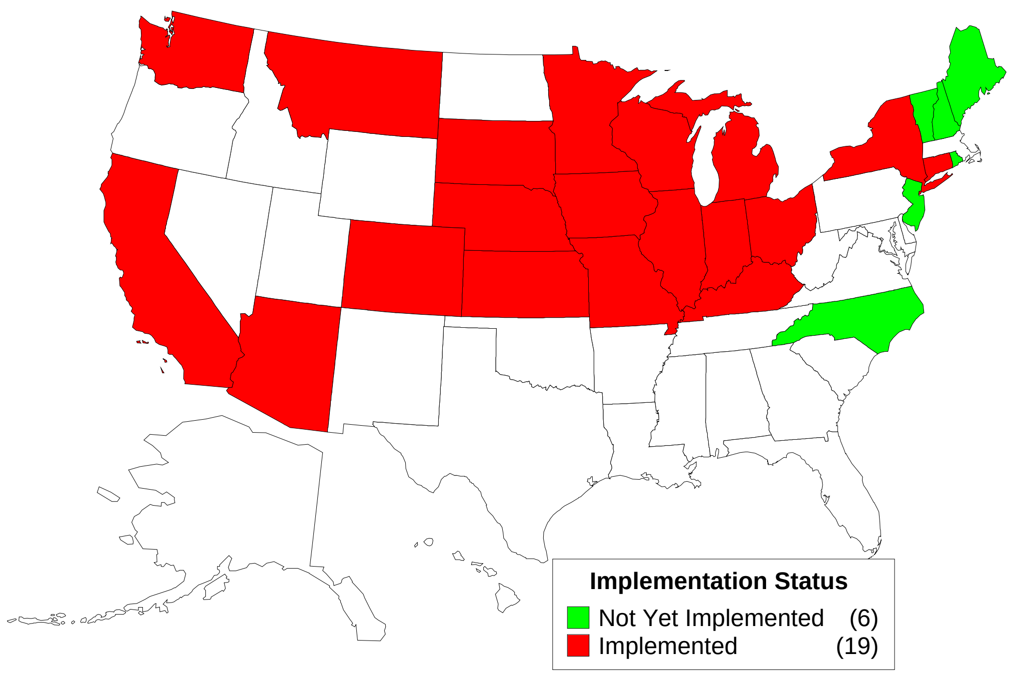
- In 25 states, legislation has been passed or governors have used their executive powers to ban or severely restrict the use of MTBE. A timetable for the implementation of the state bans is included in Figure 20 and Figure 21. The imposition of state MTBE bans has been encouraging both production and consumption of ethanol, and further bans may well be adopted since the Energy Policy Act of 2005 did not contain a nationwide ban.

Figure 20: Timetable for Implementation of State Bans of MTBE



Sources: Department of Energy, Renewable Fuel News, Various Publications

Figure 21: States Banning MTBE



Sources: Department of Energy, Renewable Fuel News, Various Publications

5. Incentives for Ethanol Production and Consumption

- Historically, the primary federal incentive for ethanol has been the exemption of ethanol-containing blends from a portion of the federal excise tax on motor fuels. For example, through late 2004, blends containing 10% ethanol (from renewable resources) were exempt from $0.052 of the $0.184 federal excise tax on each gallon of motor fuel. Because the exemption applied to 10% blends, it amounted to an effective subsidy of $0.52/gallon of pure ethanol ($0.052 ÷ 10%). Additionally, since January 1993, ethanol-gasoline blends consisting of 7.7% or 5.7% alcohol (corresponding to the oxygen content standards for the RFG and OXY Program areas) received a prorated exemption; the effective incentive on these blends was still $0.52/gallon of pure ethanol.

- The tax savings from the excise tax exemption have not gone to the ethanol producer directly, but rather have been available to gasoline companies as an incentive to blend ethanol. The gasoline companies, in turn, paid a premium for ethanol that was typically somewhat less than $0.52/gallon above the wholesale price of gasoline.

- In order to streamline the management of the ethanol incentive and to avoid depleting the Highway Trust Fund, the JOBS Act, signed on October 22, 2004, contained a provision replacing the federal excise tax exemption with an equivalent tax credit paid through general government finances. This arrangement is known as the Volumetric Ethanol Excise Tax Credit (VEETC).

- The VEETC Act provides an alcohol-fuel mixture excise credit of $0.51/gallon of ethanol. Now, all excise taxes on gasoline and ethanol-blended fuels are collected at a rate of $0.184/gallon ($0.244/gallon for diesel and biodiesel) and placed into the federal government's General Fund; the government, in turn, transfers an equivalent amount of money to the Highway Trust Fund. The blender receives a credit for the volume of ethanol it actually uses, which is paid from the General Fund. Therefore, the incentive is no longer restricted to specific blending rates, such as the 5.7% and 7.7% levels that reflected Clean Air Act requirements, which will no longer be applicable after the removal of the oxygenate requirement from the RFG Program is implemented under the Energy Bill.

6. Ethanol Supply and Demand

- The CAA90 stimulated ethanol demand, and in response ethanol production capacity grew dramatically over the next 15 years. The economics of ethanol production have been particularly strong during roughly the last five years, due to considerable periods of time when low corn prices coincided with high gasoline prices. In reaction to this period of high margins, as well as bans on the usage of MTBE in California, New York and other states, industry capacity has more than doubled over the last five years. As of February 2006, ethanol production capacity had reached approximately 4.4 billion gallons, with another 2.1 billion gallons under construction, according to the Renewable Fuels Association (Table 23 and Figure 22). Most existing facilities are in the middle of the Corn Belt, but new facilities are being proposed both on the edges of the Corn Belt and, to a lesser extent in destination market.

Table 23: U.S. Existing and Under Construction Ethanol Facilities

Company	Location	Current Capacity (mmgy)	Construction / Expansion (mmgy)	Company	Location	Current Capacity (mmgy)	Construction / Expansion (mmgy)
Abengoa Bioenergy Corp.	York, NE	55		James Valley Ethanol, LLC	Groton, SD	50	
	Colwich, KS	25		KAAPA Ethanol, LLC*	Minden, NE	40	
	Portales, NM	30		Land O' Lakes*	Melrose, MN	2.6	
	Ravenna, NE		88	Lincolnland Agri-Energy, LLC*	Palestine, IL	48	
ACE Ethanol, LLC	Stanley, WI	39		Lincolnway Energy, LLC*	Nevada, IA		50
Adkins Energy, LLC*	Lena, IL	40		Liquid Resources of Ohio	Medina, OH	3	
Advanced Bioenergy	Fairmont, NE		100	Little Sioux Corn Processors, LP*	Marcus, IA	52	
AGP*	Hastings, NE	52		Merrick/Coors	Golden, CO	1.5	1.5
Agra Resources Coop.	Albert Lea, MN	40	8	MGP Ingredients, Inc.	Pekin, IL	78	
Agri-Energy, LLC*	Luverne, MN	21			Atchison, KS		
Alchem Ltd. LLLP	Grafton, ND	10.5		Michigan Ethanol, LLC	Caro, MI	50	
Al-Corn Clean Fuel*	Claremont, MN	35		Mid America Agri Products/Wheatland	Madrid, NE		44
Amaizing Energy, LLC*	Denison, IA	40		Mid-Missouri Energy, Inc.*	Malta Bend, MO	45	
Archer Daniels Midland	Decatur, IL	1070		Midwest Grain Processors*	Lakota, IA	50	45
	Cedar Rapids, IA				Riga, MI		57
	Clinton, IA			Midwest Renewable Energy, LLC	Sutherland, NE	17.5	4.5
	Columbus, NE			Minnesota Energy*	Buffalo Lake, MN	18	
	Marshall, MN			Missouri Ethanol	Laddonia, MO		45
	Peoria, IL			New Energy Corp.	South Bend, IN	102	
	Wallhalla, ND			North Country Ethanol, LLC*	Rosholt, SD	20	
ASAlliances Biofuels, LLC	Albion, NE		100	Northeast Missouri Grain, LLC*	Macon, MO	45	
	Linden, IN		100	Northern Lights Ethanol, LLC*	Big Stone City, SD	50	
Aventine Renewable Energy, LLC	Pekin, IL	100	57	Northstar Ethanol, LLC	Lake Crystal, MN	52	
	Aurora, NE	50		Otter Creek Ethanol, LLC*	Ashton, IA	55	
Badger State Ethanol, LLC*	Monroe, WI	48		Pacific Ethanol	Madera, CA		35
Big River Resources, LLC*	West Burlington, IA	40		Panhandle Energies of Dumas, LP	Dumas, TX		30
Broin Enterprises, Inc.	Scotland, SD	9		Parallel Products	Louisville, KY	5.4	
Bushmills Ethanol, Inc.*	Atwater, MN		40		R. Cucamonga, CA		
Cargill, Inc.	Blair, NE	85		Permeate Refining	Hopkinton, IA	1.5	
	Eddyville, IA	35		Phoenix Biofuels	Goshen, CA	25	
Central Indiana Ethanol, LLC	Marion, IN		40	Pinal Energy, LLC	Maricopa, AZ		55
Central MN Ethanol Coop*	Little Falls, MN	21.5		Pine Lake Corn Processors, LLC*	Steamboat Rock, IA	20	
Central Wisconsin Alcohol	Plover, WI	4		Platte Valley Fuel Ethanol, LLC	Central City, NE	40	
Chief Ethanol	Hastings, NE	62		Prairie Ethanol, LLC	Loomis, SD		60
Chippewa Valley Ethanol Co.*	Benson, MN	45		Prairie Horizon Agri-Energy, LLC	Phillipsburg, KS		40
Commonwealth Agri-Energy, LLC*	Hopkinsville, KY	24	9	Pro-Corn, LLC*	Preston, MN	42	
Corn, LP*	Goldfield, IA	50		Quad-County Corn Processors*	Galva, IA	27	
Cornhusker Energy Lexington, LLC	Lexington, NE		40	Red Trail Energy, LLC	Richardton, ND		50
Corn Plus, LLP*	Winnebago, MN	44		Redfield Energy, LLC	Redfield, SD		50
Dakota Ethanol, LLC*	Wentworth, SD	50		Reeve Agri-Energy	Garden City, KS	12	
DENCO, LLC*	Morris, MN	21.5		Siouxland Energy & Livestock Coop*	Sioux Center, IA	25	
E3 Biofuels	Mead, NE		24	Siouxland Ethanol, LLC			
East Kansas Agri-Energy, LLC*	Garnett, KS	35		Sioux River Ethanol, LLC*	Hudson, SD	55	
ESE Alcohol Inc.	Leoti, KS	1.5		Sterling Ethanol, LLC	Sterling, CO	42	
Ethanol2000, LLP*	Bingham Lake, MN	32		Tall Corn Ethanol, LLC*	Coon Rapids, IA	49	
Frontier Ethanol, LLC	Gowrie, IA		60	Tate & Lyle	Loudon, TN	67	
Front Range Energy, LLC	Windsor, CO		40	The Andersons Albion Ethanol LLC	Albion, MI		55
Glacial Lakes Energy, LLC*	Watertown, SD	50		Trenton Agri Products, LLC	Trenton, NE	35	10
Golden Cheese Company of California*	Corona, CA	5		United WI Grain Producers, LLC*	Friesland, WI	49	
Golden Grain Energy, LLC*	Mason City, IA	40		US BioEnergy Corp.	Albert City, IA		100
Golden Triangle Energy, LLC*	Craig, MO	20			Lake Odessa, MI		45
Grain Processing Corp.	Muscatine, IA	20		U.S. Energy Partners, LLC	Russell, KS	48	
Granite Falls Energy, LLC	Granite Falls, MN	45		Utica Energy, LLC	Oshkosh, WI	48	
Great Plains Ethanol, LLC*	Chancellor, SD	50		Val-E Ethanol, LLC	Ord, NE		45
Green Plains Renewable Energy	Shenandoah, IA		50	VeraSun Energy Corporation	Aurora, SD	230	
Hawkeye Renewables, LLC	Iowa Falls, IA	50	50		Ft. Dodge, IA		
	Fairbank, IA		100	Voyager Ethanol, LLC*	Emmetsburg, IA	52	
Heartland Corn Products*	Winthrop, MN	36		Western Plains Energy, LLC*	Campus, KS	45	
Heartland Grain Fuels, LP*	Aberdeen, SD	9		Western Wisconsin Renewable Energy, LLC*	Boyceville, WI		40
	Huron, SD	12	18	Wind Gap Farms	Baconton, GA	0.4	
Heron Lake BioEnergy, LLC	Heron Lake, MN		50	Wyoming Ethanol	Torrington, WY	5	
Horizon Ethanol, LLC	Jewell, IA		60	Xethanol BioFuels, LLC	Blairstown, IA	5	
Husker Ag, LLC*	Plainview, NE	26.5		**Total Current Capacity**		**4336.4**	
Illinois River Energy, LLC	Rochelle, IL		50	**Total Under Construction/Expansions**			**2036**
Iowa Ethanol, LLC*	Hanlontown, IA	50		**Total Capacity**		**6372.4**	
Iroquois Bio-Energy Company, LLC	Rensselaer, IN		40				

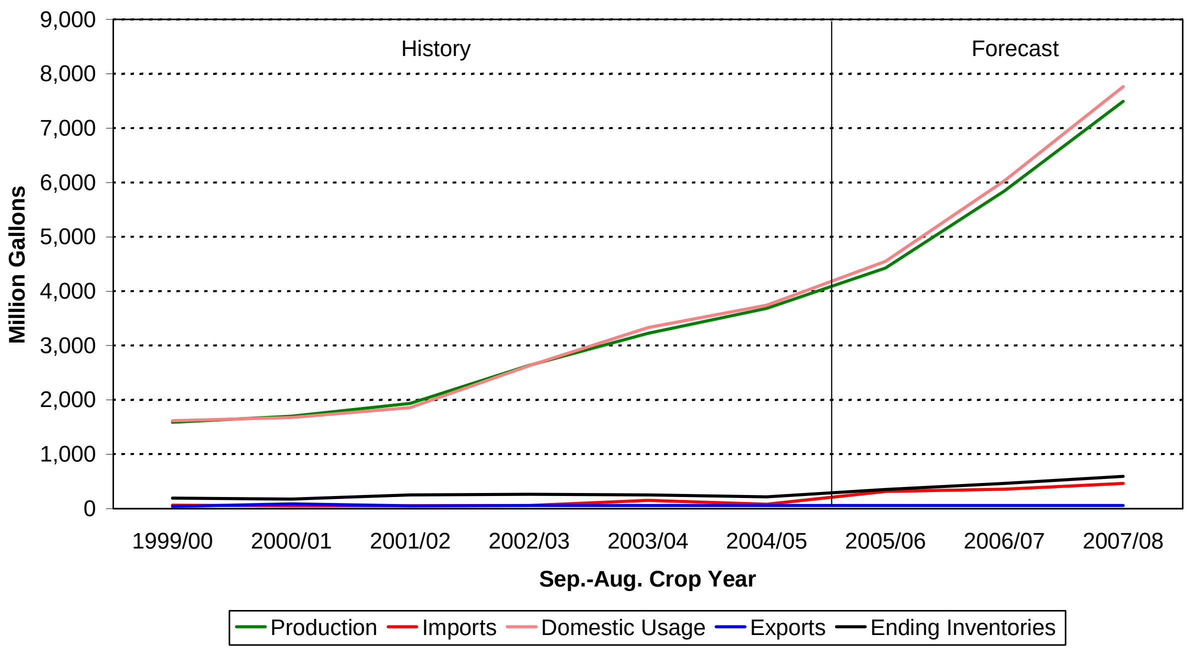
Source: Renewable Fuels Association

- The US ethanol market is in the midst of profound changes on both the supply side and the demand side. On the demand side, the RFS included in the 2005 Energy Bill will become an important determinant of the future trajectory of the consumption of renewable fuels, including ethanol, while the clean air programs that drove the doubling of ethanol usage in the 1990s will recede in importance, as the oxygenate requirement is removed.

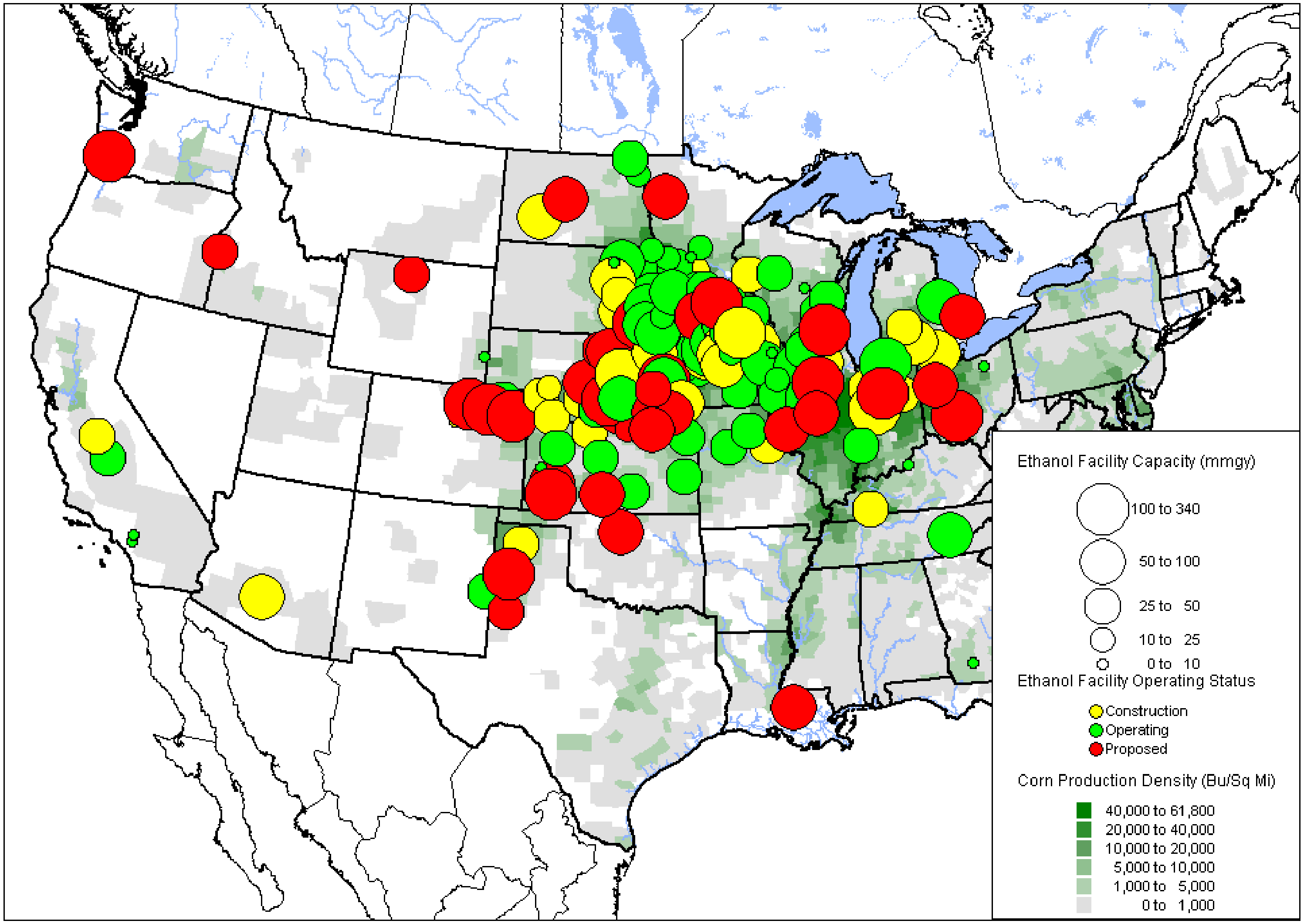
- From 2000 to 2005, the estimated annually compounded growth rate of ethanol production and usage in the US was approximately 19% per year (see Table 24, Table 25, which is in crop year format). US exports have been relatively flat with imports increasing only in the last two years. Driven by the stable policy environment provided by the Energy Bill and VEETC passage, as well as high margins for producers, ethanol production, and usage are expected to grow even more rapidly through 2008 at approximately 27% per year.

- A review of the number of facilities currently proposed (along with probabilities of being built) and under construction support this capacity scenario, and the design/build firms that serve the industry are believed to have the capability to bring up to an additional 1.5 billion gallons of capacity online per year over the next few years (Map 1). In 2008, ethanol production is forecast to be 7.9 billion gallons, which exceeds the 7.5-billion-gallon level of the RFS four years later, in 2012. Given that ethanol would account for roughly 6% of the US gasoline supply at the time and that it is expected crude oil prices will remain firm and corn prices will remain moderate (assuming normal weather), this rapid growth likely will not result in low or negative margins-at least through 2008.

Figure 22: Ethanol Balance, Sep.-Aug. Crop-Year



Map 1: Existing, Under Construction, and Proposed U.S. Ethanol Facilities



Source: Renewable Fuels Association and Informa

Table 24: Ethanol Balance, Calendar Year (Million Gallons)

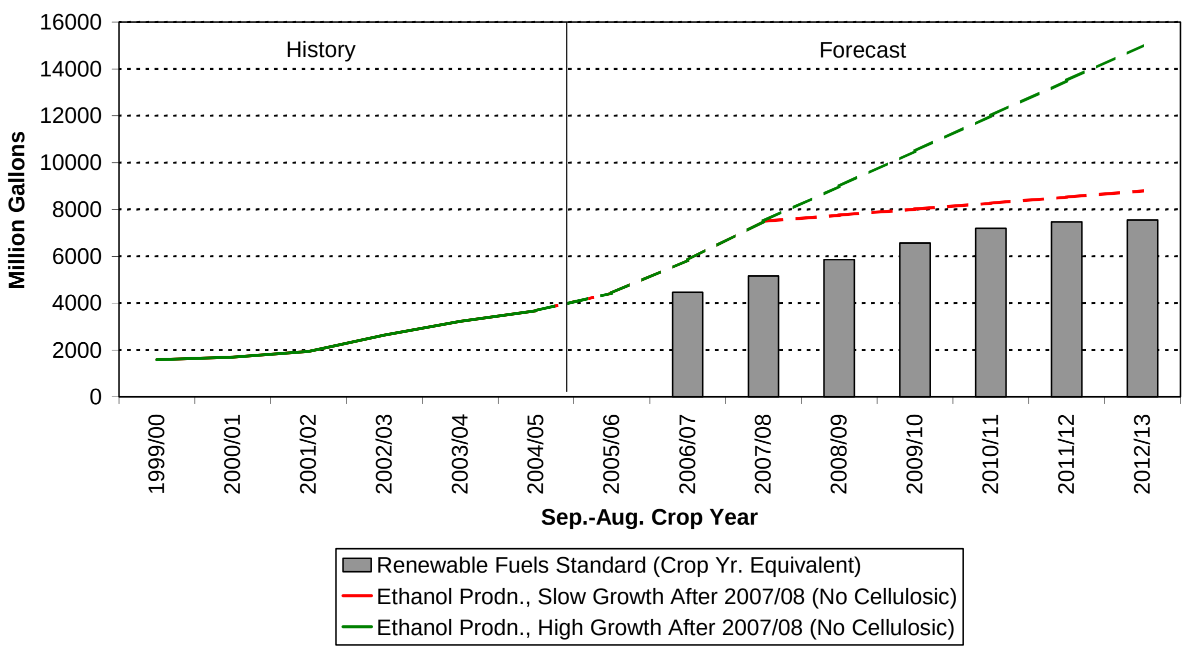
	2000	2001	2002	2003	2004	**2005**	**2006**	**2007**	**2008**
Beginning Inventories	151	140	169	259	221	252	**240**	**341**	**459**
Production	1,630	1,766	2,140	2,804	3,402	3,904	**4,773**	**6,432**	**7,902**
Imports	63	50	52	61	164	138	**257**	**360**	**463**
Total Supply	1,844	1,955	2,360	3,125	3,787	4,294	**5,270**	**7,133**	**8,824**
Domestic Usage	1,649	1,712	2,054	2,841	3,488	3,991	**4,871**	**6,615**	**8,202**
Exports	55	75	47	63	47	63	**58**	**58**	**58**
Total Disappearance	1,704	1,786	2,101	2,904	3,536	**4,054**	**4,929**	**6,674**	**8,260**
Ending Inventories	140	169	259	221	252	**240**	**341**	**459**	**564**

Table 25: Ethanol Balance, Sep.-Aug. Crop Year (Million Gallons)

	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	**2005/06**	**2006/07**	**2007/0**
Beginning Inventories	195	191	177	253	261	255	220	**351**	**46**
Production	1,590	1,699	1,936	2,634	3,228	3,685	**4,430**	**5,844**	**7,49**
Imports	62	48	50	61	153	82	**313**	**360**	**46**
Total Supply	1,846	1,938	2,163	2,949	3,642	4,022	**4,963**	**6,555**	**8,41**
Domestic Usage	1,614	1,677	1,862	2,632	3,330	3,745	**4,553**	**6,033**	**7,76**
Exports	41	83	48	56	57	57	**58**	**58**	**5**
Total Disappearance	1,655	1,760	1,910	2,688	3,387	3,801	**4,612**	**6,091**	**7,82**
Ending Inventories	191	177	253	261	255	220	**351**	**463**	**59**

- It is anticipated that after 2008 crude oil prices will recede toward a long-run equilibrium level of $40/barrel, and that increasing consumption for processing into ethanol will cause farm prices of corn to rise toward $2.40/bushel. Given these conditions and the fact that production will significantly exceed the RFS, capacity additions might slow after 2008. However, given that crude oil prices would still be significantly above their long-term average and that there appears to be considerable political support for ethanol, a more aggressive long-run growth scenario is also shown in Figure 23. It is assumed in this scenario assumes that a nationwide average 10% ethanol blend in gasoline will be achieved in 2015. Even under the high growth scenario, production growth slows after crop year 2007/08, remaining at around 17-20%/year through 2009/10. This growth rate corresponds with approximately 1.5 billion gallons of capacity added each year, or the maximum annual capacity expansion that is currently sustainable. Under both growth scenarios, ethanol production is expected to be greater than the RFS requirement for every year of the outlook.

Figure 23: Ethanol Production and the RFS

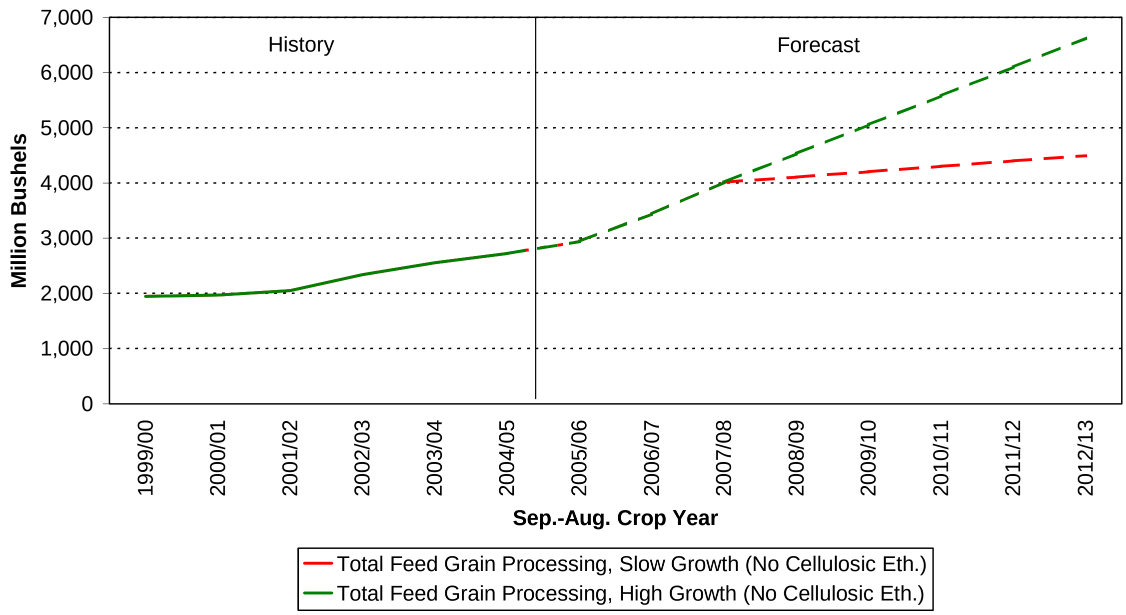


7. Feed Grain Usage

- As shown in Figure 24, 1.378 billion bushels of corn were consumed for ethanol production in crop year 2004/05. Total corn production in the US was approximately 11.8 billion bushels (a record crop). Thus ethanol production consumed approximately 12% of the total corn crop. It is expected that corn usage for ethanol production will almost double to 2.64 billion bushels by

2007/08. Under the slow growth scenario, corn usage will grow only modestly in the following years. Under the high growth scenario, however, corn usage increases to 3.67 billion bushels by 2009/10. It is expected that if ethanol production continues to grow at a high rate after 2007/08, pressure on levels of year-end corn stocks will push prices higher. However, this is expected to result in a response in acreage dedicated to corn, resulting in production that is sufficient to offset much of the added ethanol feedstock requirements at prices around $2.40/bushel, assuming normal weather.

Figure 24: Total Feed Grain Used in Processing, Assuming No Cellulosic Ethanol



8. Ethanol Co-Products

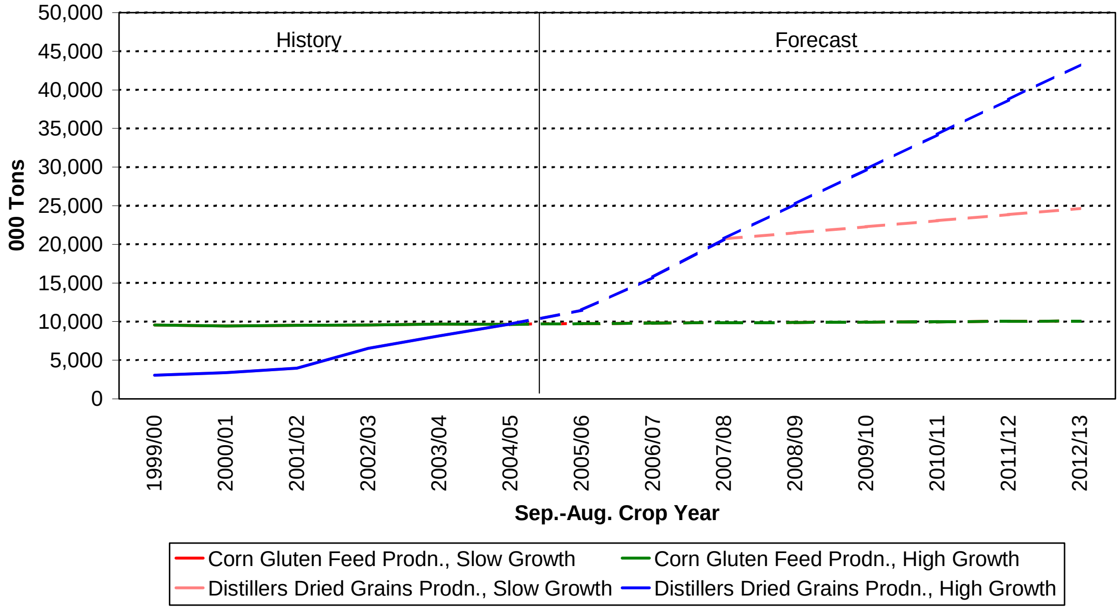
- Virtually all of the ethanol facilities built during the last decade have been dry mills, which grind and then directly process corn, as opposed to wet mills, which separate the corn kernel into its component parts. In the dry-mill process, the starch portion of the kernel is largely converted to ethanol, while the remaining material – mainly fiber and protein – is referred to as distillers grains and is usually sold as livestock feed. "Usually, (distillers grains) are dried to yield dried distillers grains (DDG), or dried distillers grains with solubles (DDGS) if solubles in the thin stillage are added back to the grains at drying. The solubles in the thin stillage may also be partially or totally dried to make condensed distillers solubles (CDS) or dried distillers solubles (DDS), respectively. Of these co-products, DDG and DDGS are the most commonly used, probably because of ease of handling, storage, and shipping."[117] Since DDGS is becoming the most common form in the market, it will be used in this section as the "common denominator" of this group of co-products.

- DDGS is a middle-protein feed with a minimum crude protein content of roughly 27%, although this can vary significantly among facilities and is typically over 30% for newer facilities. DDGS is predominantly used in feed for ruminants (mainly cattle), as its composition limits the inclusion rate in feed for monogastric animals (e.g., hogs and poultry). Both domestic consumption and exports of DDGS have risen along with the expansion of the ethanol industry. Still, the volumes involved remain modest compared with the overall size of the markets for feed grains, protein meals and non-grain feed ingredients.

- Also included in Figure 25 are co-product production estimates under both ethanol output scenarios. Output of co-products of the wet milling process (corn gluten feed and corn gluten meal) is expected to remain essentially flat in both scenarios as few, if any, of the new facilities will be wet mills. Output of DDGS is expected to increase along with the increase in ethanol production. Under both scenarios, approximately 20.7 million short tons of distillers grains will be produced in 2007/08, double the DDGS output in 2004/05. In the low growth scenario, DDGS production increases to 22.3 million tons by 2009/10. In the high growth scenario, DDGS output increases to 29.7 million tons in 2009/10.

[117] Jean-Marie Akayezu, James G. Linn, Summer R. Harty, and James M. Cassady, "Use of Distillers Grains and Co-Products in Ruminant Diets," Presented at the 59th Minnesota Nutrition Conference, Bloomington, MN, September 1998 (http://www.ddgs.umn.edu/proceedings-dairy/1998nutrconf.pdf).

Figure 25: Co-Product Output



- As mentioned above, DDGS can only be included in limited quantities in livestock rations. The total potential size of the DDGS market in the US is approximately 53 million tons/year, or about 2.5 times the estimated DDGS production in 2007/08 (Table 26). If a 10% ethanol blend (approximately 15 billion gallons/year) is achieved using corn-based ethanol n the high growth scenario, in 2012 approximately 48 million tons of DDGS would be produced. However, typical inclusion rates in livestock rations are somewhat lower than the maximum recommended rates, and some operations might choose not to utilize DDGS or are in geographic locations where DDGS usage is impractical or transportation cost make in uneconomical. Therefore, it is likely that if ethanol production were to reach 15 billion gallons, it would be necessary to increase exports of DDGS.

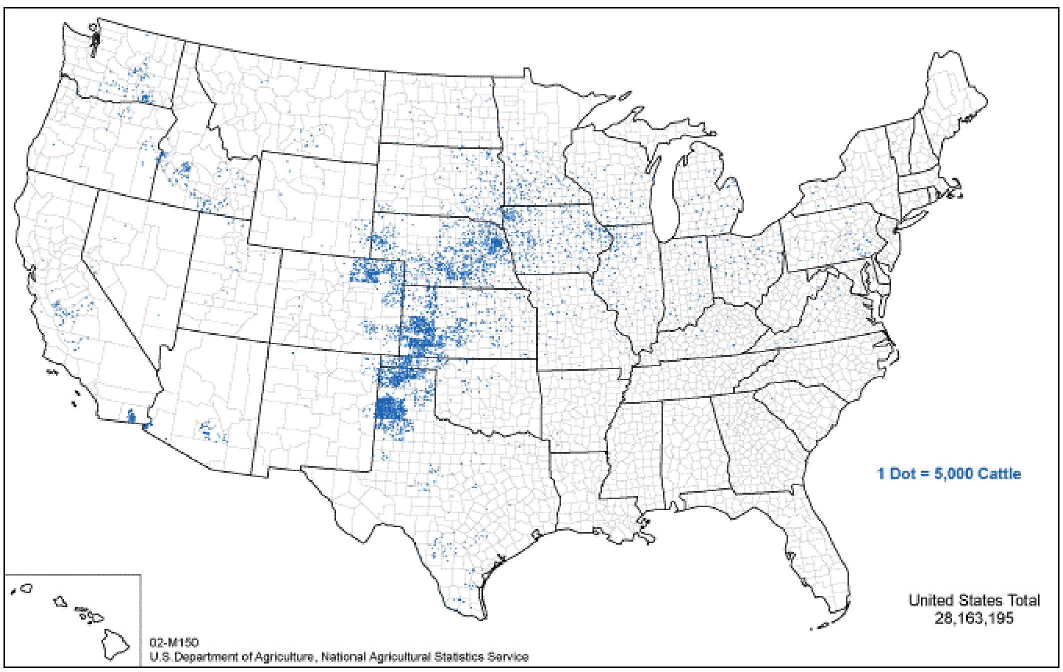
Table 26: Distillers Dried Grains: Maximum Potential Consumption by the major US Livestock Sectors

Animal/Growth Stage	Maximum Inclusion Rate	Total feed/day	Quantity co-products /day (lbs)	Animal Quantity 2005 (000's head)	Maximum DDGS Consumption (tons)
Hogs and Pigs					
Nursery pigs, under 60 lbs	5.0%	1.15	0.06	19,688	206,601
Grower pigs, 60-119 lbs	15.0%	4.77	0.72	13,054	1,704,575
Finish pigs, 120-179 lbs	20.0%	5.06	1.01	10,861	2,005,918
Hogs and pigs 180 lbs and over	22.0%	6.00	1.32	6,114	1,472,863
Hogs and pigs for breeding	35.0%	5.00	1.75	6,012	1,920,083
Developing gilts	20.0%	6.62	1.32	706	170,591
Total maximum swine DDGS use					**7,480,630**
Cattle and Calves					
Milk cows	30.0%	50.00	15.00	9,005	24,651,188
Cattle on feed	35.0%	18.30	6.41	14,132	16,518,955
Total maximum cattle DDGS use					**41,170,142**

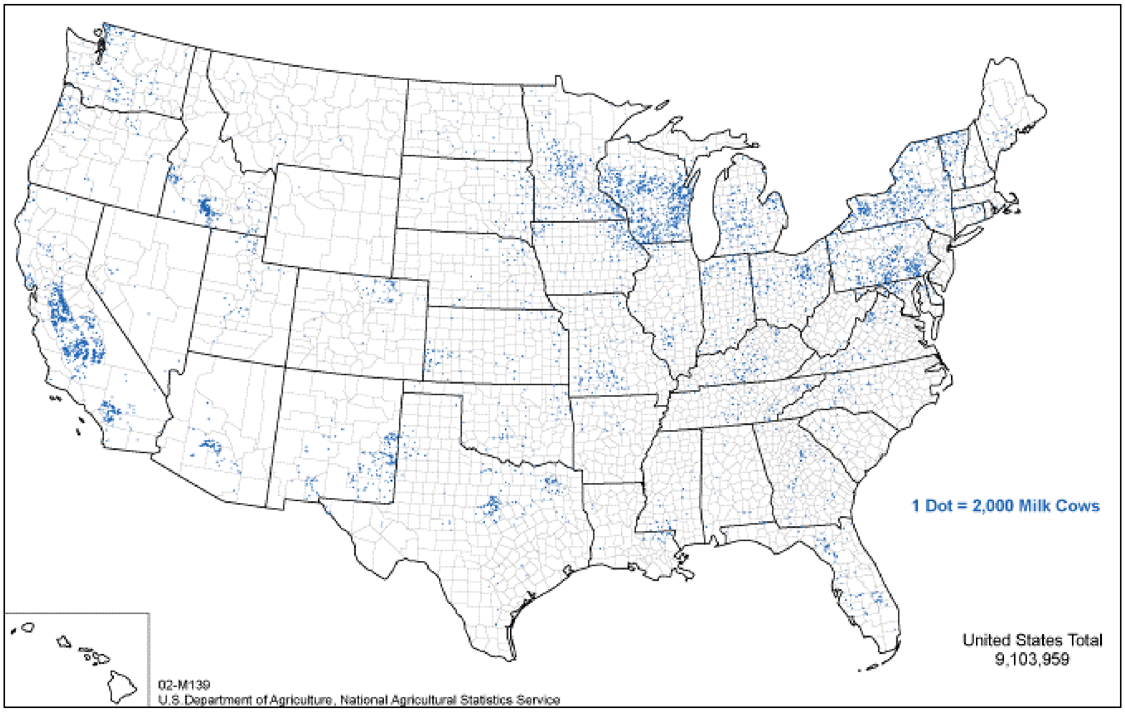
Broilers	Maximum Inclusion Rate	Total feed/pound produced		Liveweight pounds Produced 2004 (000's)	Maximum DDGS Consumption (tons)
Total broiler production	10%	2.00		44,635,400	4,463,540
Total maximum broiler DDGS use					**4,463,540**
Total maximum DDGS use (all species)					**53,114,312**

- The largest potential domestic markets for DDGS are in areas with large milk cow and cattle on feed (feedlots) inventories, accounting for approximately 41 million tons of DDGS demand. The largest cattle on feed inventories are in the central and southern Plains (Map 2) while the largest milk cow inventories are in the upper Midwest, California, Upstate New York, and Pennsylvania (Map 3). While not nearly as large as the potential market in cattle feeding, hogs and poultry together account for approximately 12 million tons of DDGS demand. Large hog inventories exist in the Midwest and in North Carolina (Map 4). In the last few years, researchers at the University of Minnesota and cooperating institutions have conducted the foundational work demonstrating the role of DDGS in swine rations. Broiler production is spread through the Southwest with Georgia and Arkansas each producing approximately 1.2 billion birds/year (Map 5).

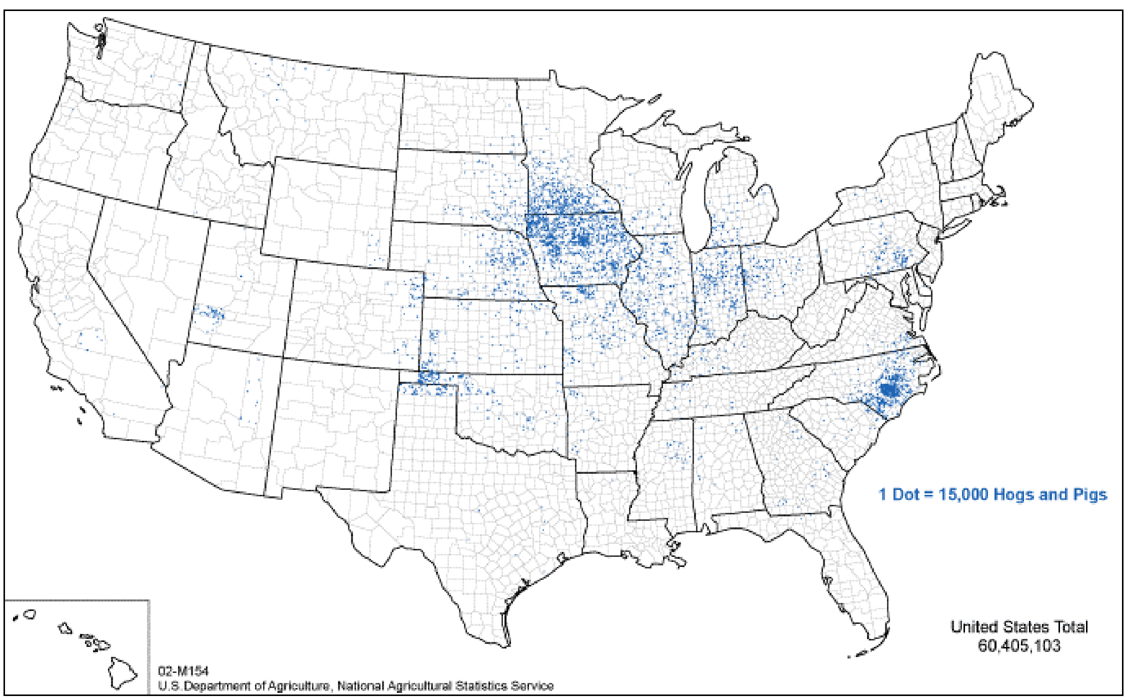
Map 2: US Marketings of Cattle on Feed, 2002



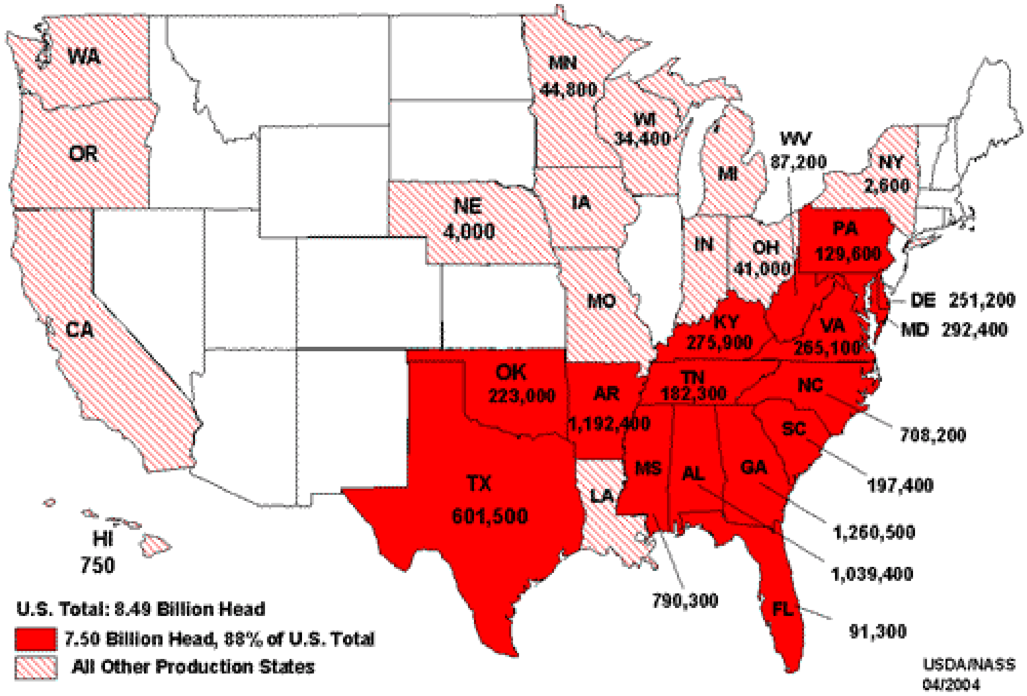
Map 3: US Milk Cow Inventories, 2002



Map 4: US Inventories of Hogs and Pigs, 2002

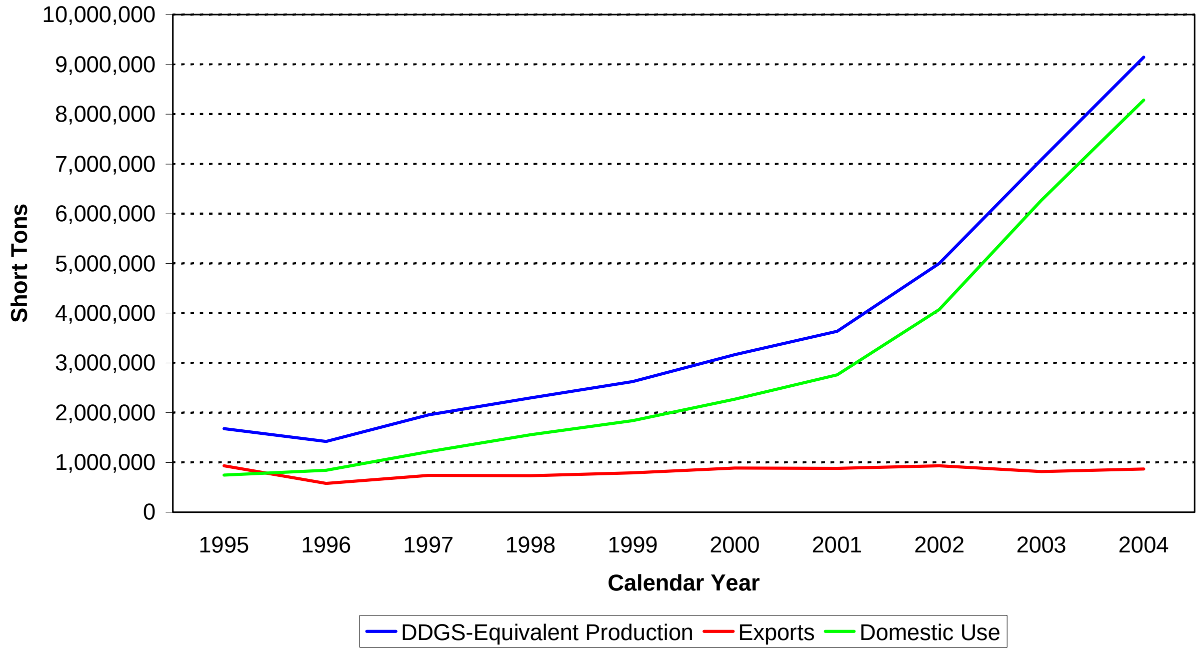


Map 5: Broiler Production by State: Number Raised (000's), 2003



- DDGS exports have been flat over the last ten years, averaging approximately 816,000 tons per year from 1995 to 2004 (Figure 26). Over half of the US DDGS exports have historically gone to the European Union, with Canada and Mexico also significant destination markets. Over the last couple of years, the Asian market for DDGS has begun to develop, though current volumes are quite small.

Figure 26: US Distillers Grains Production and Disposition



Source: US Census Bureau (Exports), Informa Economics

9. Discussion of Ethanol Producer Net Margins (excluding depreciation)

- The ethanol industry has enjoyed significant returns in recent years as the price of oil reached record highs and corn prices have remained low. What if the price of oil was to retreat to $25/barrel and corn was to rise to $4.00/bu., how would the ethanol industry be affected? An ethanol producer margin matrix has been developed (Table 27) to better understand how changes in the critical financial variables impacts the producer's bottom-line. What follows is an elaboration of the method used to construct the matrix and observations regarding some of the findings.

- Net ethanol producer margin (excluding depreciation) is calculated as follows:

Ethanol Rack Price
-Transportation and Handling Costs
-Cash Corn Price
+DDGS Price
-Natural Gas Costs
-Interest Expense (for a 100 million gallon facility)
-Operating and Other Costs (e.g. Chemicals)
Net Ethanol Producer Margin (excluding depreciation)

- The two most important variables in determining ethanol producer margins are corn and ethanol prices.

- In the current corn and energy environment (approximately $2.40-2.50/gallon ethanol in origin markets and $2.00/bushel corn) ethanol producer margins are high compared to historical averages, exceeding $1.00/gallon.

- At a modest crude oil price of approximately $45/bbl, where ethanol rack prices would be expected to average $1.80/gallon, producer margins are still estimated to be slightly positive with corn prices as high as $5.00/bushel. In such an energy environment, margins would be approximately 83¢/gallon with corn prices of $2.00/bushel.

- Demonstrating the key role of oil and gasoline prices in determining the profitability of an ethanol producer, if oil prices fall to their long run average of around $25/bbl (corresponding to an ethanol price of approximately $1.20/gallon), corn prices would have to remain below $3.00/bushel for ethanol producers to achieve a positive margin.

Table 27: Cash Ethanol Producer Net Margins (excluding depreciation)

			Energy Prices								
	Ethanol Rack Price ($/gallon)		1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60
	Conventional Gasoline ($/gallon)		0.49	0.69	0.89	1.09	1.29	1.49	1.69	1.89	2.09
	Light Crude Oil ($/bbl)		16.38	23.47	30.56	37.65	44.74	51.83	58.92	66.01	73.10
	Natural Gas ($/mmBtu)		2.23	3.40	4.58	5.76	6.93	8.11	9.29	10.47	11.64
Cash Corn and DDGS Prices	**Corn ($/bushel)**	**DDGS ($/ton)**									
	1.50	66	0.19	0.36	0.52	0.69	0.85	1.01	1.18	1.34	1.50
	1.75	77	0.14	0.30	0.46	0.63	0.79	0.96	1.12	1.28	1.45
	2.00	88	0.08	0.24	0.41	0.57	0.73	0.90	1.06	1.23	1.39
	2.25	99	0.02	0.19	0.35	0.51	0.68	0.84	1.00	1.17	1.33
	2.50	110	(0.04)	0.13	0.29	0.46	0.62	0.78	0.95	1.11	1.27
	2.75	121	(0.09)	0.07	0.23	0.40	0.56	0.73	0.89	1.05	1.22
	3.00	132	(0.15)	0.01	0.18	0.34	0.51	0.67	0.83	1.00	1.16
	3.25	143	(0.21)	(0.04)	0.12	0.28	0.45	0.61	0.78	0.94	1.10
	3.50	154	(0.26)	(0.10)	0.06	0.23	0.39	0.55	0.72	0.88	1.05
	3.75	165	(0.32)	(0.16)	0.01	0.17	0.33	0.50	0.66	0.82	0.99
	4.00	176	(0.38)	(0.22)	(0.05)	0.11	0.28	0.44	0.60	0.77	0.93
	4.25	187	(0.44)	(0.27)	(0.11)	0.05	0.22	0.38	0.55	0.71	0.87
	4.50	198	(0.49)	(0.33)	(0.17)	(0.00)	0.16	0.32	0.49	0.65	0.82
	5.00	220	(0.61)	(0.44)	(0.28)	(0.12)	0.05	0.21	0.37	0.54	0.70

Note: Crude oil and gasoline prices are not used to calculate the margins. The oil and gas prices show a general statistical relationship with the price of ethanol. For example, one might make a generalization that when the price of crude oil is near $60/gallon then ethanol will trade at approximately $2.20/gallon.

Assumptions:

1. 30,000 Btu of natural gas used per gallon of ethanol produced.
2. Ethanol conversion: 2.68 gallons/bushel of corn
3. DDGS yield: 17.5 lbs/bushel of corn
4. Interest expense: $3.4 million
5. “Other” costs: 27¢/gallon

B. Commodity Chemicals/Biofuel: Biodiesel from Oil

- The objective of this section is to examine the current market dynamics of the biodiesel market and to analyze the economic potential to use renewable oils or other biomass materials (e.g., animal fasts) to manufacture biodiesel, which is used as a substitute product for the conventional petroleum based #2 diesel. The potential demand for biodiesel as a substitute of #2 diesel or other petrochemical products is very high – greater than the potential supply – however, the most critical factor for biodiesel is its relative cost. Hence, the analysis will examine in detail the economics of manufacturing biodiesel from various oils and biomass products.

- In the last decade, there has been considerable worldwide interest and investment in the overall use of renewable fuels (e.g., ethanol and/or biodiesel). While factors such as dependence on foreign energy, global warming and the Kyoto Protocol agreement can be viewed as drivers for renewable fuels, global and US growth are primarily being driven by government mandates and fiscal incentives; however, the current environment of high oil prices have provided incentives to further develop the overall biodiesel sector around the world with and without government support.

1. Global Overview of the Biodiesel Market

- Although the European Union (EU) is currently the largest producer of biodiesel (European motor fuel consumption is 50% diesel, compared to 2% in the United States), the US and other countries have jump-started the development of a biodiesel industry. One should consider the following developments around the world:
  - The 2005 US Energy Bill provided a $1/gal incentive for biodiesel.
  - The EU has directed that 2% of the energy content of all petrol and diesel for transport must come from renewable sources.
  - All diesel sold in France is already blended with 2% biodiesel.
  - In India, a 20% blend is considered for 2020.
  - Thailand is aiming for a 10% blend by 2012.

2. EU

- Europe has dominated the biodiesel industry to date with 90% of global production, but escalating demand is outpacing supply.

- Biodiesel is Europe's dominant alternative fuel. As part of a range of measures drawn up in response to international agreements to reduce greenhouse gas emissions, the EU is encouraging greater use of biofuels.

Under the 2003 EU Biofuels Directive, a 2% share of the energy content of all petrol and diesel for transport is targeted to come from renewable sources, including both biodiesel and ethanol. This is due to rise to 5.75% by the end of 2010.

- Tax exemptions and national targets are driving demand across the EU. All diesel sold in France is already blended with 2% biodiesel. The reduction in UK duty on biodiesel by 20 pence per liter in April 2002 is also encouraging investment.

- The EU's biodiesel production capacity may exceed 4 million metric tons (mmt) by mid-2006, up from an estimated output of 570 million gallons in 2004, according to the EU's vegetable oil industry federation (Fediol). Industry estimates place the EU's demand at about 9 mmt of biodiesel per year by 2010.

- Rapeseed oil continues to be the dominant feedstock in Europe, supplying 80% of total biodiesel requirements, and about one third of the rapeseed crop in 2004 was used for the production of biodiesel. Soybean oil and a marginal quantity of palm oil make up the remaining feedstock.

- Meeting the 5.75% target will depend on feedstock availability and investment in production capacity. Thus, potentially Asian palm oil exporters such as Malaysia and Indonesia could supply a portion of the EU's biodiesel feedstock needs by 2010. Also, imported biodiesel from their countries could be used to reach the target market share of biofuels EU Directive.

3. Asia

- Asia currently consumes over 2 billion mt of oil/year, and demand is expected to increase substantially. Asia produces many vegetable oils, which can be used for biodiesel feedstock, including coconut and palm (Jatropha has great potential in the region as an energy crop). One should consider the following current developments:

India. The Indian government is proposing a national biodiesel blend of 20% by 2020.

Philippines. Biodiesel made with 1% to 2% coconut oil is mandatory for all government vehicles. Government is promoting biodiesel to improve air quality and reduce dependence on imported fuel.

Thailand. 90% of all oil is imported. The Ministry of Energy has proposed a 10% target for biodiesel use by 2012. Thailand will invest $3.2 billion into biofuel plantations and 30 refineries.

Malaysia. As the world's top producer and exporter of palm oil, Malaysia is pushing to create a mandatory blending for retail. Leading palm oil planters IOI Corp and Kuok Oil & Grains are separately building two refineries in Rotterdam to process more than 300 million gallons of palm oil/year.

4. North America

- Ethanol has dominated the alternative fuels market in North and South America, but production of biodiesel is starting to grow.

- US. Biodiesel production is now at record levels due to recent tax incentives. Approximately 75-100 mgy of biodiesel were produced in 2005, compared to 500,000 gallons produced in 1999.

- Canada. Federal excise taxes on biodiesel have been reduced, and a 10% renewable fuels mandate split between ethanol and biodiesel is under consideration by provincial governments.

5. South America

- Ethanol from sugarcane has dominated the alternative fuels market in South America, but production of biodiesel has a great potential.

Brazil. Brazil has built a leading position in ethanol production and now aims to become a biodiesel powerhouse. The government's National Biodiesel Program to promote the mass production, distribution and marketing of biodiesel has mandated a 2% biodiesel blend by 2008, rising to 5% by 2013.

- In summary, biodiesel is a growing market across the world. A testimony of biodiesel's potential is reflected in the series of initiatives and capital and political investment already made both in the US and across the world.

6. The US Biodiesel Market

- Compared to the ethanol sector, the US biodiesel market is still in its developing stages. Informa estimates that average biodiesel capacity[118] for 2006 will be 364 mgy; this includes dedicated biodiesel capacity and existing oleochemical capacity that is being used for biodiesel production. Informa's estimate is consistent with other estimates such as 354 mgt provided by the National Biodiesel Board[119] and 300 mgy noted by ADM in February 2006 issue of the Renewable Fuel News. This capacity represents considerable

[118] Production capacity adjusted for the months during a calendar year that plant under construct does not operate. For example, a 12-mgy plant that starts operation the 1st of July will only have production capacity available for 6 months.
[119] Estimate of existing capacity as of 2/2006.

growth as actual production and use of biodiesel in the US was estimated to be about 25 mgy in 2004.

- The development of the US industry is highly dependent on federal and state incentives that enable the production and distribution of biodiesel to compete with petroleum-based diesel. Additionally, a large share market for biodiesel have developed as a result of state and federal government mandates to encourage their use whenever available (e.g. Minnesota) including a federal directive for government agencies to purchase and use biobased lubricants and hydraulic fluids in government-owned transportation fleets.

- Prior to addressing the structure and outlook of the biodiesel industry, it is necessary to examine the policy environment that has and will shape the development of the biodiesel investment in the future.

a) Federal Policy Environment

(1) The Federal Bioenergy Program

- Biodiesel was a minuscule component of the US motor fuel supply as recently as 1999, when production was only 500,000 gallons. However, in 1999, the Clinton administration through Executive Order 13134 established the goal of tripling domestic use of biobased products and bioenergy by 2010. In order to achieve this goal, the administration created the Bioenergy Program to promote the industrial use of selected agricultural commodities in the production of biofuels, using payments from USDA's Commodity Credit Corporation ("CCC," leading to the program also known as "CCC-850"). Initially, payments were based on the increase in an individual facility's usage of eligible commodities for the production of bioenergy, compared to the same time period a year earlier.[120]

- This has been a popular program among ethanol and biodiesel producers. Payments were made on 6.4 million gallons of biodiesel in fiscal year 2001 and 8.9 million gallons in FY2002[121]. The 2002 Farm Bill provided for funding of the program through FY2006, with funding levels targeted at $150 million annually. By FY2004, payments were made on 6.5 million base gallons of biodiesel (payments became available on 15% of base production) and a 12.3 million gallon increase in production. For FY2005, payments were made for a total 63 million gallons. Soybean oil was the predominant feedstock used.

[120] Eligible commodities have typically included barley, corn, grain sorghum, oats, rice, wheat, soybeans, sunflower seed, canola, crambe, rapeseed, safflower, sesame seed, flaxseed, mustard seed, and cellulosic crops (such as switchgrass and short rotation trees) grown on farms in the US and its territories.

[121] Fiscal year October to September.

- While the bioenergy program have provided some incentives to produce biodiesel, the high growth and interest experienced since 2004 have been a result of two factors:
  - (i) the JOBS Act and the Energy Bill of 2004, and
  - (ii) the high petroleum and hence diesel prices.

(2) The JOBS Act and the Energy Bill

- The American JOBS Creation Act of 2004, which was signed in October, established the first national incentive for biodiesel consumption. The main attributes of this program are:

- <u>The incentive involves a credit of $1.00/gallon for biodiesel produced from "virgin" vegetable oils and animal fats and $0.50/gallon for biodiesel produced from recycled oil and grease</u>.

- The credit is available to an entity selling biodiesel at retail or, if the biodiesel is not sold via retail channels, to the entity using the biodiesel as a fuel in its business. <u>Thus, similar to the manner in which the primary federal incentive for ethanol has functioned for years, the incentive is not paid directly to the producer but rather is directed to the biodiesel user</u>, providing an incentive to use biodiesel and the means for biodiesel to be cost-competitive.

- The incentive took effect on January 1, 2005, and was originally set to expire two years later. However, the 2005 Energy Bill extended this program until December 31, 2008.

(3) Extension of the Biodiesel Credit via the Energy Bill

- Additionally, the Energy Policy Act of 2005 was signed into law by President George W. Bush on August 8, 2005. This culminated several years of attempts by Congress to pass an omnibus energy bill. There are two key provisions of the bill for biodiesel.

- The extension of the biodiesel tax credit through December 31, 2008.
- A new Renewable Fuels Standard (RFS) that would require motor fuels sold in the US to contain at least the following volumes of renewables in future years:
  - In 2006: 4.0 billion gallons;
  - In 2007: 4.7 billion gallons;
  - In 2008: 5.4 billion gallons;
  - In 2009: 6.1 billion gallons;
  - In 2010: 6.8 billion gallons;
  - In 2011: 7.4 billion gallons; and

   - In 2012: 7.5 billion gallons[122].

- Starting in 2013, the share that 7.5 billion gallons of renewable fuels represents of the total volume of gasoline sold or introduced into commerce in 2012 will have to be maintained in future years, and a minimum of 250 million gallons derived from cellulosic biomass will have to be used.

- Given the volume of ethanol production capacity (currently 4 billion gallons) compared to biodiesel, it is likely that ethanol will account for a large majority of the RFS volume. However, biodiesel does count toward the RFS, and together with the tax incentive this will spur another advance in biodiesel capacity.

- A trading system also was created that will allow refiners and blenders in areas with little renewable fuels production or constraints on usage to buy credits from areas where it is used widely. The credits would be valid for 12 months.

(4) Additional Incentives and Programs

- In addition to federal programs mentioned, there are other incentives in place that should stimulate investment in biodiesel.

- Credit for Installation of Alternative Fuel Refueling Infrastructure: The installation of infrastructure that dispenses biodiesel-blended fuel (B20 minimum) qualifies for this credit.

- Small Agri-Biodiesel Producer Tax Credit: Establishes a $0.10/gallon tax credit for agri-biodiesel producers. The credit is applicable up to 15 million gallons of agri-biodiesel produced and limited to producers under 60 million gallons of annual production.

- Biodiesel Engine Testing Program: Provides $5 million/year funding authorization (FY2006-2010) to initiate a collaborative research project testing biodiesel in advanced diesel engine and fuel system technology.

b) State Programs and Incentives

- Recent initiatives by several states to encourage biodiesel use—often through mandates that require biodiesel be blended with petroleum diesel sold in

[122] It should be mentioned that a waiver of the RFS volume requirements is provided for in the 2005 Energy Bill, in two cases: (1) if the federal government determines that implementation would "harm the economy or environment of a state, a region, or the United States" or (2) if "there is inadequate domestic supply." Based on the current capacity and ongoing construction in the ethanol industry, the latter condition is unlikely to be a problem through 2006 and 2007, if ever during the timeframe of the 2005 Energy Bill.

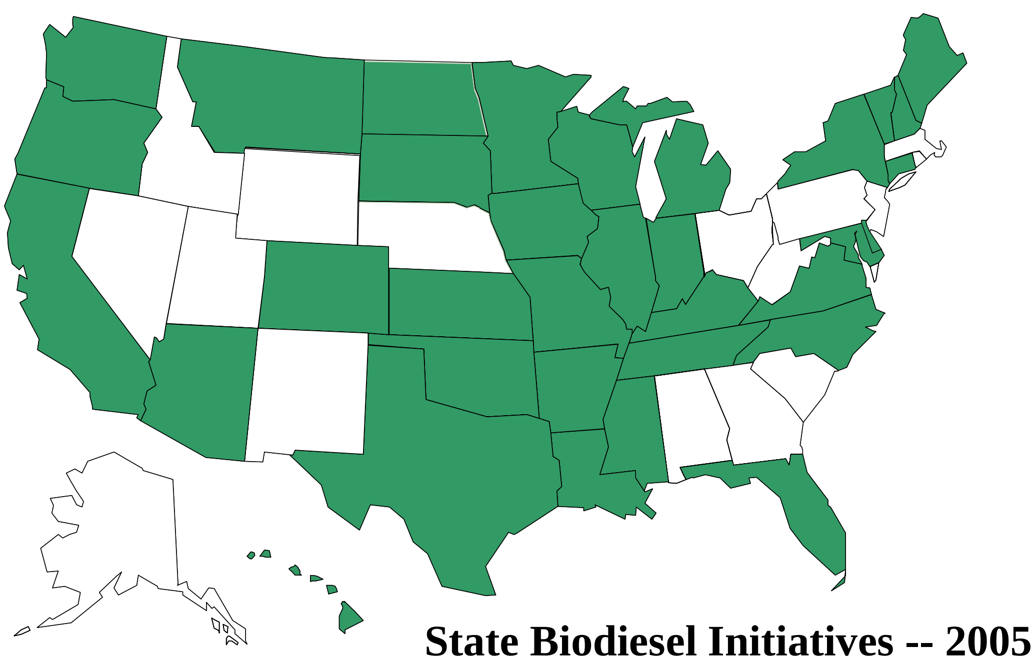
particular markets or throughout the whole state—are expected to increase biodiesel consumption.

- In 2003, Minnesota was the first in the nation to pass state legislation that will require nearly all petroleum diesel sold within the state to be blended with 2% biodiesel. The B2 Law requires Minnesota to have a production capacity of at least eight million gallons of biodiesel fuel per year, and approximately 16 million gallons of biodiesel fuel will be needed to meet the state B2 requirement. The law takes effect whenever Minnesota plants come on line, triggering a 30-day public notification.

- Other states are increasingly taking proactive steps to implement policies to enhance the use of biofuels. State incentives are a critical part of the industry; consider the following:

  - In 2004: 130 biodiesel related bills introduced; 27 passed; (30% increase over 2003)
  - In 2005: 142 biodiesel related bills introduced in 33 states.

Map 6: State Biodiesel Initiatives in 2005



Source: National Biodiesel Board

7. Federal Biodiesel Policy After 2008: Alternative and Implications

- Informa's political analysis leads to the conclusion that Congress will extend the biodiesel tax incentive, now scheduled to expire at the end of December 2008. This reflects strong and growing political support that will be important in Senate, House and presidential elections. That will add impetus for an extension of the tax incentive because both political parties will be coveting control of Congress and the White House. Congressional sources made it clear that anyone who says the tax incentive will not be extended "just has an agenda that won't get passed by Congress."

- Meanwhile, several lawmakers and congressional aides say biodiesel is increasingly being tied to the future of ethanol, and that alternative fuel has overwhelming support in Congress and the Executive branch.

- It is true that this climate could change. The incentive programs are costly, and a budget-cutting frenzy could develop. Even with about the current level of budget cutting intensity, there is a chance that Congress will reduce the biodiesel tax benefit using the argument that such a strong incentive is being made unnecessary by growing production efficiencies.

- By far the most likely scenario is that renewable fuels continue to compete with petrofuels only on the basis of government incentives and/or mandates. In this case, the prospects for extension of the current programs become critical for evaluating investment opportunities. This study concludes that strong support from the Congress and almost any administration can be expected, and that the subsidies will be extended.

- One concern sometimes heard is that biodiesel is more expensive than ethanol to produce—even when adjusted for caloric content—and that if a biofuels program is to be supported, it should be for ethanol, not biodiesel. This argument is supported by the fact that corn productivity is growing faster than soybean productivity is and that for the nation a single renewable fuels focus would be the most efficient. The interviews undertaken in connection with this study suggests that political factors would be expected to override any such considerations. Political support for biodiesel, especially, was found to have a broader commodity and geographic base even than ethanol. Sharp-penciled objections to ethanol policies in the past have been frequently overridden by political concerns about energy security. Concerns about the relative efficiency of ethanol and biodiesel programs are expected to be overridden on similar grounds, especially while the industry is in its infancy, and prospects for future efficiency are still untested.

8. US Biodiesel Production and Capacity Structure and Outlook

- US biodiesel production was roughly 25 million gallons in 2004. However, given the passage of the JOBS Act in late 2004, the 2% state requirement in Minnesota and the passage of the energy bill in 2005, a number of organizations have starter construction and announced plans to build biodiesel production facilities.

- Informa developed a list of active, under construction and proposed plants based on information collected from the National Biodiesel Board, Biodiesel Magazine and other sources including direct inquiries to biodiesel companies. This information obtained and examined became the foundation for Informa's biodiesel outlook. Informa estimated annual capacity (i.e., assigned to the year or portion of the year in which the biodiesel developer claimed to start operations) and production for the corresponding volumes of feedstock used.

a) Current Structure

- The structure of the biodiesel industry, as of February 2006, is summarized below.

- It is estimated that at least 149 mgy of biodiesel capacity were available for production during 2005. This estimate will grow to 356 mgy for 2006.

- Capacity growth was due to (i) construction of new dedicated biodiesel capacity, and (ii) conversion of additional oleo chemical capacity to the production of biodiesel.

- At the time of the study there were:
  - 59 active plants with capacity ranging from 60 thousand gy to 30 mgy and a combined capacity of 322 mgy by year-end 2006.
  - 14 plants under construction[123] with a combined capacity of 205 mgy; about one-third of this capacity would be available for production in 2006.
  - 10 proposed expansion projects with a combined capacity of 62 mgy.
  - 45 proposed new plants with an estimated combined capacity of 692 mgy.

- Production for 2005 is estimated to be between 75 and 95 million gallons. For 2006, production is estimated to reach 298 mgy.

[123] Plants that Informa has verified are under construction. The National Biodiesel Board have indicated that up thirty-five companies have reported that their plants are currently under construction and are scheduled to be completed within the next 18 months (1/2006). Their combined capacity, if realized, would result in another 278 million gallons per year of biodiesel production.

- Approximately 83% of the biodiesel produced use soybean oil as a feedstock. Yellow grease account for about 9%, animal fats for 6% and other vegetable oils for 2%.

- Map 7 shows the distribution of the biodiesel industry. Note although there is a concentration in the Midwest were most of the soybean oil is produced, there are a large number of plants located in the Northeast, South Central and West Coast regions of the country. In these regions, biodiesel production using yellow grease and/or animal fats is more popular and in some cases more feasible.

- An important distinction between biodiesel and ethanol is their geographical distribution. Ethanol production is primarily concentrated in the Midwest, where corn is grown. In the case of biodiesel, production is less concentrated in the Midwest and in fact a large number of facilities are operating or being proposed in a wide range of states (Figure 27). This structural difference is due in part to:

    - The supply of feedstocks such as yellow grease, animal fats and even some of the soybean oil crushing facilities are locate outside the Corn Belt;
    - Some of the operating production capacity is from olechemical companies, which have switched some of their chemical processing capacity to produce biodiesel. In 2005, the National Biodiesel Board estimated that the olechemical industry had 110 million gallons/year of capacity that could be used to produce biodiesel.

- One implication is that biodiesel has a broad geographic support in Washington; hence policies enabling the developing of the biodiesel industry have found support across states – not only from the farm states.

Map 7: Major Biodiesel Facilities Currently Operating, Under Construction or Proposed

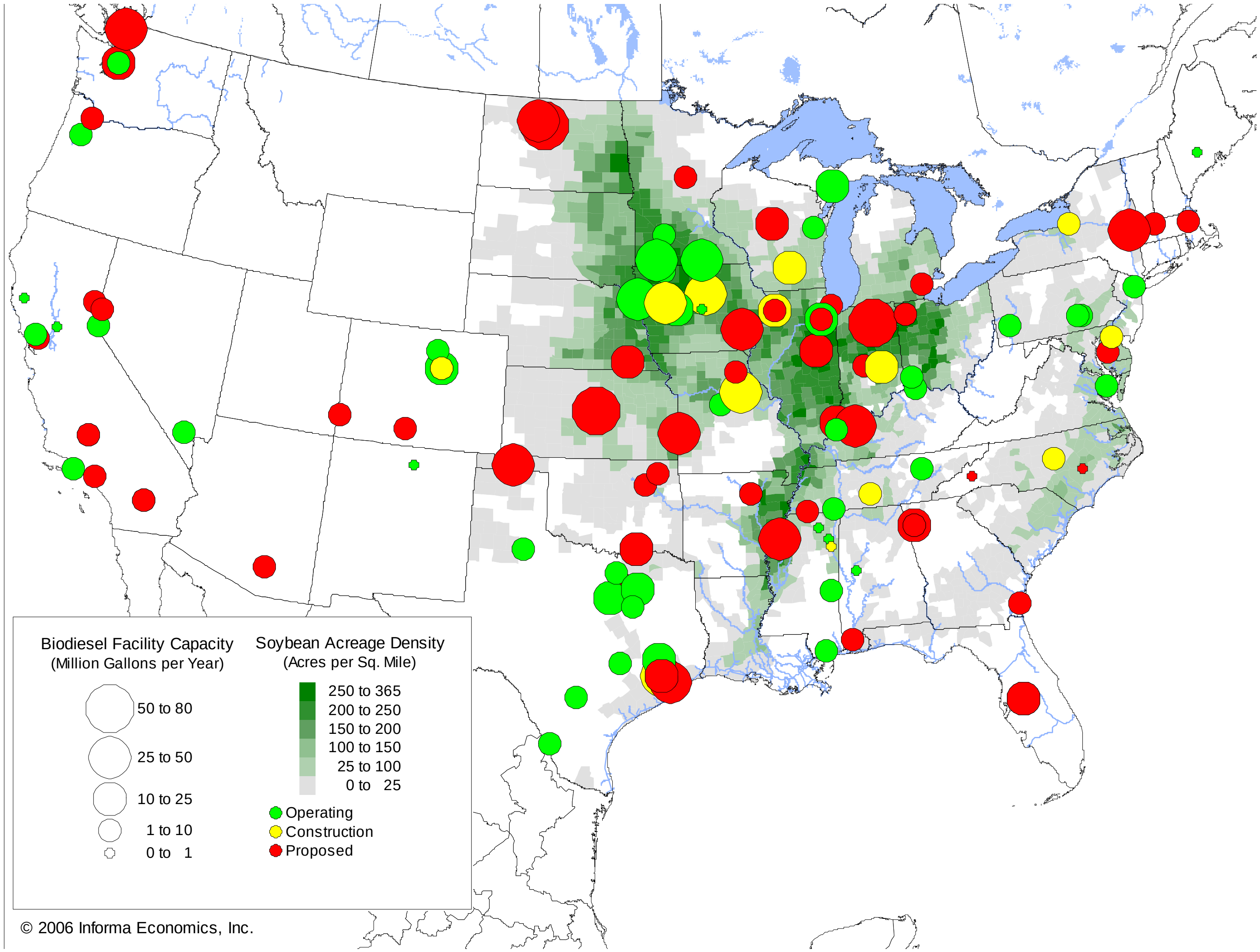
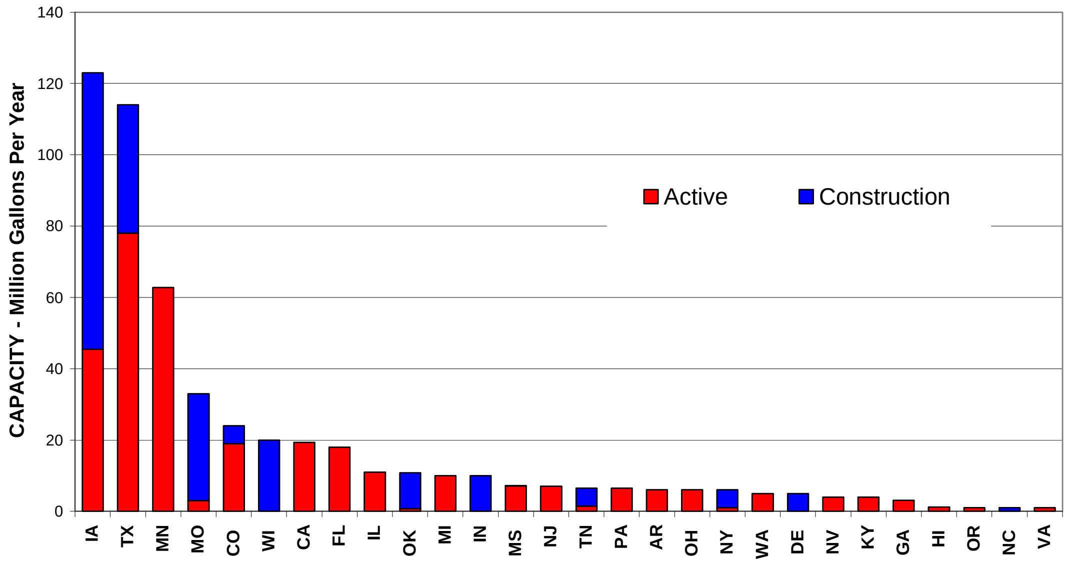


Figure 27: State Distribution of Biodiesel Capacity (Plant Active and /under Construction, 2/2006)



Source: Informa Economics.

b) Demand Implications

- According to the US Energy Information Administration (EIA), diesel demand is expected to increase by a CAGR of 2% for the next 10 years, reaching a total diesel demand of 65.7 billion gallons by 2015. During the outlook period, the US economy industry will increase diesel demand by 11.4 billion gallons. (Note that distillate fuels include diesel and other fuels, primarily heating oil.)

Table 28: US Diesel Demand Outlook[124]

Million Gallons	2003	2004	2005	2006	2007	2008	2009	2010	2015
Residential	0	0	0	0	0	0	0	0	0
Commercial	1,285	1,425	1,267	1,291	1,324	1,362	1,395	1,421	1,535
Industrial	1,587	1,937	1,622	1,653	1,695	1,743	1,787	1,819	1,965
Oil Company	396	471	475	484	496	510	523	533	575
Farm	2,618	3,439	2,756	2,809	2,880	2,962	3,036	3,092	3,340
Electric Power	1,087	625	676	689	707	727	745	758	819
Railroad	2,618	2,814	2,422	2,468	2,531	2,603	2,668	2,716	2,934
Vessel Bunkering	1,580	1,971	1,597	1,627	1,668	1,716	1,759	1,791	1,935
On-Highway Diesel	37,104	37,125	32,644	33,265	34,111	35,087	35,959	36,617	39,555
Military	232	324	259	264	270	278	285	290	314
Off-Highway Diesel	2,160	2,861	2,174	2,216	2,272	2,337	2,395	2,439	2,635
Total Diesel	**50,666**	**52,992**	**54,282**	**55,314**	**56,722**	**58,344**	**59,794**	**60,887**	**65,774**
Total Distillate	**60,202**	**62,384**	**64,207**	**65,428**	**67,092**	**69,011**	**70,727**	**72,020**	**77,800**

124 Heating oil is not included under the estimated diesel demand. Heating oil is particularly a factor in the residential and commercial market segments, but not in the transportation segment.

- While B100 can be used in unmodified diesel engines and heating oil systems, technical barriers restrict this practice to a small market segment (e.g., environmentally motivated consumers). Potential problems with B100[125] include material compatibility with seals, gaskets and other fuel system components, cold weather freezing, storage stability, and NOx[126] emissions. B100's technical problems (other than NOx emissions) can be minimized by retrofitting fuel system components, adding fuel system heaters, and using storage stability additives and biocides if necessary.

- B100 fuels are used in national parks, sensitive waterways and other locations where environmental or human health concerns are especially important (underground mines).

- The most popular biodiesel blends in the marketplace today are:
  - B20 was approved by Congress in 1998 as an EPAct fuel for federal, state, and publicly owned fleets required to meet mandated alternative vehicle use targets.
  - B2 has been promoted at the state level.

- B100 will likely be limited to small niche markets in the foreseeable future because of its potential higher price and because most current equipment would need minor modifications to use B100.[127]

- B20 can be used wherever diesel fuel is used—on-road transportation, equipment used in farming, etc. No equipment modifications are required. B20 reduces (not eliminates) problems associated with cold weather, stability, material compatibility, NOx increases, storage tank cleanliness and costs. By and large, the problems are diluted to the point where they are either manageable or reach an undetectable level.

- Some feedstocks contain high levels of saturated fatty acids—tallow, lard and some yellow grease. Biodiesel produced from these feedstocks have a high risk of freezing in tanks and forming crystals that plug fuel filters. Blending these feedstocks into a B20 reduces but does not eliminate these risks. The technical barrier of saturated feedstocks would imply that vegetable oil-based diesel has an advantage in the Northern US. Although a B20 blend, or lower, reduces the freezing problems, the transport and the blending process of saturated B100 may be problematic.

- Blends such as B2 are <u>currently</u> being sold commercially as a premium diesel fuel.[128] B5 and lower blend levels meet the ASTM standard for diesel fuel

[125] B100: Diesel that has 100% biodiesel. B20: diesel that has 20% biodiesel.

[126] Nitrogen oxide, or NOx, is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts.

[127] Biomass Oil Analysis: Research Needs and Recommendations. National Renewable Energy Laboratory, June 2004.

and all Original Engine Manufacturer warranties. An advantage of B2 is that it adds lubricity, particularly for ultra low sulfur diesel (ULSD) that will be made available nationwide by June, 2006.[129]

- The production process for making ULSD severely reduces its natural lubricity characteristics. Refiners generally plan to use a variety of low cost additives to solve the problem.[130] Petroleum-based lubricity additives would add 0.5 to 0.75 cents per blended gallon. Refiners also have the option of adding biodiesel if the price is competitive. Biodiesel blend of 2% can be blended into bulk storage tanks of diesel fuel upon entry into a respective tank farm, potentially reducing the costs associated with terminal storage and distribution associated with conventional fuel additives.

- Additionally, all feedstocks could be used including saturated animal fats and greases if the blends are smaller, such as B5 or lower. The cold flow performance difference between biodiesel made from various feedstocks narrows at a B2 level to the point where it becomes minor.[131]

c) Demand Implications for the Development of the Biodiesel Market

- The potential demand for biodiesel should not be measured by the total demand of diesel, but rather by a fraction of it that represents a realistic blend given that, at least currently, there are limitations to widespread use of a B100 blend on motor vehicles and other uses.

- A 20% biodiesel blend would be considered the maximum average for the aggregate market for at least the short and medium term (over time, new technology can be developed to increase the usage of biodiesel blends). From a market penetration perspective, a 2% to 5% biodiesel substitution rate would be more realistic. Consider that ethanol, a more developed market, currently only accounts for almost 2.8% of the on-highway gasoline demand.

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[128] The apparent premium will be eliminated as biodiesel becomes a more developed market. A more detailed analysis of prices is included later in this report.

[129] Refineries are required to produce ULSD for US motor vehicles beginning June 1, 2006. Retail locations and wholesaler purchasers/consumers are required to sell ULSD for motor vehicle use beginning September 1, 2006. The US Environmental Protection Agency (EPA) has announced plans to modify the transition period, allowing a slight delay in the ULSD compliance date for retail and wholesaler purchasers/consumers, but the plan does not delay the June 1 refinery requirement to produce ULSD.

[130] It is important to note that to date there are concerns that have come to light during the early introduction of ULSD, which include: over additization causing fuel filter plugging, under additization that could lead to fuel pump failures, and unanticipated reactions between two or more different additive packages that could occur in bulk storage or while traveling across country.

[131] Biomass Oil Analysis: Research Needs and Recommendations. National Renewable Energy Laboratory, June 2004.

- However, even at diesel displacement rates of 2% to 5%, the potential demand for biodiesel far exceeds current production and Informa's industry biodiesel production for the next 10 years.

- Biodiesel demand in the next 10 years will be largely dependent on its price relative to conventional diesel and not by diesel demand market constraints. At the right price (i.e., equal or below conventional diesel), demand for on-highway biodiesel could be as large as 9.7 billion gallons by 2015 (Table 29)

Table 29: Implied Biodiesel Demand from Alternative Diesel Displacement Rates Scenarios

Million Gallons	2005	2006	2007	2008	2009	2010	2015
Total Diesel Demand	54,282	55,314	56,722	58,344	59,794	60,887	65,774
Potential Scenarios							
20% Substitution	10,856	11,063	11,344	11,669	11,959	12,177	13,155
5% Substitution	2,714	2,766	2,836	2,917	2,990	3,044	3,289
2% Substitution	1,086	1,106	1,134	1,167	1,196	1,218	1,315
On-Highway Use	32,644	33,265	34,111	35,087	35,959	36,617	39,555
Potential Scenarios							
20% Substitution	6,529	6,653	6,822	7,017	7,192	7,323	7,911
5% Substitution	1,632	1,663	1,706	1,754	1,798	1,831	1,978
2% Substitution	653	665	682	702	719	732	791
Farm Use	2,756	2,809	2,880	2,962	3,036	3,092	3,340
Potential Scenarios							
20% Substitution	551	562	576	592	607	618	668
5% Substitution	138	140	144	148	152	155	167
2% Substitution	55	56	58	59	61	62	67

Source: EIA, Informa Economics

9. Economics of Producing Biodiesel from Various Feedstock

- Feedstocks make up the largest share of the production costs for methyl esters. Animal fats and vegetable oils generally account for between 80% and 85% of the overall cost of producing a gallon of biodiesel. Meanwhile, the other components, usually an alcohol source and a base catalyst, comprise an additional 4% to 6% of production costs.

- Fats and oils used in biodiesel production come from a variety of plant and animal sources. Even though these feedstocks are generally interchangeable in the production process once they have been pre-processed or refined, their physical and molecular structures can impact the handling and quality characteristics of the methyl esters.

a) Vegetable Oils

- The oil used to produce biodiesel is the most important cost factor in the manufacturing of the fuel. The higher the cost of the feedstock, in general, the higher the production cost of fuel. The current vegetable oil being used in the US is soybean oil, while rapeseed is used in Europe. These oils also have good low temperature flow characteristics.

- It is important to understand how the quality (chemical properties of the oil) varies across feedstocks. Oil expelled from the oilseed using high-pressure extruders is significantly different than oil extracted from the oilseed by solvents (the more common process). Managing the quality of feedstock is extremely important; key variables in oil quality are:

  FFA is the amount of free fatty acids contained in the product. Fats and oils are compounds containing three fatty acids, each chemically connected to an oxygen on a glycerin molecule. Consequently, compounds with this structure are called triglycerides. Free fatty acids are those structures that are no longer connected to the glycerin. They are a degradation product and a measure of the quality of the fat. A high quality fat has a low FFA level.

  MIU stands for moisture, insolubles and unsaponifiables. It is a measure of the remaining compounds in the oil that are not fatty acids or triglycerides. It is also a measure of quality, as is the color. In general, the lower the MIU level, the higher the quality of the oil, and the easier it is to process into biodiesel.

  TITER is the solidification point of the fat or oil in degrees Centigrade, and is a rough measure of the saturation level of the oil or fat. The higher the titer, the more saturated the fat or oil. Highly saturated oils and fats make biodiesel that will gel quicker in a fuel tank than low saturated oils like vegetable oils. This can be an extremely important characteristic.

b) Animal Fats

- Biodiesel has been made from fish oils, poultry fat, beef tallow and pork lard. These oils usually have higher titers (or lower iodine values) than most vegetable oils, and biodiesel made from these oils will often have slightly higher cloud points (the temperature at which the biodiesel starts to form solid crystals) and are less desirable in cold weather areas. Iodine values refer to the grams of iodine taken up by 100 grams of fat. It is a measure of degree of saturation of fatty acids.

c) Recycled or Waste Oils and Greases

- Oils coming from a food cooking/processing operation will have high levels of impurities such as moisture and free fatty acids. Waste oils and greases from commercial and retail cooking and frying can be collected on a regular basis and processed into biodiesel. Commercially, recycled cooking oils are called yellow grease. They may contain some amount of waste vegetable oils (usually hydrogenated or partially hydrogenated so they act more like animal fats) as well as animal fats from cooking operations. Therefore, most of the waste oils and greases are a blend of animal fats and vegetable oils. The color of the biodiesel is normally darker, but the biodiesel can meet ASTM quality standards with the proper technology selection.

Table 30: Analysis of Various Fats and Oils

Animal Fats	**% FFA**	**% MIU**	**% SS**	**TITER**	
Edible Tallow	0.8	0.05	0.00	41.0	
Edible Lard	0.5	0.05	0.00	38.0	
Extra-Fancy Tallow	2.0	1.00	0.00	41.0	
Choice White Grease	4.0	0.50	0.01	36.0	
Yellow Grease	10.0	0.50	0.05	36.0	
Vegetable Oils	**% FFA**	**% MIU**	**Chlorophyll**	**Phosphorus**	**Tocopherols**
Crude, Degummed			*ppm*	*ppm*	*ppm*
Canola	1.0	0.30	>5	>10	25
Corn	4.5	3.00	>3	>3	10
Cottonseed	3.5	0.70	>3	>3	10
Soy	2.5	0.25	>4	>5	11

Source: Bailey's Industrial Oil & Fat Products, Vol. 2 & 5, Fifth Edition

- The chart shows that the quality of the listed fats and oils will vary. The free fatty acids (% FFA), moisture (% MIU) and suspended solids (% SS) vary considerably. The quality of the feedstock is important when selecting the technology used to make biodiesel. In most cases, the oils are caustic-refined to remove the free fatty acids and then flash dried to remove excess moisture, resulting in a high quality oil feedstock to the ester making process. Biodiesel yield per gallon of oil processed will be reduced when free fatty acids are present.

d) US Supply of Oils and Fats, Implications for Biodiesel

- Soybean oil is the predominant oil (72% of 27 million lbs of vegetable oil) produced in the US and will likely be the primary feedstock for biodiesel. The supply of other oils is minor, relative to soybean oil, and more costly.

- Some of the animal fats such as beef tallow supplies could also be shifted to biodiesel (e.g., 1.8 million lbs of fats were exported in 2004/05); however, the main supply limitation of animal fats is that fats production will not increase with biodiesel demand. Biodiesel produced from saturated fats such as tallow also have a high risk of freezing in tanks and forming crystals that plug fuel filters under cold weather conditions (e.g., winter season in the Midwest). Blending these feedstocks into a B20 reduces but does not eliminate these risks. On the positive side, animal fats are a less expensive feedstock.

- Another important and potential feedstock source is imports. Note that the US is a net importer of vegetable oils (418 million lbs this year) and that imports of palm oil, for example, could be used in the future to produce biodiesel domestically.

- A popular feedstock is yellow grease (i.e., recycled restaurant oil); however, the current supply of rendered yellow grease is limited to a maximum of approximately 198 million gallons (i.e., assuming all yellow grease is turned into biodiesel). The growth in the biodiesel and high petroleum prices provides incentive for greater collection of recycled cooking oil and increases the available supply of yellow grease.

Table 31: Feedstock Supply and Biodiesel Potential

	Feedstock Supply					Biodiesel Potential	
	Production	Imports	Exports	Demand	Stocks	Supply Source	
						Net Exports	Production
2004/05			*Million Pounds*			*Million Gallons*	
Vegetable Oils	**26,858**	**3,638**	**3,220**	**26,610**	**2,538**	**313**	**3,322**
Coconut	0	900	12	774	245		0
Corn	2,425	55	825	1,688	120	107	337
Canola	776	1,150	275	1,652	90		108
Cottonseed	923	2	60	894	80	8	128
Palm	0	850	20	821	150		0
Palm Kernel	0	500	3	501	60		0
Peanut	159	30	10	175	15		22
Safflower	56	55	40	85	10		8
Soybean	19,313	15	1,400	17,300	1,703	192	2,680
Sunflower	283	75	115	253	30	6	39
Total							
Animal Fats	**8,884**	**74**	**1,875**	**7,088**	**335**	**250**	**1,233**
Edible Tallow	1,787	1	300	1,484	25	42	248
Inedible Tallow	3,609	65	1,400	2,280	240	185	501
Lard	1,135	6	160	983	10	21	158
White Grease	1,175	2	15	1,163	45	2	163
Poultry Fat	1,178	0	0	1,179	15	0	164
Yellow Grease	**1,425**	**0**	**325**	**1,106**	**55**	**45**	**198**
Fats and Oils	**37,167**	**3,712**	**5,420**	**34,804**	**2,928**	**608**	**4,753**

Source: USDA, Informa Economics.

10. Potential for Biodiesel

- The feedstock implications and potential for biodiesel need to be examined in the short and long term.

Short Term

- Biodiesel feedstock will be shifted primarily from the export markets and potentially from inventories. Thus, virgin vegetable oil biodiesel production will likely come primarily from soybean oil; it currently has the largest exportable supply and lowest vegetable oil cost (corn oil exports are also large, but this oil is on average 4.5 cts/lb more expensive than soybean oil).

- In the short run, supply of yellow grease will be important but, as mentioned earlier, in the long run there is not sufficient supply to sustain a large biodiesel industry. Furthermore, inconsistency of supplies of yellow grease makes this feedstock mode difficult to handle (hence higher processing costs) and can potentially limit its use in biodiesel.

- Yellow grease is popular among smaller or medium size (1 to 15 mgy) biodiesel producers located near large urban centers (the supply distribution of yellow grease is relatively similar to the US population density, as this is where food service is concentrated). For example, large producers will need to source 15% of the total supply of *rendered* yellow grease (1.4 million lbs in 2004/05) in order to run a 30 mil gal/yr facility.

- Some of the exportable supplies of animal fats could be used for biodiesel, especially because of the cost advantage of animal fats over vegetable oils. In the long run, animal fats supplies can be shifted from other uses such as feed, where animal fats are priced at a premium over corn, a substitute product in feed rations. Animal fats products such as tallow or poultry fat are marketed at a premium over corn in terms of their caloric content; for example, the price of inedible tallow is 1.6 times higher in terms of caloric content than corn.[132] On the biodiesel market, animal fats are priced at a discount over vegetable oils in terms of their energy content.

Long Term

- Imports, particularly palm oil, can provide additional supplies for the biodiesel market. Palm oil in the world market is priced comparatively to soybean oil and has ample exportable supplies and production growth prospects, especially in Southeast Asia. Prospects for a palm oil-based biodiesel plant will be more likely in oilseed deficit regions or regions closest to the import sources such as Texas or California, but not Iowa. The US imported 850 million lbs of palm oil in 2004/05. Informa's oilseed and biodiesel outlook estimates an increase of palm oil imports.

- Additionally, growth in the biodiesel sector in the long run can increase the supply of US soybean oil from:
    - (i) increased planted soybean acreage (or acreage shifts from wheat or other small grains);
    - (ii) increased crushing volume and capacity; and
    - (iii) supply shifts from other uses (e.g., feed) to biodiesel.

- Note that 1.1 billion bushels of soybeans were exported in 2004/05; this is equivalent to 11.8 billion lbs of oil if crushed domestically.

Extensive and large-scale implantation of biodiesel will require a stable and secure supply of the product. If biodiesel is to make a significant entry, it will be priced comparably to diesel fuel and without much economic hardship to fuel marketers and consumers. Stable supply and competitive costs is not a significant issue for biodiesel niche markets where consumers buy biodiesel for environmental or other reasons – but not price. However, these consumers typically make up a small segment of the diesel market.

132 Concentrated forms of energy such as animal fats have some benefits over corn. The price per caloric content is not the only variable examined by livestock operations when selecting a particular feed ingredient.

From a supply perspective, vegetable oil and more notably soybean oil will be the primary feedstock used in the production of biodiesel. Consider the following:

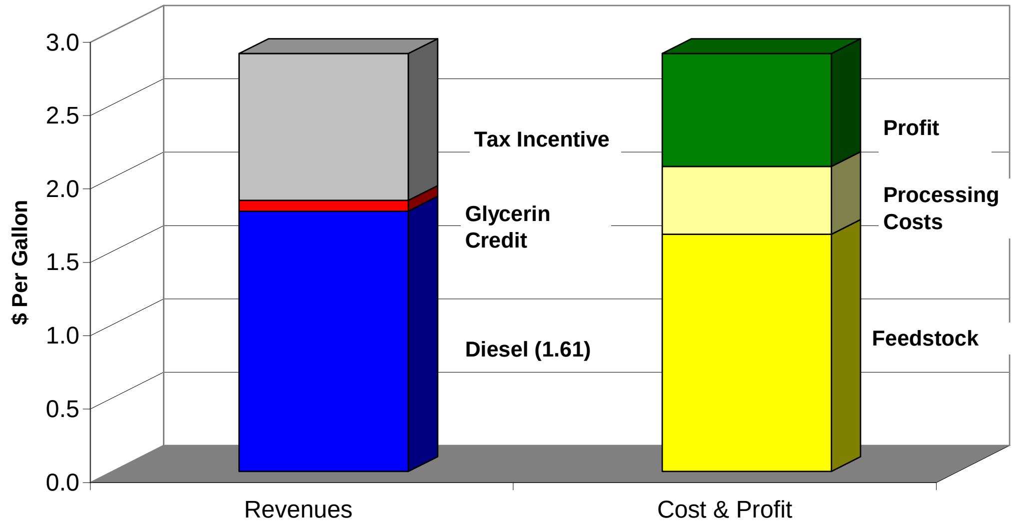
- Soybean oil is currently the most abundant feedstock in the US.
- The soybean industry, producers and processors, has been one of the major sources in the growth and commercialization of biodiesel.
- Federal incentives favor vegetable oil vs. yellow grease.
- Soybean oil is the least expensive vegetable oil.
- Biodiesel produced from animal fats freeze at higher temperatures.
- Of the proposed plants that Informa has information regarding their size and feedstock proposed use, 83% is for soybean oil, 10% is for yellow grease, 5% from animal fats and 2% from other vegetable oils.

11. Economics of Feedstock Costs for Biodiesel Production

- Biodiesel is expensive to produce because it requires a high-value feedstock—vegetable oil or animal fats. It takes about 7.43 pounds of refined soybean oil to make a gallon of biodiesel. For example, with soybean oil at 22 cts/lb, each gallon of biodiesel feedstock would cost $1.61 plus additional costs of refining, transportation, storage, etc.—considerably more than ethanol with feedstock costs of perhaps $0.81/gallon at corn prices of $2.20/bushel. However, biodiesel contains much more energy than ethanol. Each gallon of ethanol contains 76,330 btu, while the comparable number for biodiesel is approximately 128,000. To compare biodiesel and ethanol feed stock costs on a comparable btu basis implies a closer match ($0.81/gallon of ethanol, compared with $0.96) but still somewhat higher costs for biodiesel feed stock. Thus, even considering the higher energy content of biodiesel, ethanol currently has a cost advantage over biodiesel.

- The economic feasibility of biodiesel is a function of (1) feedstock costs, (2) price of diesel, (3) tax incentives/credits, (3) glycerin credit and (4) processing costs (i.e., energy, chemicals, labor, capital, etc.) Figure 28 shows the current economic structure for soybean-based biodiesel. Note that this structure is based on average 2005 diesel prices of $1.77/gal (i.e., petroleum prices of $62/barrel) and soybean oil prices of 21.1 cts/lb.

Figure 28: Economics of Biodiesel – Example with Soybean Oil for 2005



Source: Informa Economics

- Table 32 summaries the main economic drivers of biodiesel production, including processing costs, by feedstock.

  Feedstock Costs *(based on 2000MY to 2005MY average prices)*

  - Soybean and imported palm oil are the most competitive vegetable oil sources; however, it is important to note that the price used for palm oil is a CIF (commodity, insurance and freight) at a US gulf port (e.g., Galveston, TX). Hence, if palm oil is transported to Iowa, for example, the price will increase to reflect transportation costs of about 14 cents/gallon[133] and erode most of the palm oil price advantage over soybean oil.
  - Over the past five years, the price for crude soybean (Decatur) oil has averaged 21.11 cts/lb, which is equivalent to $1.62/gal.
  - Animal fats and grease are less costly than vegetable oils but when all costs and credits are considered, the price advantage over soybean oil is minimal. If the quality (freezing in cold temperatures) and supply concerns of animal fat and grease based biodiesel and glycerin are taken into account, the relative competitiveness of these feedstocks is further reduced.

133 Estimate based on current (9/2005) BNSF rates from Galveston, TX to Iowa.

Processing and Pretreatment Costs

(Average processing costs for a 30 mgy plant))

- Processing costs include energy, chemicals (e.g., methanol), process labor, capital investment depreciation and maintenance, sales and quality control.

- Processing costs are higher for animal fats and greases than for vegetable oil; the difference is approximately 15 cts/gal.

- Processing costs represent from 10% to 15% of the biodiesel operating costs. Hence, feedstock costs account for 85% to 90% of costs.

- Pretreatment costs to refined crude oil are estimated to be about 8 cts/gallon (1.07 cts/lb). If this option is not included and a plant uses refined oil instead, the price of crude oil would need to be adjusted to reflect oil-refining margins, which can range from 3 cts/lb to 4 cts/lb.

- It is important that biodiesel plants that use yellow grease are typically smaller than those that use vegetable oil. Processing costs of smaller plants are anywhere from 4 cts/gal to 30 cts/gal higher than for a 30 mgy plant.

Biodiesel Margins

- Only yellow grease-based biodiesel shows a positive margin of 6cts/gal before the tax incentive is included. The results imply that other feedstocks examined would experience potentially negative margins in the absence of the government incentives (or higher diesel prices).

- After the $1.0/gallon of virgin oil and animal fats and the $0.50 for recycled greases is included, all feedstocks except for peanut and sunflower oil become cost competitive and show positive operating margins ranging from 20cts/gal to 112cts/gal.

- Relative to the operating margin for soybean oil (67 cts/gal), only palm oil and animal fats show a better potential operating margin (Table 32).

Table 32: Economics of Biodiesel Production by Feedstock

	Biodiesel Feedstock Costs			Processing Costs						Margins	
	***2000-2005** Average Feedstock Prices*										
	Feedstock Costs /2	Feedstock Costs/4	Margin over Diesel	Pretreatment and Processing	Glycerin Credit	Feedstock+ Processing	Fuel Freight, Handling, Marketing Exp.	Margin over Diesel	Tax Incentive	Margin over Diesel	Margin over SBO
Vegetable Oils	Cts/lb	Cts/Gal	$/Gal	$/Gal	$/Gal	$/Gal	$/Gal	$/Gal	$/Gal	$/Gal	$/Gal
Coconut	22.48	1.72	0.05	0.46	0.05	2.13	0.08	-0.44	1.00	0.56	-0.11
Corn	23.62	1.81	-0.03	0.46	0.05	2.22	0.08	-0.52	1.00	0.48	-0.19
Canola	24.75	1.89	-0.12	0.46	0.05	2.30	0.08	-0.61	1.00	0.39	-0.28
Cottonseed	27.27	2.09	-0.31	0.46	0.05	2.50	0.08	-0.80	1.00	0.20	-0.47
Palm /3	19.77	1.47	0.31	0.38	0.05	1.80	0.08	-0.10	1.00	0.90	0.23
Peanut	47.14	3.61	-1.84	0.46	0.05	4.02	0.08	-2.33	1.00	-1.33	-1.99
Soybean	21.11	1.62	0.16	0.46	0.05	2.03	0.08	-0.33	1.00	0.67	
Sunflower	30.04	2.30	-0.53	0.46	0.05	2.71	0.08	-1.02	1.00	-0.02	-0.68
Animal Fats											
Edible Tallow	17.18	1.32	0.46	0.61	0.04	1.89	0.08	-0.20	1.00	0.80	0.14
Inedible Tallow	15.44	1.18	0.59	0.61	0.04	1.76	0.08	-0.06	1.00	0.94	0.27
Lard	18.12	1.39	0.39	0.61	0.04	1.96	0.08	-0.27	1.00	0.73	0.06
White Grease	15.35	1.18	0.60	0.61	0.04	1.75	0.08	-0.06	1.00	0.94	0.28
Poultry Fat	13.08	1.00	0.77	0.61	0.04	1.58	0.08	0.12	1.00	1.12	0.45
Yellow Grease	12.09	0.93	0.85	0.61	0.04	1.50	0.08	0.19	0.50	0.69	0.03

Diesel Reference Price ($/gal); 2005 Average

Average Spot Price (NY, Gulf, Los Angeles) for No 2 Diesel Low Sulfur FOB ($/gal) - 1.774

Oil WTI Spot Price FOB (Dollars per Barrel) - 62

Price Notes

Soybean Oil, Crude FOB Decatur (Cents/Pound)
Corn Oil, Crude FOB Decatur (Cents/Pound)
Cottonseed Oil, PBSY Mississippi Valley (Cents/Pound)
Sunflower Oil, Dakotas (Cents/Pound)
Coconut Oil, Crude CIF Pacific (Cents/Pound)
Canola Oil, Crude Toronto (Cents/Pound)
Poultry Fat (Arkansas)
Palm Oil, RBD CIF US Gulf (Cents/Pound)
Peanut Oil, Southeast (Cents/Pound)
Edible Tallow, FOB Chicago (Cents/Pound)
Loose Lard, FOB Chicago (Cents/Pound)
Yellow Grease - 10 Acid, Delivered New York City (Cents/Pound)
Choice White Grease, Delivered New York City (Cents/Pound)
Tallow - Packer (FOB Chicago)

1/ Includes pretreatment and processing costs for crude oil. Pretreatment costs when applicable are assumed to be 7.5 cts/gallon (Lurgi PSI)

2/ These prices are for crude vegetable oil. The analysis assumes that a pretreatment (or refining unit) would be in place. These costs are added to the processing costs.

3/ Palm oil prices are for refined oil; hence pretreatment costs are not included.

4/ The yield of crude oil to biodiesel is on average 97%. The yield from refined oil to biodiesel is one.

Sources: Multiple sources, Lurgi PSI, Informa Economics.

- o As noted earlier, the economics of biodiesel are driven by diesel and feedstock prices. Table 33 shows the biodiesel gross margin (including capital costs and handling/marketing charges) based on alternative price scenarios.

- o At current soybean oil prices of 19cts/lb and diesel prices of $1.75/gal, the gross margin per gallon is about $0.77/gal. That implies that a 30-mgy facility this year could have a gross profit of $23.1 million; that is equivalent to 75% to 80% of the capital equipment costs required to build a new biodiesel plant.

- o Under current soybean oil prices, the break-even[134] net wholesale biodiesel price for SBO based biodiesel is close to $1/gal, which implies a petroleum price of $35/barrel. This means that if petroleum prices drop below $35/barrel, the operating costs of producing biodiesel would be greater than the operating revenues. Keep in mind that this break-even cost is for a "generic" plant. For a specific location, the break-even point could be slightly higher.

Table 33: Biodiesel Gross Margin Scenarios

		Cts/Gal	CBOT Soybean Oil (Average Nearby Future)							
			Low		**- 2stv**	**Avg.**	**+ 2stv**		**High**	
		#2 Diesel	**14.0**	**16.7**	**19.4**	**22.1**	**24.8**	**27.5**	**30.2**	SBO - Cts/lb
	$/Barrel	**Cts/Gal**	104	124	144	164	184	204	224	SBO - Cts/Gal
Average of Cushing, OK WTI Spot Price FOB	**20**	55	**(1)**	**(21)**	**(42)**	**(63)**	**(83)**	**(104)**	**(125)**	
	30	85	**29**	**8**	**(12)**	**(33)**	**(54)**	**(74)**	**(95)**	
	40	115	**59**	**38**	**18**	**(3)**	**(24)**	**(44)**	**(65)**	
	50	145	**89**	**68**	**47**	**27**	**6**	**(15)**	**(35)**	
	55	160	**104**	**83**	**62**	**42**	**21**	**0**	**(20)**	
	60	175	**119**	**98**	**77**	**57**	**36**	**15**	**(5)**	
	65	190	**134**	**113**	**92**	**72**	**51**	**30**	**10**	
	70	205	**149**	**128**	**107**	**87**	**66**	**45**	**25**	
	80	234	**178**	**158**	**137**	**116**	**96**	**75**	**54**	

* Based on processing costs of a 30MGY facility.
Source: Informa Economics

12. Biodiesel Outlook

- It is important t look at the developments of the ethanol industry to construct a potential analogs scenario for the biodiesel sector. Based on the experience of the ethanol industry, it is unlikely that all of the proposed facilities – and

[134] The price at which revenues (biodiesel price) equal costs (feedstock + glycerine credit + tax incentive + processing costs).

even some of the planned expansions – will come to fruition. This overshooting of projected capacity occurred despite the fact that the ethanol industry had been established for two decades and was the recipient of a long-established excise tax exemption (now converted into a tax credit), whereas the biodiesel industry has emerged in roughly the last five years and its main tax incentive is currently scheduled to sunset at the end of 2008. Therefore, it is likely that not all of the biodiesel capacity currently planned will actually be built and come online.

- Unlike ethanol, which has a track record of consumption in certain clean-air programs and in certain geographies, the consumption of biodiesel is a relatively recent phenomenon, and the combination of the Renewable Fuels Standard contained in the Energy Policy Act of 2005 and the tax incentive that has been available since the beginning of the year is likely to propel biodiesel consumption far beyond historical volume levels. Accordingly, biodiesel consumption forecasts were constructed by taking into account several factors:

    - For the near-term forecasts, volumes were based on estimates of production capacity coming online. Based on the experience with the ethanol industry, it was assumed that not all of the announced construction and proposed facilities would come to fruition.

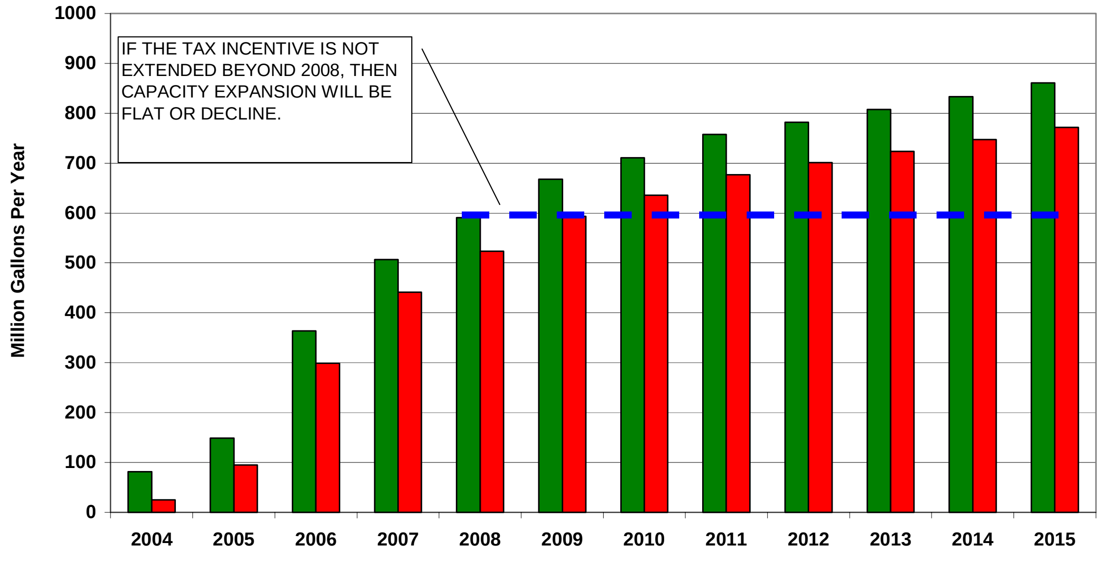
    - In determining what proportion of the biodiesel volume would be produced from soybean oil versus other feedstocks, the announced feedstock orientation of existing and planned plants was utilized in the near term, but for the long term a review of the literature and industry contacts regarding the competitiveness of various feedstocks was taken into account.

    - For the end-point of the forecast in 2015, the experience with biodiesel adoption rates in other countries (mainly Germany) and ethanol adoption rates in the US was considered, and the forecast was tempered due to the uncertainty over whether the biodiesel tax incentive will be maintained past 2008, at least at the same magnitude.

    - If the tax incentive is not extended beyond 2008, then capacity expansion, if any, will be limited. Without the $1/gallon tax incentive, biodiesel production will not be profitable unless crude oil prices are in excess of $70-$75/barrel --assuming average crude soybean oil prices are in the 22 cts/gal to 24 cts/gal range.

    - Based on these factors, biodiesel capacity is forecast to be 688 million gallons in 2008 and rise steadily to 711 million gallons by 2010 (Figure 28). By 2015, Informa's outlook is close to 860 million gallons. It is expected that the share of total feedstock usage accounted for by soybean oil will average 82%. Animal fats, other vegetable oils and, to a lesser extent, greases are expected to account for the remaining 18% of the feedstocks for biodiesel.

Figure 29: US Biodiesel Historical and Forecasted Production



Source: Informa Economics

- The outlook for the biodiesel industry implies a use of 3.9 billion pounds of soybean oil by 2010, which would represents 17.8% of Informa's soybean oil supply outlook (Table 34). This is a significant increase of "new demand" that will result on reduce soybean oil exports.

- By 2010, biodiesel will account for 1.7% of the projected demand for oh-highway diesel fuel. To put this statistic into perspective, ethanol's current share of the on-highway gasoline fuel market is close to 2.5%.

- Based on Informa's outlook for biodiesel and ethanol production, biodiesel will represent a small (7.3% by 2010) but growing share of the renewable fuels market.

Table 34: Implications of the Biodiesel Production Outlook

CY	Unit	2004	2005	2006	2007	2008	2009	2010	**2015**
Biodiesel Production	Mil. Gal	25	95	299	442	524	594	637	773
Biodiesel from Soybean Oil	Mil Gal.	21	74	249	369	437	496	519	635
Soybean Oil - Crude	Mil. Lbs	159	564	1,906	2,827	3,349	3,797	3,974	4,866
Soybeans	Mil Bu.	14	51	172	255	302	342	358	438
Indicators						**%**			
% of SBO Supply	**%**	0.8	2.7	8.8	12.8	15.1	17.1	17.8	21.1
% of SB Supply	**%**	0.5	1.6	5.0	6.7	8.0	9.6	10.5	13.0
% of Renewable Fuels/ 1	**%**	0.7	2.4	5.9	6.4	6.2	7.0	7.3	
% of Total Diesel	**%**	0.0	0.2	0.5	0.8	0.9	1.0	1.0	1.2
% of On-highway Diesel	**%**	0.1	0.3	0.9	1.3	1.5	1.7	1.7	2.0

1/ Ethanol and Biodiesel
Source: DOE, USDA, Informa Economics.

- There are some challenges and threats the industry will phase in the future that could limit its development prospects. These include: government incentives, diesel prices, imports of palm oil and/or biodiesel and availability of vegetable oil crushing and refining capacity.

Implications of Government Biodiesel Incentives

- As stated earlier, without the $1/gallon tax incentive, biodiesel production will not be profitable unless crude oil prices are in excess of $65 per barrel, assuming current soybean oil prices of 19 cts/lb. If soybean oil prices are close their long term average of 20 cts/lbs to 22cts/lb, then crude oil prices will need to be in the $70 -$75/barrel.

- The current biodiesel gross margin[135] ranges from $0.60 to $0.85/gallon, hence the industry could not be profitable without the $1/gallon tax incentive. However, the industry could be if the government tax credit is reduced $0.50/gallon; that is comparable to the incentive for ethanol.

- Informa's assessment of the future of the federal biodiesel credit is that it will likely be extended mainly because the program has a broad and bipartisan legislative support. However, if the political and economic landscape (e.g., implications of an increasing budget deficit) changed before 2008, there is a possibility that the credit would be reduced (e.g., 0.50 gal) or not extended.

- Without government support (i.e., federal credit, mandated use of biodiesel, state incentives), the industry could not be developed unless crude oil prices are in excess of $70-$75/barrel (Table 33).

[135] Biodiesel Gross Margin = (biodiesel + glycerin credit) - (feedstock + processing costs).

Availability of Crushing Capacity

- An important to examine in more detail the impact that the increase production of biodiesel will have on the supply of soybean oil and the industry crushing and refining capacity.

- Official statistics do not exist regarding soybean oil refining capacity, or refining capacity for vegetable oils and fats in general. Therefore, it is not possible to determine current levels of capacity utilization or the levels that would be implied by expected growth in the biodiesel industry. However, inferences can be made based on statistics that are reported on crude soybean oil production and usage and refined soybean oil production.

- On average, over the last five years (Oct.-Sep. crop marketing years) production of crude soybean oil has been 18.5 billion pounds/year, of which 16.9 billion pounds have been used domestically (Table 35). Refined soybean oil production has averaged 15.4 billion pounds; adjusted for the loss of material that results from the refining process, 94% of the crude oil that has been consumed domestically has been refined. On average, 87% of all crude soybean oil produced in the US (including oil exported in crude form) has been refined.

Table 35: Refined Soybean Oil Production Compared to the Production and Domestic Use of Crude Oil (Mil. Lbs.)

Refined Soybean Oil Production Compared to the Production and Domestic Use of Crude Oil (Mil. Lbs.)

Crop Year	Crude Oil Production	Crude Oil Domestic Use	Refined Oil Production	Refined as % of Crude Production, Adj. For Refining Loss	Refined as % of Crude Domestic Use, Adj. For Refining Loss
1992/93	13,778	13,012	12,184	92%	97%
1993/94	13,951	12,939	12,308	92%	99%
1994/95	15,613	12,913	12,435	83%	100%
1995/96	15,240	13,465	12,299	84%	95%
1996/97	15,752	14,267	12,351	81%	90%
1997/98	18,143	15,261	13,389	77%	91%
1998/99	18,078	15,653	13,002	75%	86%
1999/00	17,825	16,058	14,782	86%	95%
2000/01	18,420	16,318	14,779	83%	94%
2001/02	18,898	16,833	15,559	85%	96%
2002/03	18,430	17,083	15,695	88%	95%
2003/04	17,080	16,894	15,197	92%	93%
2004/05E	19,313	17,300	15,521	83%	93%
Maximum Monthly Production					
Oct. 2002	1,693	1,660	1,452	89%	91%
Annualized	20,311	19,924	17,420		
% of 5-Yr. Avg.	110%	118%	113%		

- The highest monthly production level during this time period was 1.45 billion pounds in October 2002. If this level of refined soybean oil production were maintained across an entire year, the equivalent annualized volume would be

17.4 billion pounds. This is 1.7 billion pounds higher than the peak annual production of refined soybean oil during the last five years (11% higher), and 2.1 billion pounds above the average annual level (13% higher).

- Assuming that the federal tax credit for biodiesel usage is maintained, consumption of all oils and fats for biodiesel production would be forecast at 668[136] million gallons in 2010/11, of which 551 million gallons or 4.2 billion pounds would be soybean oil-based.

- It is likely that the expansion of the biodiesel industry could cause soybean oil to be "bid away" from the export market. On average, roughly 500 million pounds of refined oil are exported annually from the US, while 1.2 billion pounds of crude soybean oil are exported, though crude oil volumes vary significantly from year to year (Table 36).

- Thus, redirected exports of refined oil could meet approximately 12% of the 2010/11 need for soybean oil in biodiesel production, but unless additional refining capacity is built or capacity utilization rates are increased as discussed above, any remaining volumes diverted from export would need to be utilized by facilities with pre-processing equipment that allows them to take in crude oil.

Table 36: Composition of US Soybean Oil Exports

		October-September Crop Year					Oct.-July Comparison	
Commodity	**Tariff Code**	**1999/00**	**2000/01**	**2001/02**	**2002/03**	**2003/04**	**2003/04**	**2004/05**
Crude Soybean Oil	1507100000	873	989	1,983	1,563	511	430	785
Percent of Total		64%	72%	79%	70%	58%	58%	75%
Fully Refined Soybean Oil	1507904050	330	284	365	503	293	245	202
Percent of Total		24%	21%	15%	22%	33%	33%	19%
Once-Refined Soybean Oil	1507904020	154	104	160	173	79	63	65
Percent of Total		11%	8%	6%	8%	9%	9%	6%
Total		1,357	1,377	2,508	2,240	882	738	1,052

Source: USDA-Foreign Agricultural Service

13. Additional Information Gained from Interviews

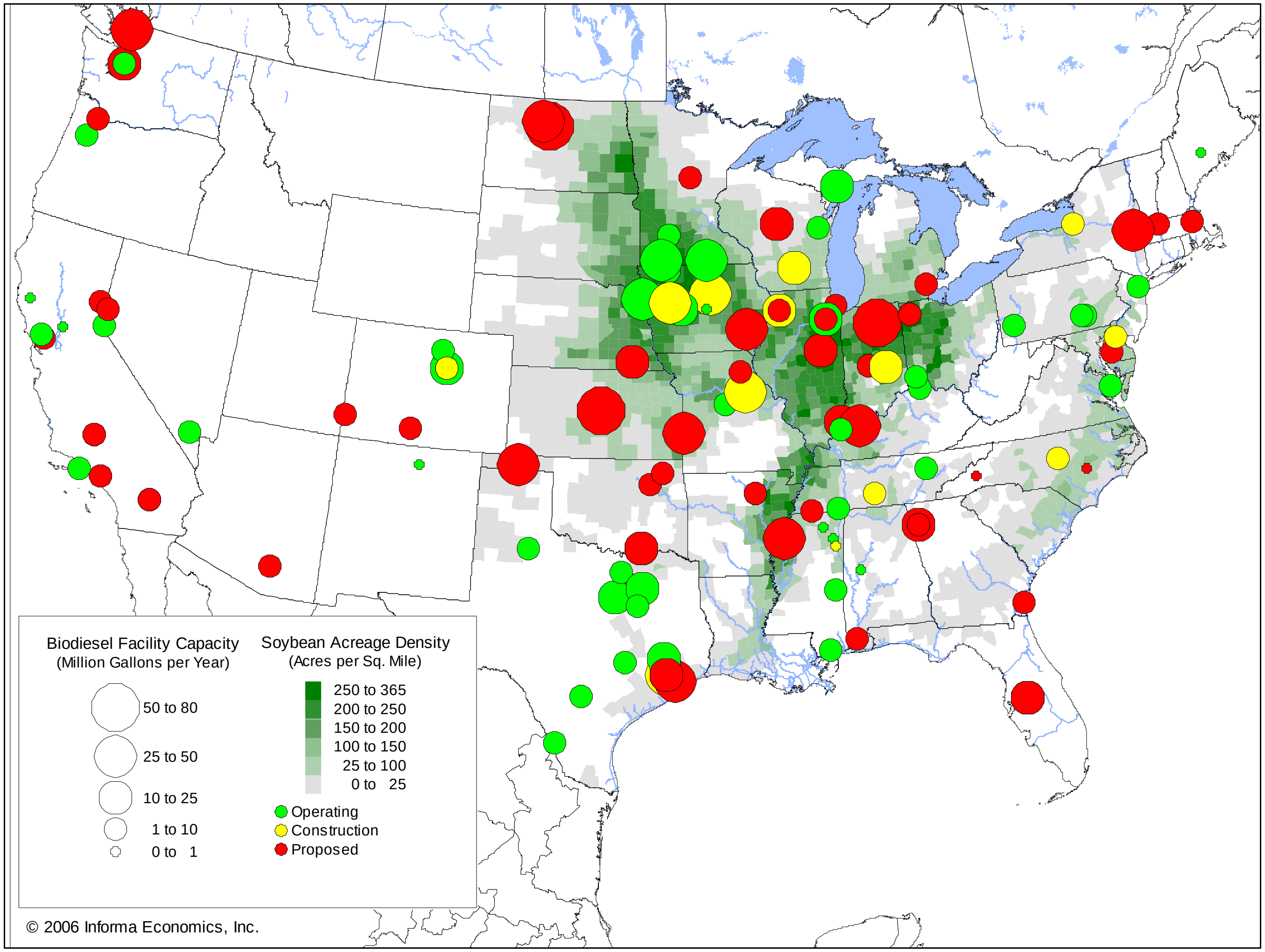
- As mentioned above, since official statistics are insufficient to provide an overall "picture" of the status of the refining industry and likely responses to biodiesel growth in the future, interviews were conducted with representatives of key, large-scale soybean oil producers and users. The general consensus was that integrated crushing/refining companies would want to perform the refining function rather than selling crude soybean oil to biodiesel facilities with pre-processing equipment, and that refining capacity either is currently sufficient to meet the demand that is on the horizon for the next few years or could be expanded at acceptable cost (and without long lag times) to meet

[136] Marketing year.

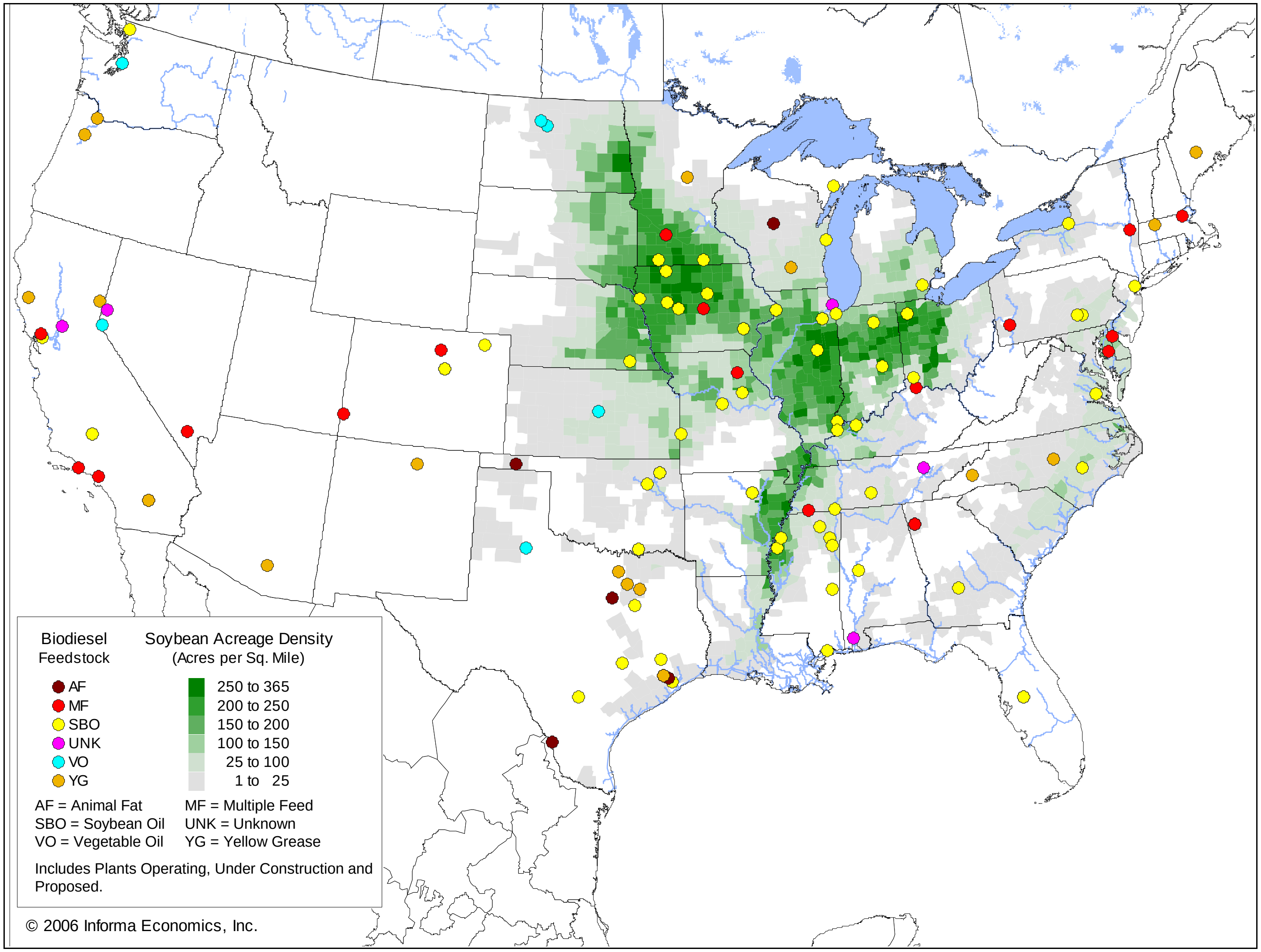
demand from biodiesel producers; however, given that oil has represented only 36% of the combined meal and oil product value to crushers and that the tax incentive currently is slated to expire at the end of 2008, it is unlikely that additional crushing capacity would be built specifically to meet biodiesel demand in the short to medium term. While it is known that a handful of companies have built or are building crushing facilities that would be tied in with biodiesel production, it is unlikely that the major crushers that control a large share of the industry will expand their overall crush capacity to meet the biodiesel market in particular.

- The emergence of the ethanol industry has been characterized as having plants that are relatively close (localized) to the production of the feedstock source, i.e., corn. As profit margins have expanded, with the rise in oil, plants are beginning to migrate away from the feedstock source to what are called destination markets, where the corn is now being shipped long distances to be processed into ethanol. The biodiesel industry is emerging as more of a blend between destination processing and localized processing. Map 8 through Map 11 highlight the proximity of biodiesel production relative to a number of important variables such as soybean production, soybean crushing facilities, animal production regions (hogs and poultry) and the type of feedstocks being used by the plants. The majority of biodiesel capacity will likely gravitate near the production of soybeans/soybean oil, however, because the diversity of feedstock used, plant locations will vary more widely geographically relative to the ethanol industry.

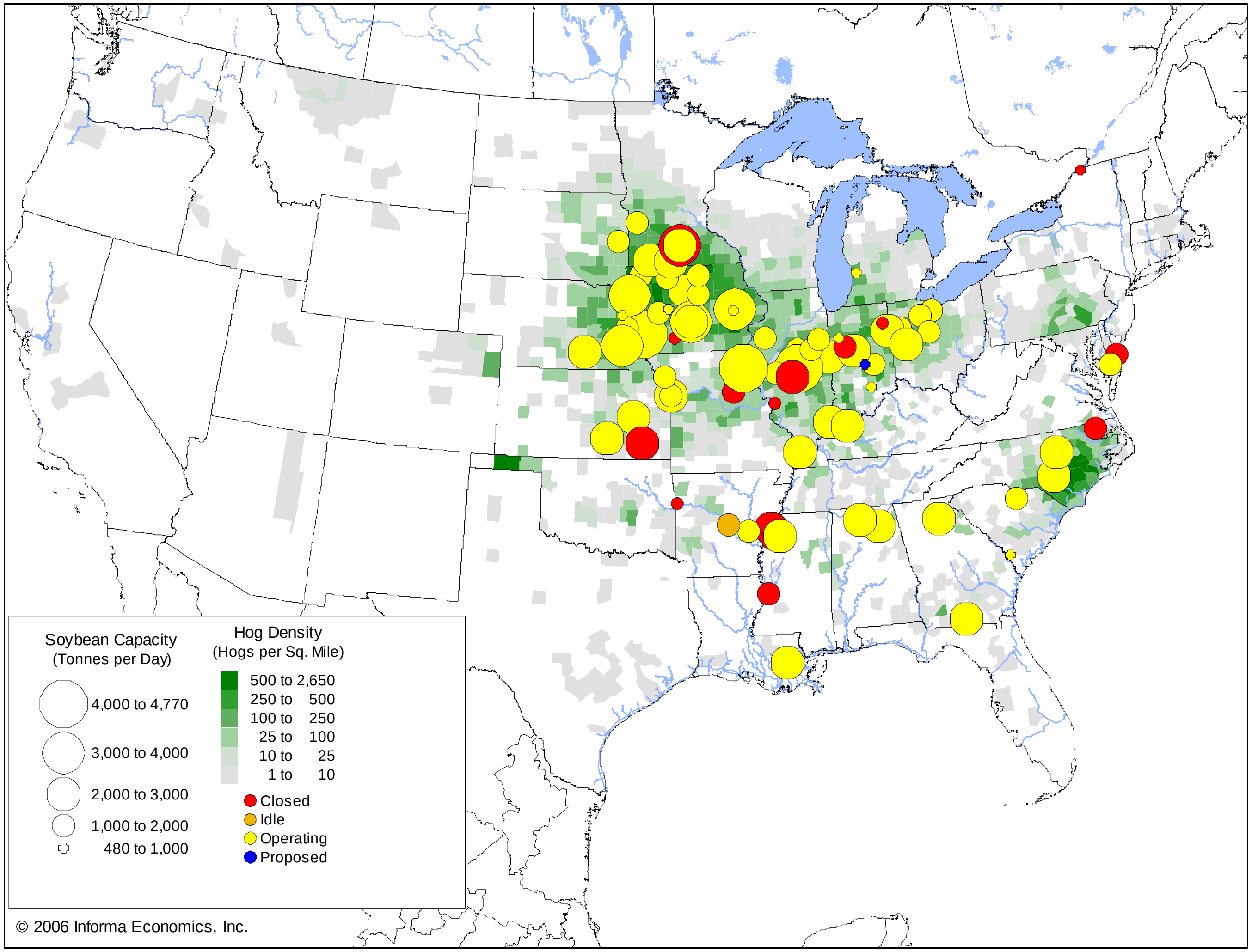
Map 8: Biodiesel Facilities versus Soybean Acreage Production Density



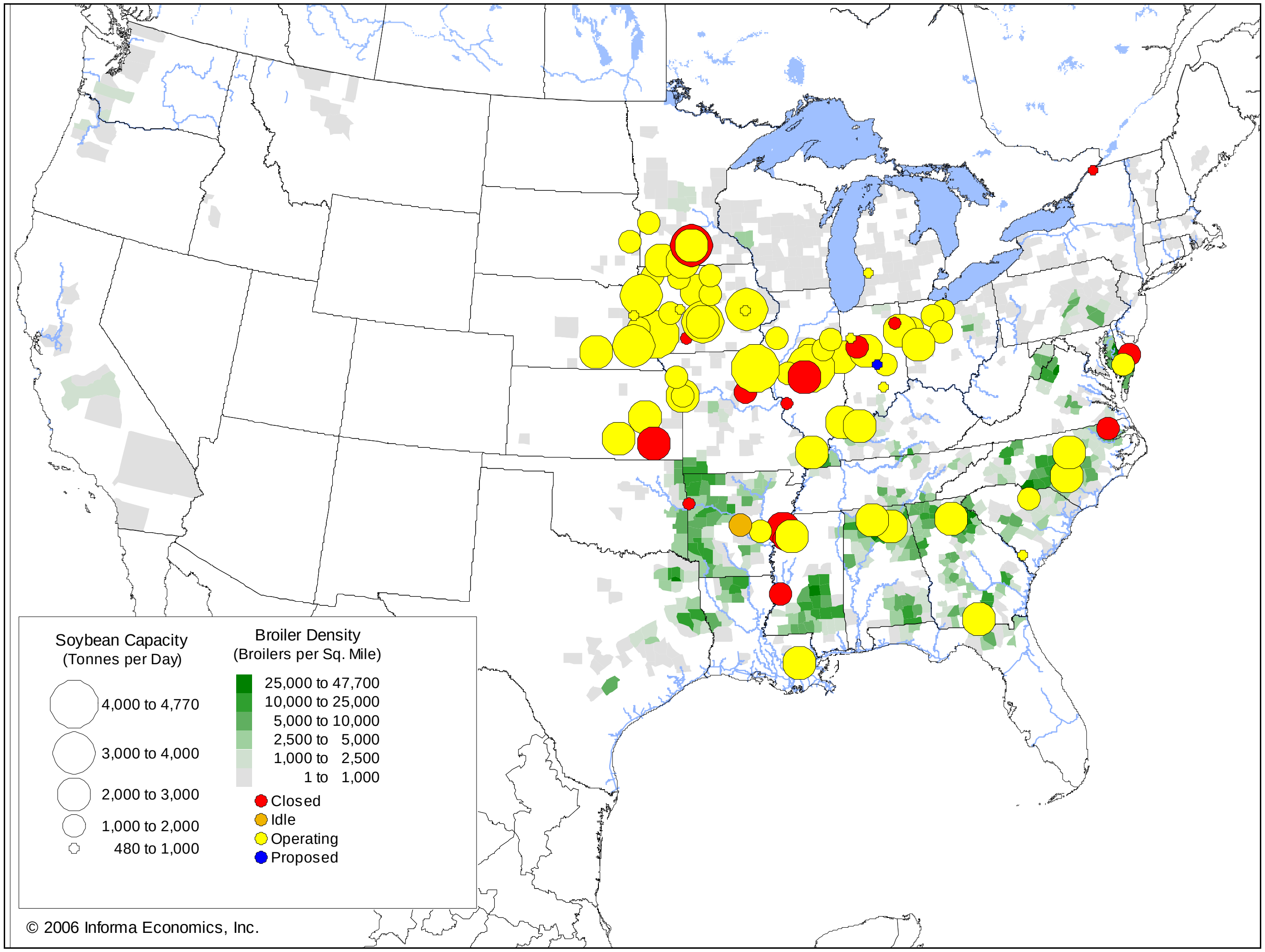
Map 9: Biodiesel Facilities by Type of Feedstock versus Soybean Acreage Production Density



Map 10: Soybean Crushing Facilities versus Hog Inventories



Map 11: Soybean Crushing Facilities versus Broiler Inventories



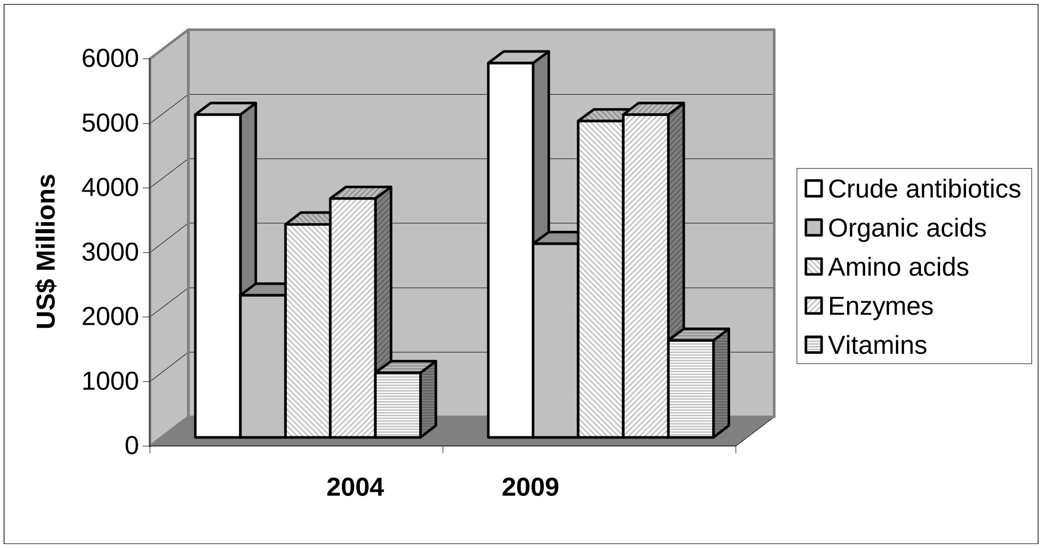
C. Biobased Chemicals

The production of common chemical substances is not a new concept and such processes have a long history. The solvents acetone, butanol, and most importantly ethanol, plus the common chemicals citric, lactic, itaconic, gluconic and related organic acids have been produced primarily by fermentation until the middle of the 20th century[137], and have only lost the biological connection to fuels and chemicals in the past half-century. Even 25 years ago, the concept of replacing fossil carbon feedstocks with "biomass" was well considered.[138] From this perspective, the production of at least some current commodity chemicals by non-biological means is the historical exception.

The potential of biotechnology and metabolic engineering is not questioned for the production of many compounds, from simple commodities, such as organic acids, to complex structures such as beta-lactam antibiotics and vitamins which sell in very large volume. It is useful to define the subject of biobased chemicals at this point. In the context of this report, the term is used to describe chemicals which could be produced by processes that are dependent on carbon from existing biological sources. Such sources are lignocellulosic materials, vegetable oils, chitin and agricultural wastes that are promising but largely unexplored as chemical feedstocks.[139,140] Some products currently made by biological methods, such as antibiotics, vitamins, enzymes, and high fructose corn syrup, have never faced competitive commercial processes based on petrochemical feedstocks, all successful examples of the utility of biological production methods and are also described briefly (Figure 30).

[137] Perlman, D., et al., 1952. Ind. Eng. Chemistry, 44(9): 1996-2012
[138] Lipinsky, E.S. 1981. Science, 212: 1465-1471
[139] Rawls, R.L. Chem. Eng. News, May 14, 1984, p. 42-45
[140] Suzuki. K., et al., 2002. Biosci. Biotechnol. Biochem., 66(5): 1075-1083

Figure 30: Global Market for Fermentation Products by Category, 2004-2009[141]



An overlooked commonality between the current chemical industry and a biobased chemicals industry, is the dependence on fuel products.[142] The total chemical industry accounts for about 10% of the use of petrochemical feedstock.[143] The ability to cover production costs of non-fuel chemical products from a high volume fuel-product stream is of enormous importance. The technical requirement is that non-fuel chemical production processes be fully integrated with fuel production processes. In 2004, bio-ethanol was estimated to be about 2.6% of the US gasoline pool, with bio-diesel at about 0.5%.[144] In order to directly compete with non-fuel chemical products, biobased chemicals will need to be directly integrated with bio-fuel production, and biofuel production will need to increase significantly.

Beyond the nearly universal consideration of process integration, biobased chemicals face two economic pressures also faced by fossil based chemicals, the cost of energy and the cost of capital. With respect to capital costs existing chemical plants have the advantage, but even these plants must be improved, expanded, and repaired. In a 2003 report McKinsey concluded that returns on invested capital matter far more than revenue growth, and the generally poor performance of the chemical industry was largely the result of decades of neglect of capital improvements and plant capacity.[145]

Beyond the capitalization of new plants the barriers to the entrance (or re-entrance) of biobased chemicals into the general market are energy and feedstock costs. In the case of commodity chemicals (i.e. those with current market prices below $1/kg)

[141] BCC, Inc, 2005; www.bccresearch.com
[142] Wyman, C.E. 2003. Biotechnol. Prog., 19: 254-262
[143] Danner, H., and R. Braun. 1999. Chem. Soc. Rev., 28: 395-405
[144] Ibsen, K.N. Abstracts of Papers, 228th ACS National Meeting, Philadelphia, August 22-26, 2004
[145] Augat, T., et al, 2003. The McKinsey Quarterly (online), No.3

the product price is affected mainly by raw material costs. Such costs are recognized as being far more than “immediate production costs”, which has been the historical basis for fossil carbon feedstocks. The costs of energy consumed during the production and collection of biobased feedstocks, and the amount of land required to produce them, are recognized and considerable.[146] For specialty chemicals (i.e. in the range of $2-5/kg), process and recovery costs, including energy, make increasing contributions to final prices.[147] Still relatively unrecognized in the US is the potential credit from emissions reduction and trading, especially for carbon dioxide. Currently, the Climate Exchange in Chicago lists contracts for greenhouse gases from $0.75 in 2003 to a recent high of $3.75/metric ton of carbon dioxide. However, in the EU, contracts are currently at 22 to 25/metric ton; this is three years ahead of the market predicted by a McKinsey report in 2003.[148] A calculation by Dale in 2003 considered these issues for the biobased feedstocks of corn, soybeans, alfalfa, and switchgrass, and concluded that the total energy required for production and transportation varied over a factor of 2, and global warming impact (expressed as carbon dioxide equivalents) varied to the same extent.[149]

Beyond such immediately calculated costs are the long-term costs over the entire lifetime of a commodity chemical in its final commercial product form, usually a polymer. This includes everything from the utility of the product as a CO_2 sink, its ability to be recycled or otherwise disposed, and the energy needed to perform all these actions.

In 2004 the USDOE identified twelve chemicals that could be produced from sugars by either chemical or biological methods (Table 37

Table 37). These twelve chemicals are considered building blocks or platform chemicals from which many value-added chemicals may be derived. The USDOE considers these high priority chemicals and is focusing their funding efforts towards development of technology for the conversion of biomass to these biobased products.

146 Dornburg, V., et al., 2003. J. Ind. Ecology 7(3-4): 93-116
147 Wilke, T., and K-D. Vorlop. 2004. App. Microbiol. and Biotech. 66(2): 131-142
148 deLeyva, E., and P.A. Lekander. 2003. The McKinsey Quarterly (online), No. 1
149 Dale, B.E. 2003. J. Ind. Ecology. 7(3-4): 147-162

Table 37: DOE Top Value-Added Chemicals from Biomass [150]

Chemicals	Carbon Number
1,4 diacids	4
succinic, fumaric and malic	
2,5 furan dicarboxylic acid	6
3 hydroxypropionic acid	3
aspartic acid	4
glucaric acid	6
glutamic acid/MSG	5
itaconic acid	5
levulinic acid	5
3-hydroxybutyrolactone	4
glycerol	3
sorbitol	6
xylitol/arabinol	5

The USDOE developed this list from an original list of three hundred candidates. Original selection criteria included the cost of feedstock, estimated processing costs, current market volume and prices, and relevance to current or future biorefinery operations. For the second tier selection (narrowed down to 30 chemicals) the chemicals were ordered according to carbon number (C_1 to C_6) and reviewed for chemical functionality and potential use. The selection criteria for the final twelve was based more on a traditional petrochemical industry approach (i.e. a priority was assigned to building block chemicals). For the purpose of this study we will look at biobased products in relation to market segment (i.e. commodity chemicals, fine chemicals, specialty chemicals, polymers, etc.). Most of the USDOE top twelve chemicals are covered here; however, this list is too narrow for the purposes of our discussion. Therefore, other biobased products of importance are also discussed.

The potential impact of biobased chemicals can be viewed in terms of their impact on the existing chemical industry. McKinsey & Co. consider the main levers for value creation for biobased products to be in the production of raw materials (such as transitioning from petroleum to corn or corn stover), reduction of process costs (reduced process steps, increased yield), reduction of risk (reliable and stabilized supply), value-added processes (shorter time to market, "natural" label), and new businesses (routes to compounds not accessible through classical chemistry).[151] It was estimated that approximately 55% of value-creation potential in biotechnology will be driven by revenue increases. The segment specific impact on cost and revenues is shown in Table 38. It is estimated that by the year 2010 approximately 20% of the chemical market will be impacted by biotechnology amounting to a value creation of $160 billion.

[150] Top Value Added Chemicals from Biomass. Vol 1.2004. U.S. DOE, EERE

[151] Bachman, R. 2003. Industrial Biotech-New Value Creation Opportunities. Conference Proceedings, BIO Third Wave: Analyst Briefing on Industrial Biotechnology, New York.

Table 38: Estimated biotechnology impact on cost and revenues[151]

Chemical Segment	Cost	Revenue
Fine Chemicals	35%	65%
Polymers	40%	60%
Bulk Chemicals	75%	25%

1. Commodity Chemicals

Solvents

Existing Technology

Acetone, butanol, and ethanol (ABE) were commercially produced by fermentation processes up to 1950 with *Clostridium acetobutylicum* the organism of choice for conducting this fermentation. This organism was originally isolated by Charles Weizmann and his process was of enormous importance to the British war effort during the First World War. The process was patented in the US in 1919.[152] Between 1945 and 1950, 66% of the n-butanol (over 45 million pounds) and 10% of the acetone in the US was produced by fermentation of molasses and starch. Increased prices of the sugar feedstock and decreased prices of petrochemical feedstock ended the fermentive production of these solvents. With the low cost petrochemical feedstocks beginning in the 1950s, the fermentation-based processes became economically unattractive and most of the commercial installations were closed by 1952. With the reverse of this particular economic trend, the production of these important solvents by fermentation appears increasingly attractive. Current production of butanol involves the hydrogenation of *n*-butyraldehyde.[153] The cost of production is approximately $0.66/kg.[154]

In biological production the fermentation yields the three solvents (Acetone:Butanol:Ethanol) in an approximate ratio of 3:6:1. The formal stoichiometry of the chemical reaction from glucose for the various products is:

$$1 \text{ glucose } (C_6H_{12}O_6) \rightarrow 1 \text{ butanol } (C_4H_{10}O) + 2\ CO_2$$
$$1 \text{ glucose } \rightarrow 2 \text{ ethanol } (C_2H_6O) + 2\ CO_2$$
$$1 \text{ glucose} + 1\ H_2O \rightarrow 1 \text{ acetone } (C_3H_6O) + 3\ CO_2 + 4\ H_2$$

Butyric acid (BA) can also be recovered. The stoichiometry for this product is:

$$1 \text{ glucose } \rightarrow 1 \text{ BA } (C_3H_7COOH) + 2\ CO_2 + 2\ H_2$$

This is an anaerobic fermentation and produces carbon dioxide and hydrogen as off-gases. Presumably, the acetone can be reduced to isopropanol as there are sufficient reducing equivalents available, but this would require capturing the

152 US pat. 1,315,585
153 Chemical Market Reporter 256(1), 41. 1999.
154 Process Economics Yearbook International. SRI Consulting. 2001.

hydrogen as cellular reducing equivalents (NADH or NADPH) and this is not considered part of the ABE fermentation. It is an obvious extension of the fermentation, and should be possible with conventional molecular biology.

Solvents are a $5 billion market with 10 billion pounds being consumed annually in the United States. Traditional petrochemical solvents such as acetone, ketone, xylene, toluene, methylene chloride are being replaced by biobased solvents with great success.

Emerging Technology

Considerable recent work has been performed and the modern tools of molecular biology have been applied to production of ABE. The genome of the original organism[155], a new hyper-producing strain of *Clostridium beijerinckii* with yields of total solvents up to 165 g/L[156], process issues[157], and full-scale production economics[158] have all been published. The use of lactose (whey) is possible rather than glucose (starch) as feedstock, and this gives up to 100 g/L total solvents with an overall molar yield of 0.44. As lactose is actually an inhibitor of ABE fermentation, a process was designed to circumvent this particular issue.[159] The fermentation conditions can be adjusted to give different ratios of the three solvent products. Using glucose, fermentation conditions were arranged to give 77g/L acetone and 152 g/L butanol, with almost no ethanol (3 g/L) and very low total acids (8 g/L). In this particular case the molar conversion was 47%.[160] Process patents continue to be sought despite the history of this endeavor.[161]

Concerns over volatile organic compounds and associated health concerns are driving the introduction of environmentally benign solvents. These include methyl soyate, lactate esters, and citrus derived solvents such as D-limonene. These solvents are gaining an increasing share of the market and are valid replacements for petrochemicals in a number of applications including removal of metal working fluids, ink and paint removal, adhesive removal, household cleaners and in the microelectronics sector in the production of semiconductors. These solvents not only have an environmental advantage but compete in performance and in price (Table 39). Currently there are over 75 soy-derived solvents being produced for the industrial and consumer markets.[162] Producers of biobased solvents include Vertec Biosolvents, Purac, AG Environmental Products, Bio Chem Systems, Florida Chemical Company, and CPC Aeroscience, Inc.

155 Nolling, J. et al., 2001. J. Bact., 183(16): 4823-4838
156 Qureshi, N. and H.P. Blaschek. 2001. J. Ind. Microbiol. Biotechnol., 27: 287-291
157 Ezeji, T.C., et al., 2004. Appl. Microbiol. Biotechnol., 63: 653-658
158 Quershi, N. and H.P. Balschek. 2001. J. Ind. Microbiol. Biotechnol., 27: 292-297
159 Qureshi, N. and I.S. Maddox. 2005. Trans IChemE, Part C, Food and Bioproducts Processing, 83(C1): 43-52
160 Qureshi, N. and H.P. Blaschek. 2001. Bioprocess biosystems Eng.,24: 219-226
161 Ezeji, T.C., et al, US Pat. Appl. US2005/0089979 A1, Apr. 28, 2005
162 Colorado Agriculture IOF Technology Assessments: Biobased Products. 9/30/2005. McNeil Technologies, Inc.

Table 39: Selling Price of Common Solvents[163]

Solvent	Price ($/kg)
Methyl Soyate	0.66 – 1.00
D-Limonene	Up to 0.88
Methylene Chloride	0.66
Methyl ethyl ketone	1.00
Trichloroethylene	1.43
Perchloroethylene	0.77

Lactic Acid

Existing Technology

Lactic acid has been known as a discrete chemical since the late 19th century. It is the principal ingredient in sour milk, hence the German name Milchsäure. It is produced by the fermentation of lactose by *Bacillus* species or related organisms such as *Lactobacillus delbrueckii*, *L. bulgaricus*, etc., and is performed at large scale using whey (lactose), cornstarch (glucose), potatoes, molasses and other mixed sugar streams from various agricultural processes. The fermentation is carried out above 40°C and pH below 4.5.[164] Lactic acid is a product of the glycolysis pathway of central carbon metabolism, resulting from the reduction of pyruvate. As a commodity chemical itself, lactic acid is used as an acidulant and a preservative in foods and annual consumption in the United States is approximately 72 million pounds.[165]

Emerging Technology

Cargill's most recent US patent application covering the fermentation of lactic acid from glucose discloses examples in which the culture (referenced only as a "homolactic acid-tolerant bacteria) was capable of growing at pH 3.8 in the presence of 100g/L of glucose, and producing nearly 100g/L of lactic acid.[166] At this low pH, over half of the lactic acid is protonated, considerably enhancing the recovery of the lactic acid for the subsequent process steps to poly lactic acid (PLA).

While the work revealed in the patent literature by Cargill suggests that all the lactic acid fermentation is run from glucose (from corn starch), it is very possible to produce lactic acid by other organisms growing on both hexoses (such as glucose from either starch or cellulose) as well as pentoses, which are the carbohydrates making up hemicellulose. Further, the properties of PLA are significantly affected by the chirality of the lactic acid produced. The Cargill patent application above reveals that the lactic acid produced is essentially the pure L-isomer. Obviously PLA made from the pure D-isomer would be expected to have identical bulk properties, but varying the ratio of the L- and D-isomers used to make the PLA would affect the bulk material properties. PLA will be discussed further in a later section.

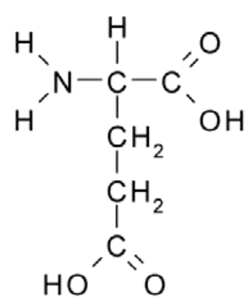
163 United Soybean Board. 2002.
164 Prescott, S.C. and C. G. Dunn, *In* Industrial Microbiology (McGraw-Hill, New York, 3rd ed., 1959) pp 304-331
165 Energetics, Inc. 2003. Industrial Bioproducts: Today and tomorrow. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of the Biomass Program, Washington, D.C.
166 Carlson, T.L. and E.M. Peters, Us Pat. Appl. US2003/0129715 A1, July 10, 2003

A metabolically engineered *E. coli* strain has been constructed to produce the D-isomer of lactic acid growing on only minimal salts and glucose under either aerobic or anaerobic conditions with excellent conversion of glucose to D-lactic acid.[167] While the publication does not contain an experimental example of the use of pentoses, it does state that *E .coli* is capable of fermenting pentoses, and presumably this particular engineered *E. coli* can produce lactic acid from pentoses.

Glutamic Acid

Existing Technology

Glutamic acid is a non-essential amino acid for humans and is the most abundant amino acids in foods. It is produced primarily by fermentation using the microorganism *Corynebacterium* (there are patents for processes using *Brevibacterium* also). The vast majority of glutamic acid is used to produce monosodium glutamate (MSG), a food flavoring agent. Glutamic acid is also used in pharmaceutical applications, such as ophthalmic preparations and nasal solutions, as well as industrial applications, such as surfactants and fabric coatings. The worldwide demand for monosodium glutamate (MSG) is approximately 1.1 million tons/yr. Primary producers are Ajinomoto, Kyowa Hakko and CJ Corp, although Chinese manufacturers are now entering the market as well.[168]



Glutamic Acid

Emerging Technology

Glutamic acid also has the potential to be a building block for the production of five carbon polymers that could improve and provide new functionality to polyamides and polyesters. The current production of MSG is a single fermentation that produces the sodium salt of glutamic acid. In order to fully exploit the potential of glutamic acid as a building block, low cost fermentations must be developed that produce the free acid. This approach would significantly lower the cost by eliminating neutralization and simplifying downstream purification. Improvements could also be made in the productivity and yields of existing production strains. Development of

167 Zhou, S., et al., 2003. Appl. Environ. Microbiol., 69(1): 399-407

168 Monosodium Glutamate. 2003. Science & Technol. 81(30): 57

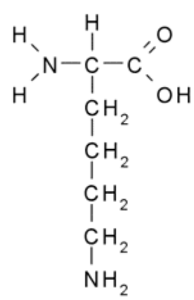
catalysts for the efficient production of desired derivatives, particularly glutaminol, 5-amino-1-butanol, 1,5-pentanediol, and norvoline, is also needed.[150]

Lysine

Existing Technology

Lysine is an essential amino acid but is not produced in grains in sufficient amount to supply the nutritional needs of animals. Lysine can be chemically synthesized although the cost is approximately 1.5 times the cost of production by fermentation of carbohydrate feed stocks.[169] The world market value for feed-grade lysine exceeds $1 billion/yr.[170] Ajinomoto and Archer Daniels Midland (ADM) lead the world market with 25% and 22% share respectively. Other producers include Degussa and CJ Corp. From 2002 to present the lysine market has been extremely volatile with prices ranging from $1.20/kg to highs near $3/kg. Current prices are depressed due to the recent increased production in Asia; however, the growing demand in Asia for swine and poultry feed is expected to generate a global demand increase of 8%/yr according to ADM.

Lysine is a limiting amino acid in feeds for poultry and swine, as are threonine, methionine and tryptophan. Production of lysine, threonine, and tryptophan are accomplished by fermentation, however methionine is currently manufactured by chemical synthesis from acrolein. While the market for amino acids as feed additives is substantial, the largest growth for amino acids in the next five years is expected to be for the use of amino acids for synthesis applications in the pharmaceuticals and biotechnology markets. The market for amino acids for synthesis applications is expected to grow at a rate of 7% through 2009, increasing from the current $713 million/yr to $1 billion/yr.[171]



Lysine

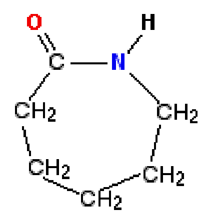
Emerging Technology

An alternative approach to providing lysine in animal feeds is the marketing of a genetically engineered feed corn, high in lysine, developed by Renessen, LLC, a

[169] Commercial Amino Acids: Products and Technologies. 1994. Business Communications Co., Inc., Norwalk, CT
[170] CEH Market Research, 2004
[171] BCC, Inc. March 4, 2005.

joint venture of Cargill, Inc. and Monsanto Co. The product contains about ¼ the amount of lysine needed in a poultry broiler's diet (~1,000ppm lysine). A second generation product is expected to provide the full lysine requirement, eliminating the need for supplemental lysine in animal feed products.[172] To date methionine has been produced by fermentation only at laboratory scale and is not economical for commercial production. Development of organisms with pathways for efficient production of methionine could offer a fermentative route as an alternative to the synthetic production, a process that results in the production of hazardous waste streams.

Lysine could also be used in the near future for production of caprolactam. Caprolactam is a monomer used in the production of polyamide-6 (Nylon 6) for use in the artificial fiber industry as well as a structural material in the automotive and electronics industries. BASF and DSM produce 610 million pounds/yr and 450 million pounds/yr, respectively, using cyclohexane as the feedstock.[173] New technologies are being developed that produce caprolactam from L-lysine (John Frost, Michigan State University, personal communication).



Caprolactam

Succinic Acid

Existing Technology

The production of non-captive succinic acid as a final product is small, and is purchased mostly by the food and pharmaceutical industries where it is used as an acidulant and a salt-forming compound agent for specific formulations. However, succinic acid is an intermediate occurring in the great majority of current industrial process which use maleic anhydride as starting material. Maleic anhydride in turn is made by a number of processes from butane, isolated from natural gas and from petroleum cracking. Approximately 4 billion pounds of maleic anhydride are consumed globally each year. As the scheme below illustrates (Figure 31), the maleic anhydride is first converted to succinic acid (or in some processes, the dimethyl ester of succinic acid). A number of well-established, high-volume processes produce the three commodities shown: the solvent tetrahydrofuran (THF) the diol 1,4-butanediol (BDO), and another intermediate, γ-butyrolactone (GBL). The

[172] St. Louis Post-Dispatch, 11/20/2005
[173] Chemical Market Reporter 2004

chemical processes used require hydrogen and operate at high temperatures and pressures, but the conditions can be adjusted to give any one of the three products out of the same process. THF can be opened, and partially polymerized to give low molecular weight polymers of polytetramethylene glycol (PTMG), while GBL can be taken on to another solvent, N-methyl pyrrolidone (NMP).

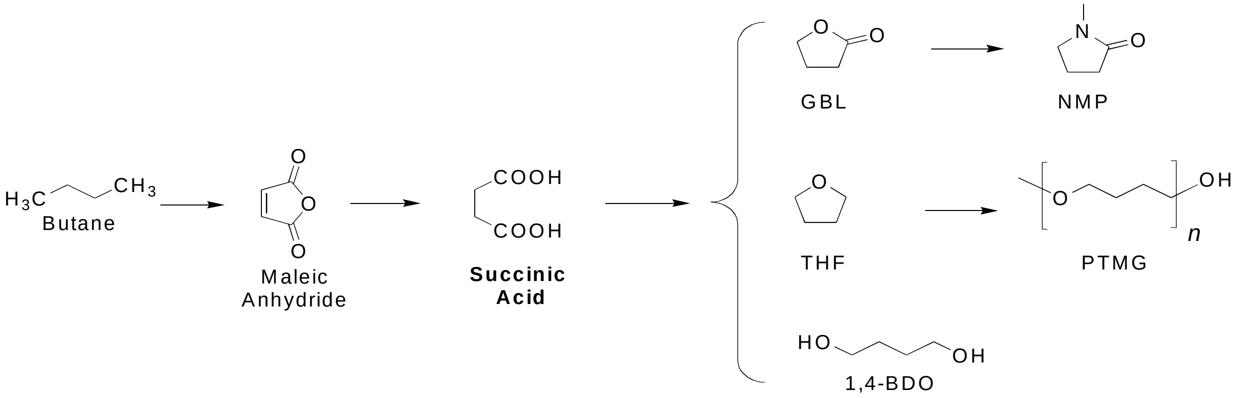


Figure 31: Petrochemical route to succinic acid and succinic derivatives

Further, BDO can be used together with PTMG and (captive) succinic acid to make polyesters, which in turn are used in polyurethane materials. The company Invista (a subsidiary of DuPont), markets PTMG as TERATHANE® glycol as the key intermediate for both LYCRA® elastane and high-value polyurethanes.

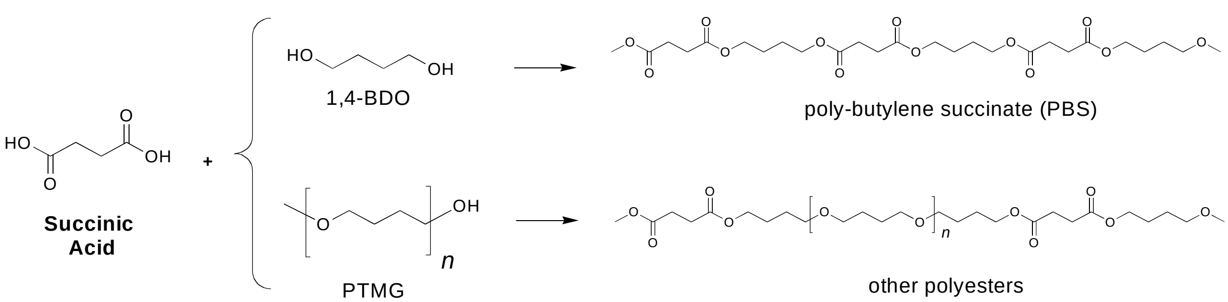


Figure 32: Production of polyesters from succinic acid

Emerging Technology

Succinic acid has attracted a large amount of attention for several reasons;

- The biochemistry from monomeric sugars (both pentoses and hexoses) is known
- All of the enzymes involved have been cloned and are available for manipulation by standard biotechnology
- The processes are very well studied from the perspective of fermentation engineering and process scale-up

- The product has a small but known market in the food industry as an acidulant
- The product can be used to replace maleic anhydride by simple, well-established industrial chemistry with an global annual production of approximately 4 billion pounds

A very simplified scheme of the metabolic pathways to succinic acid, plus other products of biobased production (ethanol, lactic acid, and potentially pyruvic acid and fumaric acid) is shown below (Figure 33). While a significant portion of the metabolic pathways have been omitted, the flow of carbon is complete. Note that the consumption of both the five-carbon sugars (the pentoses xylose and arabinose from hemicellulose) and six-carbon sugars (hexoses, of which glucose from starch and fructose from cane sugar are the chief examples) goes through a common intermediate phosphoenol pyruvate (PEP). From PEP, a number of metabolic pathways are derived; of most interest here are the pathways to ethanol, lactic acid, pyruvic acid, and succinic acid. It is clear from this simple scheme that the production of ethanol requires the production of carbon dioxide for redox balance. Not shown in Figure 33 are the other pathways which also require the production of carbon dioxide to maintain the redox balance for the production of lactic acid.

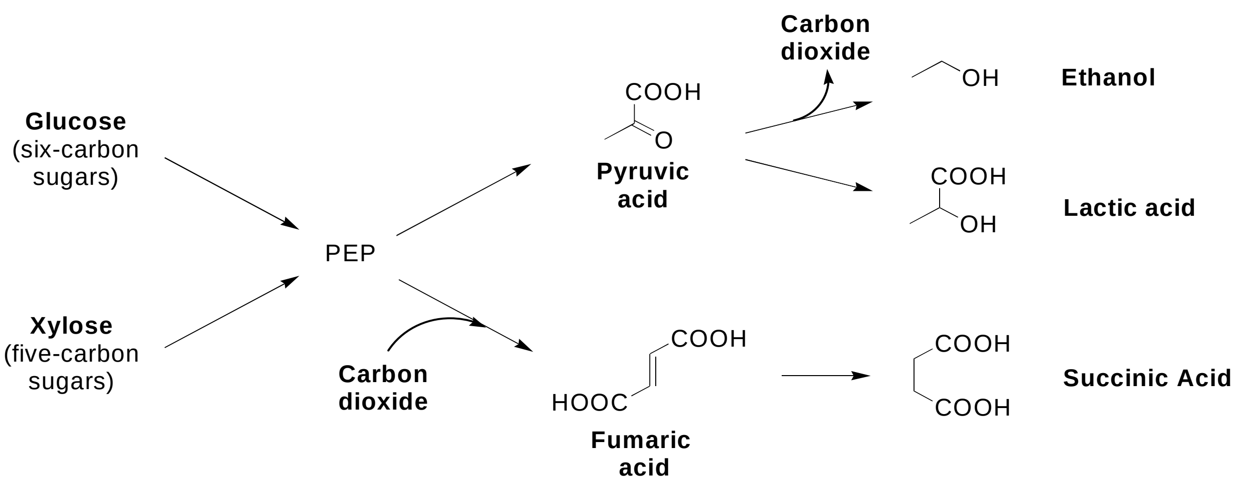


Figure 33: Biochemical pathways to ethanol, lactic acid and succinic acid via PEP

The production of succinic acid can be capnophilic in some organisms, that is, the redox balance is maintained by the consumption of carbon dioxide. This is chemically possible because succinic acid is slightly more oxidized (has a higher redox potential) than hexoses or pentoses. The correct stoichiometry for the production of ethanol (EtOH), lactic acid (LA), pyruvic acid (Pyr) and succinic acid SSA) from glucose is given by the equations below.

Redox-balanced Stoichiometry

7 glu + 6 CO_2 → 12 SA + 6 H_2O
7 glu → 14 Pyr + 14 H_2O
7 glu → 14 EtOH + 14 CO_2
7 glu → 12 LA + 12 H_2O + 6 CO_2

For comparison, the balanced equation for the complete oxidation of glucose to carbon dioxide is below. This equation is chemically correct for both the cellular metabolism of glucose (respiration) and the actual burning of glucose in air; in both cases the same amount of energy is released.

7 glu + 21 O_2 → 42 CO_2 + 42 H_2O

However, the issue of productivity is critical to production of commodities and requires more than the right metabolic pathways. Very few microorganisms are known to produce succinic acid in sufficiently high concentrations to permit economical production. A review of the patent literature reveals three well-studied organisms for which claims of useful succinic acid production have been allowed; *E. coli* (ATCC 202021),[174] *Anaerobiospirillum succiniciproducens* for which two strains are patented (ATCC 29305 and ATCC 53488),[175,176] and *Actinobacillus succinogenes* (ATCC55618).[177]

Of this list of organisms, the *A. succinogenes* organism is unique in its ability to use both hexoses (glucose) and pentoses (xylose and arabinose) simultaneously, and is thus well suited for the biobased production of succinic acid form lignocellulosic feedstock. The stoichiometry for the production of succinic acid from pentoses is:

$$7 \text{ xylose} + 5\, CO_2 \rightarrow 10 \text{ SA} + 5\, H_2O$$

Propanediol

Existing Technology

Propanediols (PDO) can exist as different isomers. Two of these, 1,2-propanediol and 1,3-propanediol have significant utility. 1,2-propanediol (propylene glycol) is currently produced from petrochemical feedstocks mainly by the hydration of propylene (which is the monomer for the production of polypropylene). Like lactic acid, 1,2-PDO has a chiral center and exists in two enantiomers. However, the current methods for production of 1,2-PDO from petrochemical feedstocks produce equal amounts of the two enantiomers, and chiral 1,2-PDO is considered an expensive, low-volume specialty chemical. The primary uses of 1,2-PDO are in unsaturated polyester resins, liquid laundry detergents, pharmaceuticals, cosmetics,

[174] Donnelly, M., et al., US Pat. US5770435, June 23, 1998
[175] Guettler, M.V. and M.K. Jain, US Pat. US5521075, May 28, 1996
[176] Datta, R. US Pat. US5143833, Sep. 1, 1992
[177] Guettler, M.V., et al., US Pat. US5504004, Apr. 2, 1996

antifreeze and de-icing formulations. In 2004 the annual global market for propylene glycol was estimated at 3.1 billion pounds. Dow Chemical was the largest producer with a capacity of 1.2 billion pounds/year. Prices have been increasing steadily due to cost increases for the petrochemical feedstocks.[178]

Emerging Technology

It is possible to engineer metabolic pathways to both enantiomers of 1,2-PDO, and this has been published and patented.[179,180,181] The 1,3-isomer of propanediol (1,3-PDO) cannot be easily produced from any current petrochemical propylene chemistry. Although this molecule has been known for many years to have utility as a diol for polyesters, it has only recently become available via biological methods. The biological production of 1,3-PDO from glucose by a metabolically engineered culture of *E. coli* was a joint effort between Genencor and DuPont, and has been extensively presented and patented.[182,183,184] Formally, only two enzymes are needed to transform glycerol to 1,3-PDO; glycerol dehydratase, and 1,3-propanediol dehydrogenase. Practically however, the metabolic engineering is more complicated and improvements have been published by others.[185] A re-activation factor is required to make the dehydratase useful, and since *E. coli* does not produce glycerol metabolically from glucose, two additional genes had to be inserted, and three potential pathway branch points were blocked.

The current *E .coli* construct used by DuPont is reported to be capable of producing 120 g/L 1,3-PDO in 36-40 hours, using only glucose as the carbon source. 1,3-PDO is one of two components for the polyester Sorona™, and DuPont has announced the construction of a fermentation facility in Loudon, TN that will produce 100 million lbs of 1,3-PDO/yr, and is estimated to have between 4 and 5 million liters of production capacity. Sorona™ and similar polymers will be discussed further in a later section.

Hydroxyproprionic Acid

Emerging Technology

3-hydroxypropionic acid is a platform chemical from which several commercially valuable chemicals, including 1,3-propanediol, malonic acid, acrylic acid and acrylamide can be derived. These are high volume chemicals used to manufacture polymers, resins, plastic packaging, fibers, and adhesives. There is no viable petrochemical production route to 3-hydroxypropionic acid although several of the derivative chemicals are produced from petroleum feedstocks.[165] Cargill teamed with the Pacific Northwest National Laboratory and Codexis, Inc. to develop a

[178] Dow Chemical. Products and News. 2005. //news.dow.com
[179] Altaras, N.E., and D.C. Cameron. 1999. Appl. Environ. Microbio., 65(3): 1180-1185
[180] Cameron, D.C., et al., 1998. Biotechnol. Progress, 14(1): 116-125
[181] Cameron, D.C., et al., US Pat. US6087140, July 11, 2000
[182] Laffend, L.A., et al., US Pat. US5686279, Nov. 11, 1997
[183] Cameron, D.C. US Pat. US6303352, Oct. 16, 2001
[184] Emptage, M. and S. Haynie. Eur. Pat. Appl. EP1586647 A1, 19 Oct 2005
[185] Zhu, M.M., et al., 2002. Biotechnol. Prog. 18: 694-699

process for production of 3-hydroxypropionic acid from glucose with a yield of 100% of theoretical.[186] The market for acrylic acid derivatives is estimated at $950 million and the market for acrylamide derivatives is estimated at $370 million.[165]

Worldwide production of acrylic acid reached 2,895 million pounds in 2002. Rohm and Haas/StoHaas, BASF, American Acryl, Celanese, and Dow are the major producers. Most acrylic acid is consumed in the form of a polymer. Growth in demand for superabsorbents (diaper and hygienic products) increased consumption at an annual rate of 6.5% until 2000. Current growth has slowed somewhat due to oversupply and a depressed economy. While prices for acrylic acid increased 5% in 2002, feed stock propylene prices increased 15%, depressing margins. Growth is expected to continue at around 5% and the utilization of biobased feedstocks could offer a competitive advantage as petrochemical feedstock prices increase.

2. Fine Chemicals

Pharmaceuticals

The scope of pharmaceutical manufacture is too broad for full review in this study. A brief description will be given of current markets and examples of biotechnology's impact on pharmaceutical production.

The global market for pharmaceuticals was estimated to be approximately $466 billion in 2003.[187] Biopharmaceutical products accounted for approximately 12% of global sales. Visiongain estimates the 2005 biopharmaceutical market at $70.8 billion. By 2010 biopharmaceutical products are expected to represent 17% of total pharmaceutical sales.[188] The global market for antibiotics is approximately $25-30 billion.[189,190] Cephalosporins dominate with 26.3% of the market; however quinolones and fluoroquinolones are expected to gain market share on cephalosporins in the near future.

Emerging Technology

Many pharmaceuticals are semi-synthetic molecules, in that part of their structure is synthesized by biological means and later modified by chemical processing. The switch from chemical processing to microbial/enzymatic processing is being driven by development of new enzymes and processing methods. Keneka Corporation has developed a fully enzymatic process for production of amoxicillin using thermostable enzymes,[191] replacing a chemical synthesis method that had problems with off-color of the product, low energy efficiency and formation of by-products.

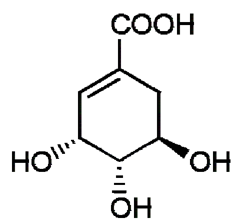
[186] Cargill, Inc. Cargill and Codexis launch research collaboration to develop industrial bioproducts platform. May 2003. http://www.cargill.com
[187] Norwegian Association of Pharmaceutical Manufacturers. 2004; www.lmi.no
[188] The World Biotech Market 2005; www.bioportfolio.com
[189] The World Antibiotics Market, 2002-2009. 2004. Visiongain; www.visiongain.com
[190] Gavrilescu, M. and Y. Chisti. 2005. Biotechnology Advances. 23: 471-499.
[191] Europabio.com

Shikimic acid is a six-membered carboxylic ring that is naturally produced in plants and microorganisms. It is an important intermediate in the production of Oseltamivir, marketed by Hoffman-La Roche as Tamiflu®. Presently the shikimic acid is harvested from the fruit of *Illicium* plants (Chinese star anise), a tedious multi-step process that precludes its use in large volumes. The lack of sufficient sources of shikimic acid to support large scale production has made production of the chemical by fermentation an attractive alternative.

A process for producing shikimic acid from glucose was patented in 2002[192] and licensed non-exclusively to Roche, who used the process to produce 8,000 kg for Tamiflu® manufacture (John Frost, personal communication). The market for Tamiflu® is estimated at greater than $1 billion annually. It is considered a strategic asset in control of pandemic outbreaks of influenza.

Acid catalyzed dehydration of shikimic acid yields p-hydroxybenzoic acid, a precursor to parabens and an intermediate in the production of liquid crystal polymers (polymers are discussed in a later section).

Quinic acid can also be produced from glucose in a scheme similar to the Frost shikimic acid route.[193] Quinic acid is used in the production of pharmaceuticals. With the Frost technology it is possible that hydroquinone (another pharmaceutical) could be produced from quinic acid.[194]



Shikimic acid

The production and use of biologically active proteins and other biologics is being driven by biotechnology. These products include erythropoietins, interferons, insulins, blood factors, enzymes, growth hormones, monoclonal antibodies, growth factors and therapeutic vaccines. In 2003 the market for therapeutic proteins was $37 billion and could grow to $90 billion by 2010 with improvements in drug delivery and cost of production.[195] Numerous companies are involved in the production of a wide range of biologics and include Amgen, Johnson & Johnson, Roche, GE Healthcare, Repligen, GlaxoSmithKline, Merck, Cambrex, Baxter, Bayer AG, Degussa AG, Novartis, Novozymes, Genencor International, Schering-Plough and Wyeth (among many others). The expiration of patents on some leading biologics is expected to impact this market during the next few years. The introduction of

[192] Frost, J.W. et al., 2002. Biocatalytic synthesis of shikimic acid. U.S. Patent 6472169
[193] Liese, A., and M.V. Filho. 1999. Current Opinion in Biotechnology. 10: 595-603.
[194] Ran, N., et al., 2001. Journal of the American Chemical Society. 123: 10927-10934.
[195] Visiongain. 2005.

generic "biosimilars" worldwide is expected to drive prices down and increase the competition for these products. New technologies and new products will be critical for some manufacturers to continue in this area.[196] Table 40 shows some of the current biologics being produced.

Table 40: Current Biologics and Market Size[197]

Product	**Market Size** (US$ million)
Erythropoietin	6803
Blood clotting factors	2585
Interleukin	184
Insulin	4017
Inteferon	3919
Monoclonal antibody (cancer)	1751
Monoclonal antibody (various)	1152
Growth hormone	1706
Growth factor	115

An emerging technology is the production of pharmaceutical proteins in plants. Field testing of this technology has been taking place since the early 1990s and has accelerated in the last few years. More than 325 sites of field trials were approved in the US between 1991 and 2004 for novel proteins and pharmaceuticals[198]. Table 41 shows some of the companies involved in this technology and the type of products being developed.

Table 41: Technologies under development for plant made pharmaceuticals[198]

Company	**Crop**	**Pharmaceutical**
Ventria Bioscience	Rice	Lactoferrin, lysozyme
Chlorogen, Inc.	Tobacco	Cholera vaccine, human serum albumin, interferon
Medicago	Alfalfa	Hemoglobin
Meristem	Corn, tobacco, alfalfa	Hemoglobin, gastric lipase, albumin, cancer therapeutic antibodies
EpiCyte	Corn	Monoclonal antibodies
SemBio Systems	Safflower	Antiobesit peptid, somatotropin
MPB Cologne	Potato, rapeseed	Antibodies for the detection of food/water borne pathogens
AttaGen	Potato	Hemoglobin, factor VIII, human growth hormone
Large Scale Biology Corp.	Tobacco	Alpha galactosidase A, patient specific cancer vaccines, B-cell non-Hodgkin's Lymphoma

[196] Genetic Engineering News. December 1, 2005. Biosimilars Shake up the Biologics Market.
[197] Melmer, G. 2005. Biopharmaceuticals and the industrial environment. In: Gellissen G., editor. Production of recombinant proteins: novel microbial and eukaryotic expression systems. Weinheim: Wiley-VCH; pp. 361-383,
[198] Elbehri, A. J. 2005. Agrobiotechnology. 8(1): 18-25

Vitamins
Most vitamins are produced by chemical synthesis. Ascorbic acid (vitamin c) is the largest volume vitamin with an annual production of 100 million kg. Vitamin C has been traditionally manufactured by the Reichstein process, a combination of microbial oxidation and chemical synthesis, although a two step fermentation method is now being employed. New advancements also permit the production of vitamin B_2 by BASF in a single step fermentation from vegetable oil using the fungus *Ashbya gossypii*.[199] DSM developed another single step fermentation for production of B_2 from *Bacillus subtilis*. An increase in yield of 300,000 fold reduced production cost by 50% over the conventional process.[190] Increasing pressure from Chinese manufacturers has been pushing American manufacturers out of the Vitamin C market.[200] New fermentation methods such as the ascorbic acid jointly developed by Genencor International, Argonne National Laboratory, and Eastman Chemicals[201] hold promise for competing against the Chinese production. Major producers of vitamins include Archer Daniels Midland Co., BASF/Takeda, Boehringer Ingelheim Consumer Health Care, Cognis Deutschland GmbH & Co. KG, DSM Nutritional Products, Daiichi Pharmaceuticals, Degussa, Jiangsu Jiangshan Pharmaceutical Co., Ltd, Kuraray Company, Lonza Group, North China Pharmaceutical Group Corp, Northeast General Pharmaceutical Factory, Pharmavite, Inc and Sanofi-Aventis. The global market for vitamins is expected to reach $1,272 million by 2009 (Figure 30). Table 42, shows a sampling of industrially produced vitamins and their applications.

[199] Nutraingredients.com. BASF ups production of B2. October 11, 2003
[200] Chemical & Engineering News
[201] Genencor International; www.genencor.com

Table 42: Industrial Production of Vitamins[202]

Compound	Production Method			Applications
	Biotechnology	Chemical	Extraction	
Ascorbic Acid (C)	+[a]			Feed, food, pharmaceutical
Thiamin (B_1)		+		Food, pharmaceutical
Riboflavin (B_2)	+			Feed, pharmaceutical
Biotin	+[b]	+		
Pantothenic acid	+[a]	+		Feed, food, pharmaceutical
Pyridoxine (B_6)		+		Feed, food, pharmaceutical
Vitamin D_3		+	+	Feed, food
Vitamin A		+		Feed, food, pharmaceutical
α-Tocopherol (E)	+[b]	+	+	Feed, food, pharmaceutical, nutraceutical

[a] Combination of microbial and chemical reactions
[b] Pilot scale process

Flavors & Fragrances

Existing Technology

Flavors and fragrances encompass a huge array of products and applications that is beyond the scope of this study. The following information is meant to communicate a vision of the market potential and a few examples of products.

While Western Europe, the US and Japan have historically dominated the flavor and fragrance market, there is currently significant growth in Asia, Latin America and Eastern Europe. Food and beverages account for the largest share of the current market at 47%.[203] Market growth is expected in soft drinks, snacks, convenience foods, confections, cosmetics and skin care products. Demand for flavor and fragrance products was estimated to be $16.3 billion in 2003[204] and the global market is expected to increase at an annual rate of 4.7% and be $19 billion in 2009 ($4.4 billion in the US alone).[205]

Demand for more natural ingredients and authentic flavors is expected to be a primary driver in the expansion of the flavors and fragrances market during the next five years, along with an increase in the demand for anti-aging products in cosmetics and skin care.[205]

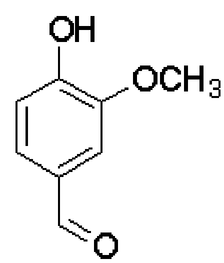
[202] Shimizu, S. 2001. Vitamins and related compounds: microbial production. In Biotechnology. Volume 10. Reed, G., Rehm, H-J, eds., VCH, Weinheim, pp 320-340.
[203] Global Information, Inc. 2005.
[204] SRI Consulting. SCUP Report. 2004.
[205] Freedonia Group. 2005.

Traditionally, microbes have played an integral role in the complex flavors and aromas of beer, wine, cheese and soy sauce for thousands of years. Microbial catalysis is currently used for the production of a wide range of flavors and fragrances. Flavoring agents such as citric acid and glutamic acid are produced on a commodity scale and are discussed elsewhere in this study. Many of the ingredients of products in the flavors and fragrances market are derived from natural sources but in a non-sustainable fashion (extraction from limited botanical sources). Production of these compounds through the sustainable use of renewable resources will be important for these products in the future. Other ingredients are chemically synthesized, often from petrochemical resources.

Microbial production of chemicals has the advantage of being able to produce chirally pure substances. This can have a significant effect on flavor quality and intensity.[206] Enzymatic transformation can also be employed for the optical resolution of racemates, especially with regard to alcohols, esters and carboxylic acids.

Emerging Technology

Vanillin has an annual market volume of 12 million kg and is second only to aspartame. While current manufacture is based on the conversion of ferrulic acid to vanillin, technologies are being developed to produce vanillic acid from glucose, using a microbe-catalyzed process, with subsequent reduction to vanillin catalyzed by aryl-aldehyde dehydrogenase isolated from *Neurospora crassa*.[207]



Vanillin

Allylix is developing a technology for the production of a range of terpene compounds using high-yield fermentations. Terpenes are typically produced by extraction from plants.[208] Other chemicals that could impact the flavors and fragrances market are succinic acid and sugar polyols, which are covered in other sections of this study. New fermentations are also being explored for the production of ingredients for fragrances and skin care products.

[206] Schreiber, W.L., L.G. Scharpf, and I. Katz. 1997. Chemtech. 27(3): 58-62.
[207] Frost, J.W. 2002. US Patent 6372461
[208] Industrial Biotechnology. 2005. 1(3): 135-140.

Energetic Materials (1,2,4-butanetriol and phloroglucinol)

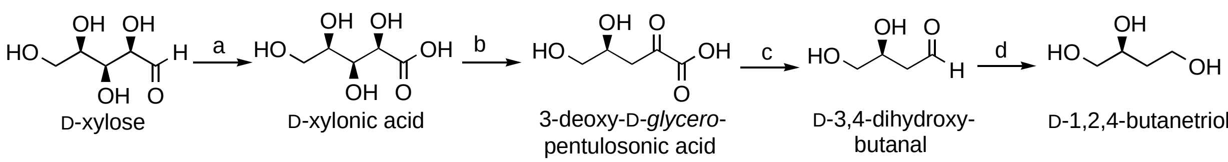
Existing Technology

1,2,4-butanetriol (BT) is a polyol intermediate that can be nitrated to produce 1,2,4-butanetriol trinitrate (BTTN), a compound that is thermally more stable, has a lowered shock sensitivity, and is less volatile than nitroglycerin.[209] BTTN can be used as a co-plasticizer in castable explosives. BT is currently derived from petrochemical feedstocks. The cost of racemic BT ($30-40/lb) currently limits its use in the production of BTTN.[210]

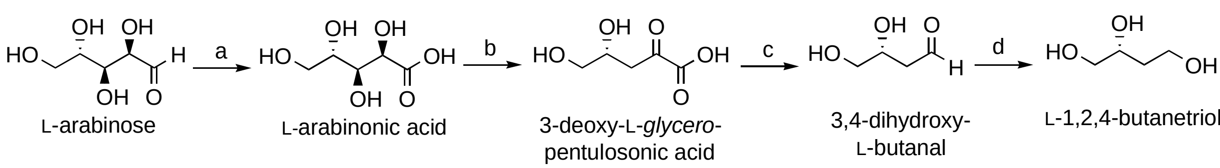
Another intermediate with potential for production of propellants/explosives is phloroglucinol, which could be used in the synthesis of 1,3,5-trinitro-2,4,6-triaminobenzene (TATB), a stable energetic material used by the US military. The current manufacture of phloroglucinol involves oxidation of 2,4,6-trinitrotoluene (TNT), a process that presents an explosion hazard, and generates carcinogenic chromates as well as other waste streams. Phloroglucinol can also be used in the synthesis of resorcinol, widely used to produce resins used in adhesive applications for the production of a range of products including tires and plywood.

Emerging Technology

Dr. John Frost (Michigan State University) has developed a synthesis of BT that utilizes microbial catalysis and renewable carbohydrate feedstocks.[211] In this process D-BT is produced from D-xylose and L-BT is derived from L-arabinose.



a. D-xylose dehydrogenase; b. D-xylonate dehydratase;
c. 2-ketoacid decarboxylase; d. alcohol dehydrogenase.



a. L-arabinose dehydrogenase; b. L-arabinonate dehydratase;
c. 2-ketoacid decarboxylase; d. alcohol dehydrogenase.

Figure 34: Production of 1,2,4-butanetriol from pentose sugars

[209] CPIA/M3 Solid Propellant Ingredients Manual; The Johns Hopkins University, Chemical Propulsion Information Agency; Whiting School of Engineering, Columbia, Maryland, 2000

[210] News Release. Office of Navy Research. December 22, 2003. www.onr.navy.mil/media

[211] Niu, W., M.N. Molefe, and J.W. Frost. "Microbial Synthesis of the Energetic Material Precursor 1,2,4-Butanetriol" 2003, *125*, 12998-12999

While the market for BTTN explosives/propellants is relatively small, it is anticipated that BTTN could also replace nitroglycerin as a vasodilator for the treatment of angina. Advantages of BTTN over nitroglycerin include BTTN resistance to degradation by nitrate reductase and the ability to produce chirally pure D-BTTN and L-BTTN, minimizing the number of metabolites generated from degradation by nitrate reductase.

Other possible derivatives of BT include the chiral intermediates D-3,4-dihyroxybutanoic acid, L-3,4-dihydroxybutanoic acid, D-3,4-dihydroxybutanal and L-3,4-dihydroxybutanal. Crestor®, a cholesterol-lowering drug manufactured by Astra Zeneca, is derived from D-3,4-dihyroxybutanoic acid.

The Frost Group have also developed a process for microbial synthesis of phloroglucinol from glucose and a process for catalytic hydrogenation of phloroglucinol for production of resorcinol.

Enzymes

Enzymes are biologically produced proteins that catalyze chemical processes without themselves being altered or destroyed. Bioprocessing utilizes the ability of enzymes to catalyze chemical transformations to produce a variety of chemicals. Enzymes are used industrially to process foods, textiles, leather goods, pulp and paper, grains, and detergents. Enzymes, as a whole, are typically produced biologically by fermentation of a carbohydrate substrate. In the fine chemicals area they are used primarily in research and development activities and diagnostics. These products are generally low in volume and command a higher price than the specialty enzymes. Products and markets are discussed in more detail in the following section.

3. Specialty Chemicals

Enzymes

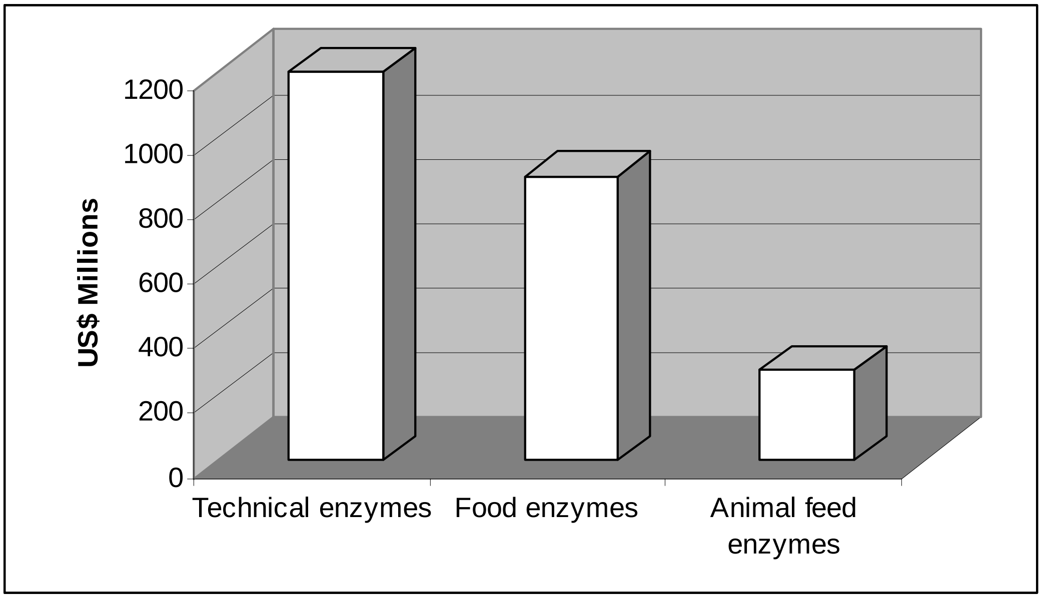
Existing Technology

The global market for industrial enzymes was $3.7 billion in 2004 and is expected to grow at an annual rate of 6.5% through 2009.[212] Technical enzymes account for 63% of the market, food enzymes 31%, and feed enzymes 6%.[213] Figure 35 shows the projected global market by enzyme type through 2009.

[212] Freedonia. World Enzymes to 2009. 2005

[213] Novozymes; www.novozymes.com

Figure 35: Projected Global Enzyme Markets Based on Application Sectors 2009[141]



Distribution of industrial enzymes by substrate are protein hydrolyzing (59%), carbohydrate hydrolyzing (28%), lipid hydrolyzing (3%). Specialty enzymes for analytical, pharmaceuticals and diagnostics account for approximately 10% of the market. Table 18 shows application areas and types of enzymes used. As the biobased economy emerges enzymes will play a significant role.

Emerging Technology

Enzymes will be the replacement for current catalysts used in the chemical synthesis of many products. New enzyme discovery, development of new processes for production of enzymes, and development of microbial systems with specific enzymatic steps for production of desired products will drive the commercialization of new biobased products. The cost of enzymes has long been an impediment to the widespread use of these catalysts in chemical manufacture. Recently, both Genencor and Novozymes embarked on independent programs to reduce the cost of cellulase for the conversion of biomass cellulose to monomeric glucose. This was considered crucial to developing a cost efficient process for the conversion of biomass to fuels and chemicals. In a four year period both companies succeeded in reducing the cost over 30 fold through the development of higher enzymatic activities and the reduction of production costs, placing the cost of these enzymes more in the commodity price range than that of specialty chemicals.[214] The development of these enzymes should have an effect on their use in the pulp and paper industry as well. New developments in enzyme technology will be a significant factor in driving a biobased economy.

[214] Current Opinion in Biotechnology. 2002. 13:338–344

Table 43: Applications for Industrial Enzymes

Applications for Industrial Enzymes

Market	Application	Enzyme
Food Processing	Baking	Amylase, protease
	Flavor development	Lipase
	Cheese	Protease
	Fruit Juice Clarification	Pectinases
	Cereals	Amylase
	Brewing	Amylase, glucoamylase
	Oxygen removal	Glucose oxidase
	Meat tenderizing	Protease
Grain Processing	Corn syrups	Amylase, glucose isomerase
Textiles	"stone-washed" texture	Cellulases
	Desizing of fabrics	Amylase, protease
Leather	Bating	Protease
Feed	Improve digestibility of animal feed	Phytase, xylanase, cellulase
Detergents	Improved cleaning	proteases
	Cold-soluble laundry starch	Amylase
Pulp & Paper	Kraft Bleaching	Xylanases
	Starch modification for paper coating	Amylase
	Recycling/deinking	Cellulase, hemicellulase

Inks/Dyes

Existing Technology

Petroleum-based inks have dominated the market for several decades; however, during the oil crises of the 1970s inks from soy, linseed, corn and canola began to infiltrate the market. Today over 90% of the US newspapers and 25% of commercial printer use soy-based ink.[162] The market share for vegetable oil-based inks increased from 5% in 1989 to approximately 25% in 2002.

Until 1890 all available dyes (pigments and tannins) were from natural sources. Starting in the late 19th century these natural dyes were progressively replaced by synthetic dyes. While the synthetic versions were not as durable they cost much less to produce. Today the US market for dyes and organic pigments is approximately $3.1 billion with a volume of approximately 600 million pounds.[215] Producers include Ciba Specialty Chemicals, DyStar, Clariant, Sun Chemical, Bayer, BASF, Buffalo Color and Fabricolor.

[215] Freedonia Goup. 2001; www.freedoniagroup.com

Emerging Technology

Although biobased inks are prevalent in the current market there is still significant potential for their increased use. New applications for improved biobased inks include toner for printers and copiers, ballpoint pen ink, and UV curable lithographic inks.[216] Investigators are pursuing the production of anthraquinone compounds by various fungal species[217] to replace synthetic dyes in the violet, blue and green hue sectors. In the 1990s Genencor International developed a biological process for production of indigo with Ceiba Geigy.[218] Others are attempting to genetically engineer crops for production of dyes such as indigo.

Adhesives

Existing Technology

Many conventional adhesives contain volatile organic compounds (VOCs) that can combine with nitrogen oxide in the atmosphere where sunlight can catalyze the production of ozone, a major cause of respiratory problems in humans. In the 1930s urea-formaldehyde and phenol-formaldehyde resins, began replacing corn starch and soy-based adhesives due to their greater water resistance and lower cost. Today methylene diisocyanate (MDI) adhesives have replaced soy as the primary resins in wood adhesives.[219] Current uses of adhesives are shown in Table 44.

Table 44: Common Uses of Adhesives[220]

Industry	Applications
Construction	Manufacture and installation of laminated wood panels, prefabricated beams, wall panels, general building construction; installation of flooring, tile, carpeting, ceiling panels and wall coverings.
Consumer goods	Manufacture of office supplies, hobby and model supplies, and stationery.
Nonrigid bonding	Bonding of woven and non-woven fabrics; manufacture of athletic shoes, rugs, filters, books, and sporting goods.
Packaging	Manufacture of cartons, boxes and corrugated boards; bags, envelopes, disposable products (diapers, paper products); cigarettes; and labels and stamps.
Rigid bonding	Manufacture of appliances, electronics, household products and furniture.
Tapes	Manufacture of all tapes, including those used for surgery, packaging, industrial applications, consumer applications and masking applications.
Transportation	Aircraft and aerospace structural assemblies; automotive, truck, boat, and bus assembly; mobile home manufacturing.

[216] National Soy Ink Information Center and Illinois Soybean Association
[217] Hobson, D.K. and D.S. Wales. 1998. J. Soc. Dyers and Colourists. 114: 42-44.
[218] Berry. A. et al., 2002. J. Industrial Microbiol & Biotechnol. 28: 127-133.
[219] American Soy Association
[220] Waterbased Adhesives Technology Review. 1999, Pacific Northwest Pollution Prevention Resource Center www.pprc.org

Emerging Technology

The replacement of petroleum feedstocks with biobased feedstocks is being driven by environmental, health and safety concerns as new adhesives and sealants are being developed. In 2003 global sales of adhesives was $ 29.5 billion with a total volume of 32.12 million dry pounds.[221] The industry on average is growing at approximately 2-3%/yr; however, new applications, such as electronics and medical adhesives is growing at a rate of 4-5%/yr. Packaging is the largest end use of adhesives and sealants, followed by wood and related products. The largest producers of adhesives in the US are Henkel, National Starch, H.B. Fuller, 3M, and Bostik Findley. Producers of starch-based adhesives include National Starch, A.E. Staley Manufacturing Company (part of Tate & Lyle), Roquette (France), Croda Chemicals, Cerestar, American Protein Corporation, and Chitogenics Ltd. Research into new adhesives from corn starch, soy and sugar-based polymer resins are promising new products and new applications for biobased adhesives.

In 2004 Rohm and Haas Company was awarded a $2 million grant from the US DOE to develop a new generation of adhesives and sealants. Rohm and Haas is working with researchers at Virginia Polytechnic Institute and State University as well as the Eastman Chemical Company and the USDA Eastern Regional Research Center to develop new adhesives from sugars, soybean oil, castor oil, and other biomass resources.[222] Other groups actively pursuing biobased adhesives include Ecosynthetix (Lansing, Michigan), the Plant Polymer Research group at the National Center for Agricultural Utilization Research, the Thames Research Group at the University of Southern Mississippi, and Omni Tech International, Inc. (along with the New Uses Committee of the US Soybean Board).

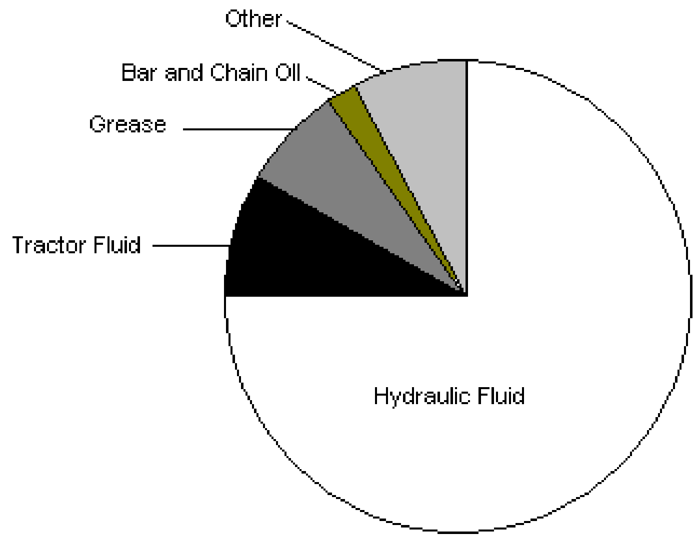
Lubricants and Functional Fuels

Lubricants and functional fuels represent a multi-billion dollar market. Current products are almost exclusively produced from petrochemical feedstocks, although new biobased products are starting to enter the market. Hydraulic fluids currently make up 75% of the biobased lubricant market (Figure 36). This represents 2% of the total hydraulic fluid market.[223] It is estimated that by 2010 biobased lubricants will command 35% of the total lubricant market.

Vegetable oils are used in such applications as hydraulic fluids, chain bar oils, metal working fluids, industrial gear oils, two-stroke motor oils, wire rope lubricant, and greases. Some advantages of biobased oils are 1) marketing advantage based on environmental concerns, 2) lower cost vs. synthetic esters, 3) inherent high viscosity index, 4) good anti-wear properties, and 5) high flash point.[224] About 85% of vegetable oil based lubricants are derived from canola. Soybean and other oils make up the balance.

[221] Chemical Market Reporter, March 7, 2005
[222] Rohm and Haas news release, July 29, 2004
[223] Miller, S., C. Scharf, and M. Miller. 2002. Utilizing new crops to grow the biobased market, Purdue University. Pp 26-28
[224] Fields, S. 2003. Environ. Health Perspectives. 111(12): 655-657

Figure 36: Use of biobased lubricants by application

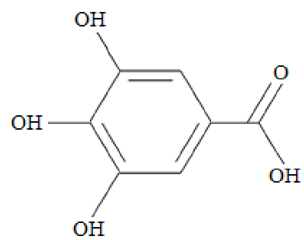


Manufacturers of biobased lubricants and hydraulic fluids include large oil companies such as Burah Castrol, Exxon, Pennzoil, Texaco, Quaker State, and Mobil, as well as Cargill, Lubrizol and a number of smaller companies in North America. Development of genetically engineered crops, such as soybean, with increased levels of oleic acid are expected to yield increased stability of biobased lubricants. In 2004 Cooper Power partnered with Cargill to launch a vegetable oil based transformer oil that has several advantages over traditional mineral oils including better compatibility with paper insulators, more fire resistance, lower flash point, and less environmental concerns over spills.[224] While the US government has mandated the increased use of biobased products, biobased lubricants still face several challenges in developing future markets. These include: 1) must compete in cost; 2) need to increase oxidation stability for more severe applications; 3) still need environmentally safe additives for full environmental benefits; and 4) the US Environmental Protection Agency still does not differentiate between oil types in the event of spills.

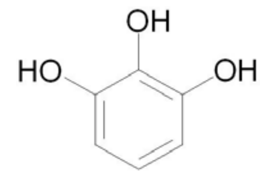
Gallic Acid and Pyrogallol

Gallic acid and pyrogallol are aromatics that have a high oxygen content. These chemicals are ideal candidates for synthesis of such products as trimethoprim, gallamine triethiodide, and trimetazidine. Propyl gallate is used in food applications as an antioxidant. The market for gallic acid is 170,000 kg annually. The market for pyrogallol is 200,000 kg annually. Gallic acid is currently isolated from insects and pyrogallol comes from the seed pod of a tree native to Peru. Gallic acid can be produced by fermentation of biomass-derived carbohydrates using a recombinant *E.*

coli.[225] Gallic acid can be converted to pyrogallol via decarboxylation by another recombinant *E. coli* at a yield of 97%.



Gallic Acid



Pyrogallol

Sugar-Polyols

<u>Existing Technology</u>

Sugar polyols are polyhydric alcohols derived from the catalytic hydrogenation of sugars. They occur naturally in plants throughout the world and most commercial production is based on extraction of the specific sugar from plant material and subsequent processing to the polyol (hydrogenation). The most widely used polyols are sorbitol, mannitol and malitol, with sorbitol accounting for about 50% of the market. They are used primarily in confectionary, food and oral care applications. Polyols have the sweetness characteristic of sugars, with fewer calories, and are able to hold moisture. They are versatile ingredients and are used as sweetners, bulking agents, humectants, freezing point depressants, plasticizers, chelating agents, color stabilizers, and flavoring agents (Table 45).

The total sugar polyol market was estimated to be 1,397,000 metric tons in 2001.[226] In 2004 690,000 metric tons of sorbitol was produced at a value of ~$500 million.[227] The sorbitol market has increased at an average rate of 1-2%/yr since 1997 and is expected to increase at a rate of 1% through 2009. Producers of sugar polyols include Roquette Freres, Archer Daniels Midland, Danisco, SPI Polyols, Cerestar, BASF, and Bayer AG.

[225] Frost, J.W. US Patent 6472190. 2002
[226] AP-Foodtechnology.com. Danisco ramps up xylitol production in China, new deal. 3/16/2005.
[227] CEH Report: Sorbitol. SRI Consulting. August 2005.

Table 45: Sugar-Polyol Applications

Polyol	Applications	Function
Adhesives	sorbitol	Flexibility and gloss enhancer, plasticizer, shelf-life extender
Paper Products	sorbitol	Anti-static agent, chelating agent, humectant, plasticizer, softener, fluidizing agent
Surfactants	sorbitol	Raw material
Textiles	sorbitol	Anti-static agent, chelating agent, humectant
Personal Hair Care	sorbitol	Conditioner, softener, shelf-life extender
Food/beverages	Sorbitol, mannitol	Flavoring agent, bulking agent, crystal modifier
	Xylitol, erythritol	Sweetener
Mouthwash/Toothpaste	Sorbitol, xylitol	Crystallization inhibitor, flavoring agent/sweeter

Emerging Technology

While hydrogenation sounds simple, it is actually a sophisticated process practiced by a few large companies with the appropriate know-how. New research is not focused on new products but rather new applications. Progress in biotechnology is leading the way for the complete production of sugar polyols through the use of microbes and microbial enzymes in an effort to eliminate the chemical hydrogenation step.[228] zuChem is developing fermentation pathways to the production of mannitol and xylitol. zuChem estimates the global market for mannitol as a reduced-calorie sweetener to be $100 million/year.[229] Other polyols being developed by industry leaders include lactitol and erythritol.

D. Biobased Plastics, Polymers, Films and Packaging

Polymers are long chain link molecules consisting of repeating structural units connected by covalent chemical bonds. The subunits, or building blocks, are called mers, hence the name polymers. Monomers are the small molecules of low to moderate molecular weight used to produce polymers. Cellulose is a homopolymer consisting of glucose (the monomer) molecules connected by ß-1,4 ether linkages. If a polymer is constructed from two (or more) different monomers it is called a copolymer or terpolymer. An example would be the polymerization of ethylene with 1-hexene to form a low density copolymer of ethylene and hexane.

One way to classify polymers is based on their thermochemical properties. Elastomers have a structure causing them to possess memory or elasticity. Elasticity is caused by the bonds along the carbon backbone of a polymer to undergo reversible bond rotations allowing the chain to be extended or elongated. Natural

[228] Rainer, J. and M.M. Silveira. 2004. Appl. Biochem. Biotechnol. 118: 321-336

[229] Pharmaceutical Packaging Solutions. November 1, 2005. www.in-pharmatechnologist.com

and synthetic rubbers are examples of elastomers. Plastics are polymers that can be molded or shaped with heat and generally have a greater stiffness and less elasticity than elastomers. The two main types of plastics are thermoplastics and thermosets. Thermoplastics soften when heated and harden again when cooled. Thermosetting materials, when heated, melt and flow but then further react (cross-link) to form rigid material. Table 46 shows several examples of polymers by type. Thermoplastics account for the majority of commercial usage and the vast majority of commercial polymers are currently produced from petrochemical feedstocks. Another form of polymers found in nature is natural fibers formed in plant and animals, for example cotton, wool and silk.

Table 46: Types of Polymers

Thermoplastics	Thermosets	Elastomers
Polyethylene, polypropylene	Phenolics	Polyisoprene (natural rubber)
Polyvinyl chloride, polyvinylidene chloride	Polyesters (unsaturated)	Polybutadiene (synthetic rubber)
Polystyrene	Epoxies	Polyurethane (foams, spandex)
Acrylonitrile butadiene styrene (ABS)	Polyurethanes	Ethylene-propylene-diene terpolymer (EDPM rubber)
Acrylics		Polysiloxanes
Celluloid		
Cellulose acetate		
Polyacetal		
Polyesters (PET, PBT)		
Polyamides (nylons)		

Polymers may also be classified into groups with regard to chemical structure, such as polysaccharides (polymers composed of sugar monomers), polyesters (contain an ester functional group), polyurethanes (organic units connected by urethane groups), polyamides (monomers joined by amide peptide bonds), polyolefins (hydrocarbon or olefin backbone) and polyacrylates (polymers of vinylic esters or acids).

Cellulose, starch, protein, chitin, and rubber are some of the more abundant naturally occurring polymers found in nature. They are produced by plants, animals and microbes. Commercial use of natural polymers is widespread and has a long history. For the purpose of this study biobased polymers are sorted into three different groups. The first is biopolymers, or those polymers that are naturally occurring such as starch, cellulose, protein, cotton fibers, wool, silk, and rayon (formed from cellulose). The second is biologically-derived polymers. These are polymers derived from biobased feedstock usually by fermentation. An example would be the production of polylactic acid (PLA) from glucose fermentation by an engineered strain of *E. coli.* The third group consists of those polymers that are produced using a combination of biological and synthetic routes (biological/synthetic). An example would be the production of Sorona™ by DuPont.

This copolymer is derived from 1,3-propanediol (produced by fermentation) and terephthalate (produced by petrochemical synthesis).

This section discusses emerging groups of biobased polymers. Each of these is described in a brief overview of current production technologies, properties and uses, substitution potential in current markets, and when available, plant size and costs. As shown in Table 47, the biobased polymers (excluding natural rubber) belong to five main types of polymers; polysaccharides, polyesters, polyurethanes, polyamides, and polyacrylates. Starch polymer and polylactic acid (PLA) are the most important resins in current biobased production although this is rapidly changing. The polysaccharides covered here generally represent modified natural polymers.

In the case of biobased polyesters, the monomer (which may be an alcohol or acid) is generally produced by fermentation from a renewable feedstock. The polyester may be composed of only one type of monomer. Whenever this is not the case, the comonomer is generally a petrochemical for the products shown in Table 47. Polyhydroxyalkanoates represent a special case since they can be either produced by fermentation or in a genetically modified crop, e.g. potatoes. In the case of polyurethanes, the polyols used are biobased while the isocyanate component is synthesized by petrochemical processes. The three representatives of the fourth group, polyamides, are produced by fermentation or by conventional chemical transformations of a crop-derived feedstock. The monomers in the last group, polyacrylates, can be produced by both fermentation and conventional petrochemical transformations.

Fermentation can also be used to convert biomass into the traditional starting materials and intermediates used to make conventional plastics and polymers. For example, cheaper bio-based routes to monomeric raw materials such as ethylene glycol, propylene glycol or even routes that make and dehydrate alcohols to olefins or acrylates could redefine polymer feedstocks as we know them.

Plastic packaging is the single largest market for polymer resins and is the target of most new biobased products. As the price of oil and natural gas continue to rise, these will become more economically competitive as well as being environmentally advantaged. Historically, petrochemical processing costs have exceeded feedstock costs, but over time the processing efficiencies have increased and processing costs have decreased dramatically. As oil and gas costs increase, there will be a shift to make these materials from biomass. Today the dominant cost of biomaterials is in processing, but just as with the petrochemical industry, we should expect rapid reduction of processing costs by both improved fermentation systems and development of more efficient separation and isolation technology. Many petrochemical processes are extremely energy intensive, which is driven by the availability and cost of natural gas. The rise in oil and energy costs is due to 1) depleted and harder to recover resources; and 2) increased worldwide demand, especially in Asia.

According to a recent McKinsey report, despite multi-billion dollar investments over the past decades, no commercial breakthrough of biopolymers has been made to date.[230] Even with the large commitment by NatureWorks® LCC to build a new PLA plant, the slow timing to develop this market was likely a cause for Dow withdrawing from the joint venture with Cargill. The most significant factor affecting the rate of technical substitution of bio-based resins for petrochemical products will be the increasing cost of oil and energy. The cost of biobased products will need to be equal to, or lower, and their performance equal to, or better, than current petrochemical products.

The current global production of biobased plastics was estimated to be approximately 800 million pounds in 2003, and should top 1.3 billion pounds by 2008. The prices of two major families of bio-based resins, polylactide and aliphatic aromatic polyesters, have dropped considerably since 1999 bringing them closer to those of commodity plastics while commodity resin prices have climbed steadily since 2002 as oil and natural gas prices have surged.[231]

In his 2004 report for the European Commission's Institute for Prospective Technological Studies (IPTS), Patel estimates the maximum substitution potential of biobased polymers in place of petrochemical-based polymers to be 33% of total polymer production. However he admits that many variables (including diminishing supplies and high prices for petroleum feedstocks) could raise the potential substitution[233]. As a point of reference BASF expects the market for biodegradable plastics to grow by more than 20%/year for the next five years and has explored many technologies to move closer to a bio-driven organization.[232]

[230] Riese, J., McKinsey & Company, ACS-BIO CTO Summit Oct 29, 2004 Washington, DC
[231] Commercializing Bioresins 2005; Nov 7 2005 Atlanta, Plastic News.com article Nov 18, 2005
[232] BASF develops biodegradable plastic based on renewable raw materials. www.plasticsnet.com. November 29, 2005

Table 47: Overview of Important Groups and Types of Bio-based Polymers

Polymer	Type	Monomer/ Feedstock	Source	Commercial[a] Stage	Current & Potential Use[e]
Biopolymers					
Starch	Polysaccharide	Glucose	Plants (corn, potato)	C	Fo, A, T, Pp, Ph, Fm, Pac
Cellulose	Polysaccharide	Glucose	Plants (cotton, trees)	C	Pac, Co, F, Ph, AP, EE
Chitin	Polysaccharide	Glucosamine	Shellfish	C	Cm, Ph, T
Protein	Thermoplastics	Amino acids	Plants (soybean), animals (gelatin), *de novo* synthesis	C	T, A, MD
Natural rubber	Elastomer	Emulsion[b]	Plants (Para rubber tree)	C	Pa, Co, T, Pac, A MD
Natural fibers	Polysaccharide	Glucose	Plants (cotton) or animals (wool)	C	T
Bio-derived Polymers					
Polyhydroxyalkanoates (PHA)	Polyester	Glucose	Corn, potato	C	Pac, T, Fm
Polybutylene succinate (PBS)	Polyester	Succinic acid	Corn	C	Fm, Pac, T
Polylactic acid (PLA)	Polyester	Lactic Acid	Corn	C	Pac, Fi, T
Ethylene glycol (EG)	Polyurethane	Glucose/glycerol	Corn	C	Polyester substitution
1,2-Propylene glycol (PG)	Polyurethane	Glucose/glycerol	Corn	C	Co, Pa, F, Ph
Polyols	Polyurethane	Triglycerides	Soybean	C	Fms, Fi
Nylon 6	Polyamide	Caprolactam	Corn	R	Fi, Pac, Fu,
Nylon 66	Polyamide	Adipic Acid	Corn	R	Fi, Pac, Fu
Biological/Synthetic Polymers					
Nylon 69	Polyamide	Oleic Acid		C[c]	Fi, Pac, Fu
Polyethyleneterephthalate (PTT)	Polyester	PDO and terephthalate	Corn	P/C	Fi, T, Pac
Polybutyleneterephthalate (PBT)	Polyester	BDO and terephthalate	Corn	D	AP, EE
Polybutylenesuccinate terephthalate (PBST)	Polyester	Succinic acid and terephthalate	Corn	D	Fm, Pac
Polyacrylamide	Polyacrylate	Acrylonitrile[d]	Petrochemical	C	Pac, Fu, Fi
Starch-based polymers	Thermoplastics	Glucose + petrochemical	Corn	C	Fm, Pac

[a] R = Research; D = Development; P = Pilot Scale Production; C = Commercial Production
[b] Emulsion of proteins, starch, alkaloids, tannins and gums
[c] Synthetic pathway from biobased oleic acid
[d] Enzymatic conversion (nitrile hydratase) of acrylonitrile to acrylic acid
[e] Use codes: Fo = Food; T = Textiles; Ph = Pharmaceuticals; MD = Medical Devices; Pa = Paints; Co = Coatings;
Fi = Fibers; A = Adhesives; Pp = Paper; Cm = Cosmetics; Fm = Films; Pac = Packaging; EE = Electrical and Electronics; AP = Automotive Parts; Fu = Furniture; Fms = Foams

Table 48: Producers of Bio-based Polymers[233]

Producer	Polymer Type and Trade Name
Starch Polymers:	
Novamont, Italy	Mater-Bi™
Rodenburg, Netherlands	Solanyl™
National Starch & Chem	Ecofoam™
Chinese company	Thermoplastic starch
BIOP, Germany	BIOpar™
Biotec, Germany	Bioplast TPS™
Japan Corn Starch	Cornpol™
Nihon Shokukin Kato, Japan	Placorn™
Potapakm Avebe Earthshell	Baked starch derivatives
Polylactic acid (PLA)	
Cargill	Natureworks™ (Mitsui Lacea in Japan)
Hycail, Netherlands	Hycail™ HM, Hycail™ LM
Toyota, Japan	Toyota Eco-plastic™
Project in China	Conducted by Snamprogetti, Italy
Other potential BB-polyester (currently petrochemical based)	
DuPont	Poly(trimethylene terephthalate) PPT Sorona™
Mitsubishi Chemical, Japan	Poly(butylenes succinate)
Showa Highpolymer, Japan	Poly(butylenes succinate) Bionelle™ 1000 and Poly(butylenesuccinate terephthalate) Bionelle™ 3000 Poly(butylene terephthalate) PBT
DuPont, Japan	Poly(butylenesuccinate terephthalate) Biomax™
Eastman, Japan [a]	Poly(butylenesuccinate terephthalate) Eastar Bio™
BASF, Japan	Poly(butyleneadipate terephthalate) Ecoflex™
Polyhydroxyalkanoates (PHA) –	
PHA homopolymers	
Metabolix, US	P(3HB), P(3HO)
Biomer, Germany	P(3HB) Biomer™
Mitsubishi Gas, Japan	P(3HB) Biogreen™
PHA copolymers	
Metabolix, US	P(3HB-co-3HV) Biopol™
P&G, US	P(3HB-co-3HXx) Nodax™
PHB Industrial, Brazil	P(3H-co-3HV)
Bio-Based Polyurethanes (PUR)	
Metzeler-Scham, Germany	PUR from bio-based polyol
Dow Chemical Company	PUR from bio-based polyol
Bio-Based Polyamides	
No biobased production	
Cellulosic polymers	
Plant cellulose-based	
Lenzing	Regen cellulose Lyocell™
Accordis	Regen cellulose Tencel™
Eastman	Cellulose acetate Tenite™
IFA	Cellulose acetate Fasal™
Mazzuccheli	Cellulose acetate Bioeta™
UCB	Cellulose acetate
Bacterial cellulose	
Weyerhauser, US	Bacterial cellulose Cellulon™
Ajinomoto, Japan	Bacterial cellulose
Cellulosic esters	
Dow	Methocel™, Ethocel™

[a] In 2004 Eastman Chemical Co. sold the Eastar Bio™ technology to Novamont SpA

[233] Patel, M., et al, Techno-economic Feasibility of Large Scale Production of Bio-based Polymers in Europe (Prepared for the European Commission's Institute for Prospective Technological Studies, Sevilla, Spain) October 2004

1. Biopolymers

Starch

Starch is a major storage carbohydrate (polysaccharide) in higher plants and is available in abundance surpassed only by cellulose as a naturally occurring organic compound. It is composed of a mixture of two polymers, an essentially linear polysaccharide, amylase, and a highly branched polysaccharide, amylopectin, which are both built of glucose repeat units. Starch derived from plant sources (corn, potatoes, etc.) has many industrial uses in foods, adhesives, textiles, paper, explosives, cosmetics, pharmaceuticals, construction materials, as well as the manufacture of biodegradable plastics.

Starch polymers may be viewed in three categories: 1) pure starch polymers; 2) chemically modified starch polymers; and 3) fermented starch polymers. Pure starch polymers undergo no modifications and can be used in extrusion processes or blending with copolymers for production of thermoplastics. Starch may be chemically modified (i.e. crosslinking, replacement of hydroxyl groups with ester or ether groups) to produce polymers with specific characteristics. Starch can be fermented to produce monomers, such as lactic acid, for specialized polymers.

Since starch is a relatively low cost material, it is an attractive alternative to petrochemical based polymers. Polymers produced from starch do not typically exhibit high strength characteristics so it may be mixed with petroleum based plastics such as polyethylene and polyvinyl alcohol to increase strength. Mixtures have been sold as biodegradable plastics, but when composted, only the starch rapidly degrades, while the polyethylene and polyvinyl alcohol do not.[234] These polymers dominate the bio-based polymer market which was 30,000 metric tons in 2002. Approximately 75% of starch polymers are used in packaging applications and leading producers are Novamont, National Starch, Biotec and Rodenburg. Starch can be used in copolymer (typically petrochemical) with as much as 50% (wt/wt) composition, although recent blends have been made with bio-based resins to give complete degradability.

Cellulose

The class of polymers based on cellulose includes the following: native cellulose from wood and most plant matter; regenerated cellulose fiber (viscose rayon) or film (cellophane) and chemical derivatives including organic esters such as cellulose acetate and ethers and hydroxyalkyl ethers. Cellulose, as a polyhydric alcohol, can undergo the reactions of most alcohols: etherification, nitration, acetylation etc. Cellulose ethers are made by reaction of base-treated cellulose with methyl chlorides while cellulose hydroxyalkyl ethers are made by addition of ethylene oxide or propylene oxide to the free hydroxyl groups on the polymer. Examples of commercial products include Dow Methocel™ and Ethocel™ resins. These resins have unique solubility properties which provide high value as water-soluble packaging, suspension agents, coatings, thickeners for food, and binders for

[234] Farrin, J. Biodegradable Plastic from Natural Sources, Institute of Packaging Professionals, December 5, 2005; www.iopp.org/

ceramics and drug tablets. These have been on the market for decades but are losing market share to petrochemical polymers.

Chitin

Chitin is one of the most abundant polysaccharides found in nature, second only to cellulose. It is a polymer composed of beta 1,4-linked poly-N-acetylglucosamine monomers and is found in the cell walls of fungi, exoskeletons of insects and shellfish. Shellfish waste represents a major source of this polymer. Chitin is extracted from crustacean shells by treatment with dilute sodium hydroxide at temperatures of 85-100^{o}C. Chitosan is the deacylated derivative of chitin and is produced by heating (90 – 120^{o}C) in a strong sodium hydroxide solution (>40%). Chitosan has a variety of applications in the areas of agriculture, water treatment, food, cosmetics, and biomedical uses. The estimated cost to produce chitosan with current technologies is $8.58/kg, limiting its current use to high value markets.[235] Biotechnological advances in developing an enzymatic deacylation of chitin to chitosan could potentially lower the cost and open up additional markets. HemCon, Inc. has developed a unique wound bandage containing chitosan that accelerates the clotting of blood and has antibacterial properties.[236] The bandages are currently used only in military applications; however, HemCon, Inc. is pursuing FDA approval for other uses.

Protein

Proteins are polymers consisting of amino acid monomers linked by peptide bonds. Proteins have a long history of industrial applications including adhesives, feed binders, coatings, and drug delivery. Sources of protein include plants, animal tissues and microbes. Biotechnological advances now allow the expression and production of specific proteins in plants, animals and microorganisms. An example is the production of spider silk protein in mammalian cells by Lazaris and coworkers.[237] Nexia Biotechnologies has produced spider silk protein in the milk of genetically modified goats; however commercialization of this technology has not occurred to date.[238]

Protein Polymer Technology (PPTI) is developing synthetic protein polymers for use in medical applications. Their NuCore™ Injectable Disc Nucleus (IDN) was developed for repair of spinal disc damage and has been licensed by Spine Wave, Inc. for commercial manufacture, although its current use is limited to investigational studies outside the United States.[239] DuPont manufactures a soy protein product (Pro-Cote®) used primarily as a paper coating.[240] ADM and Eka Chemicals both produce soy protein-based adhesives for wood products. Proteins are also being developed for use in the production of thermoplastics.[241]

[235] Morrissey, M.T. Marine Biotechnology. TAFT Meeting. Reykjavik, Iceland. June 11-13, 2003.
[236] ChemMatters. October, 2004.
[237] Lazaris, A., et al., 2002. Science 295(5554): 472-476.
[238] Nexia Biotechnologies. 2006. www.nexiabiotech.com
[239] Spine Wave, Inc. 2006. www.spinewave.com/nucore
[240] DuPont. 2006. http://soypolymers.dupont.com
[241] Vaz, C.M. et al. 2003. Journal Biomedical Material Research. 65A: 60-70.

Natural Rubber

Natural rubber is found in certain plant species (i.e. the Brazilian rubber tree – *Hevea brasiliensis*) and is a high molecular weight polymer of isoprene (2-methyl-1,3-butadiene). Synthetic rubber having similar elastomer properties can be made from polybutadiene (BR), polystyrene-co-butadiene, ethylene-propylene-diene monomers and polysiloxanes. Approximately 40-45% of the rubber consumed in the world is made from natural sources. Global consumption of all rubber in 2004 hit 11.8 million metric tons.[242] Applications of rubber materials are extensive and include paints, coatings, textiles, packaging, adhesives, furniture, medical equipment, carpet backings, seals, etc. Although there are differences in the performance of various rubber materials, many applications can use either natural or synthetic resin and are driven by price and availability. High oil prices favor natural rubber utilization. The largest market for rubber materials are for the manufacturing of tires and gaskets. Styrene-butadiene copolymers (SBR) are the most commonly used synthetic latex rubber with approximately 2.4 million tons consumed each year.

Allergic reactions to natural latex rubber have increased to the point that over 20 million Americans exhibit reactions to the proteins found in *Hevea* rubber.[243] The US Department of Agriculture developed the use of guayule, a desert shrub, as an alternative source of natural latex. The purpose was to establish a domestic source of natural rubber (important due to the lack of dependability of world rubber supplies). An added advantage is that guayule rubber does not contain the proteins responsible for allergic reactions from *Hevea* rubber. Yulex™ commercially produces guayule-derived latex products in the US. Research at Mendel Biotechnology is aimed at increasing the rubber content of guayule through the use of *Arabidopsis thaliana* transcription factors to activate promoter genes in rubber synthesis pathways.[244] A coproduct of guayule rubber is resins that can be used in adhesives. In 2004 the global demand for natural rubber was 8.28 million tons with a value of >$1 billion. Natural rubber continues to dominate the market due to the fact that synthetic rubbers developed to date are weaker and less elastic than natural rubber.[245]

Plant-based Polyols

In addition to the large market opportunity for conversion of seed oil triglycerides to glycerin and fatty esters for biodiesel use, these unsaturated materials also can be used as intermediates to form polyols. These materials can also used to make novel epoxy derivatives or new materials (via metathesis with ethylene) that can be incorporated into a variety of plastics. Polyols (or polyhydric alcohols) are alcohols with several hydroxyl groups. The hydroformylation of seed oils can also generate polyaldehydes that can be converted by reduction to primary alcohols, oxidation to

[242] Chemical Engineering News. 2005. 83(42): 21-24.
[243] Cornish, K. et al., 2001. Agro-Food-Industry Hi-Tech. November/December.
[244] Carole, T.M., J. Pellegrino, and M.D. Paster. 2004. Applied Biochemistry and Biotechnology. 115: 871-885
[245] BusinessWeek Online. December 27, 2005. High Hopes of a Would-Be Rubber Baron.

polycarboxylic acids, or reductive amination to polyamines that can be used in polymer applications.[246]

BioBased Technologies, located in Rogers, Arkansas, was started in 2003 and is focused on the development of agriculturally-based polyols derived from soybeans. The products can be used to make flexible and rigid foams and for spray on foams.[247] The North American market for polyols, for the manufacture of polyurethane, is approximately 3 billion pounds. The United Soybean Board estimates that 800 million pounds could be made with soybean polyol.[248]

Urethane Soy Systems Company (USSC) is another small company that has been issued a US patent for a new bio-based chemical feedstock based on soybean feedstock called SoyOyl™ .[249] Dow Chemical's BIOBALANCE™ soy-based polymer is a new development product for use in carpet manufacture.[250] They are initially focusing on developing soy based polyols for flexible slab polyurethane products, the largest market for polyols, at their pilot facilities in Freeport, Texas. These formulations contain approximately 35 percent soy monomer and can be used in conventional processing equipment without any modifications. They are currently sampling customers in the US and Europe. If pre-commercial trials are successful full commercial investment will be evaluated.

Seed oils can be converted directly to urethane polyols by functionalization (epoxidation, hydroformylation, hydration) or to generate the unsaturated fatty esters and glycerin by transesterification (biodiesel feedstock). The unsaturated fatty esters can be further converted to alpha olefins, dienes and 9-decenoic acid by a metathesis reaction under ethylene. The alpha olefins generated (mainly 1-octene) have potential to be used in linear low density polyethylenes (comonomer to induce branching) or to make synthetic lubricants. The dienes, although in smaller yields, can be used in rubber, latex and other polymer applications while the 9-deconoic acid is considered another platform chemical that could be used, for example, to make sebacic acid.[251]

2. Bio-derived Polymers

Polylactic Acid

Polylactic acid (PLA) is a thermoplastic resin made from fermenting and processing starch from corn and other crops. The sugar fermentation product is lactic acid which is converted to a lactide, which is then purified and polymerized using a ring

[246] Energetics Inc., 2003. Industrial Bioproducts Today and Tomorrow. U.S. DOE/EERE/Biomass Program, Washington, D.C.

[247] BioBased Technologies; http://www.biobasedtechnologies.com/products.htm

[248] United Soybean Board. www.unitedsoybean.org

[249] www.SoyOyl.com

[250] Dow Press release on June 22, 2005 http://news.dow.com/dow_new/prodbus/2005/20050622a.htm

[251] Plastic News. November 21, 2005.

opening polymerization process[252] (Figure 37). In April 2002 NatureWorks® LCC started up its' first large scale PLA plant in Blair, Nebraska making resins under the trademark Natureworks™ PLA with a capacity of 140,000 metric tons. The projected market for the product was estimated at 3.6 million metric tons by 2020.[253] With recent upswings in the cost and availability of standard petroleum-based resins PLA is at a price competitive level (ranging between $0.75-1.50/pound) with polyethylene terephthalate (PET) and polystyrene.[254]

PLA most closely resembles polyethylene in structure and properties. It is a hard, transparent, crystalline plastic. The resin is also stiff, clear and glossy and has barrier properties similar to PET. It is an excellent water and grease barrier and performs well as both a rigid and flexible material. The resin can be coated on other materials and copolymerization and blending with other materials can be used to modify its properties. The melting point is high and the resin can be fabricated using conventional polymer processing equipment by extrusion, injection molding, blow molded, fiber spun and thermoformed. The main advantage of this resin is that it is compostable and also recyclable.[234]

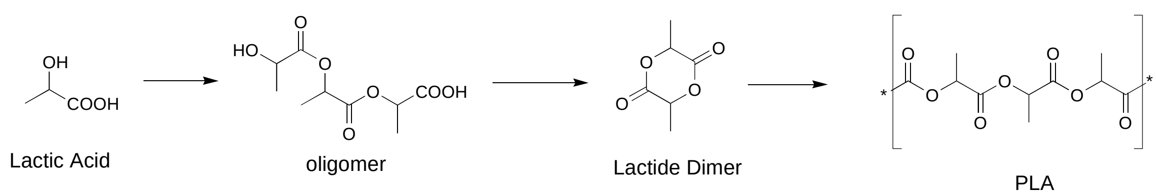


Figure 37: Production of PLA from lactic acid

Polyhydroxyalkanoates

Polyhydroxyalkanoates (PHAs) are a family of polymers that have a wide spectrum of properties allowing them to compete with a large share of the plastics market and they can be made by bacterial fermentations. The resins are semi-crystalline thermoplastics that can be used in most basic plastic processes and on conventional processing equipment. In the 1990s, poly (3-hydroybutyrate-co-2-hydrohydroxyvalerate) (PHBV) was commercialized by Zeneca, and later Monsanto, under the trade name Biopol™; however production costs could not compete with petroleum based plastics using the separation and fermentation technology available at that time.[255] Metabolix was a company spun out of the Massachusetts Institute of Technology in 1992 and acquired the bio-polymer technology from Monsanto in 2001. They began commercial production of organic polyhydroxyalkanoate (PHA) resin based on fermentation of corn sugar in a partnership with ADM in October 2005. The plant was expected to produce 90

[252] Cargill –Dow Natureworks™ , www.natureworksllc.com
[253] Fahey, J. (2001) *Forbes Magazine*, November 26, 206
[254] Plastic News.com Nov 21, 2005
[255] Process Economic Program Yearbook Internationals, 2001, SRI Consulting, Menlo Park, CA

metric tons in 2005 and 907 metric tons in 2006 at a price of $1.50 per pound. The price is expected to drop to around $1 per pound by 2008.[256] A still lower cost to PHAs could be found in genetic modification of plants (such as corn or Switchgrass) to directly produce the polymers.

Polyurethane

Polyurethane (PUR) resins are formed using a two component mix of a polyol and a polyisocyanate. Plant-based polyols were discussed above. In polyurethane chemistry the polyols are polymers or monomers with hydroxyl functional groups available for organic reactions. Examples of these polyols are polyethers such as polyethylene glycol, polypropylene glycol or polytetrahydrofuran. Global polyol sales are $10 billion annually and support the $20 billion/year global polyurethane market. Today, 99% of polyols are petroleum based so there is ample market opportunity for bio-based polyols for use as direct replacements. There are a number of companies looking at penetrating this large market. The polyol or diol length is adjusted to control the stiffness and other properties of the resins to give either hard or soft segments. Many biobased polyols, typically diols, can be made via fermentation processes and used as equivalents to petrochemical-derived diols or polyols from ethylene oxide or propylene oxide. Alternative biochemical routes to ethylene glycol and propylene glycol represent a major shift for the chemical industry which relies on olefin epoxidation that generates high salt byproducts and consumes excessive energy. As other diols, such as 1,3-propanediol and 1,4-butanediol, become less expensive via fermentations, they could also be incorporated in polyurethane formulations. Polyols generated from cheap seed oil sources such as soy oil could also be used. Some typical polyols and diols used in polyurethane manufacture are described below.

Ethylene Glycol and 1,2-Propylene Glycol

Ethylene glycol (EG) and 1,2-propylene glycol (PG) are commodity intermediates made by the epoxidation of ethylene and propylene respectively, followed by hydrolysis and used for making polyols and polyurethanes. They can also be made by hydrogenation and hydrocracking of sugars or by the reduction of lactic acid or 2-hydroxypropionic acid made by fermentation of sugars. IPCI (International Polyol Chemicals Inc) has built a 10,000 metric tons/yr plant in Changchun China and is planning a second 200,000 metric tons/yr facility targeted to start in 2006-2007. They are also considering building a $130 million dollar plant in Eastern Washington or Oregon.[257]

ADM recently announced plans to build a polyols facility to produce propylene glycol and ethylene glycol from carbohydrates as an alternative to traditional petroleum-based industrial chemicals. Propylene glycol is used primarily in industrial application such as paints, coatings and resins, and is also used in food and pharmaceutical applications. Ethylene glycol is used to produce polyesters and

[256] Plastic News.com Nov 21, 2005

[257] International Polyol Chemicals, Inc. http://www.agbob.com/polyol.html

industrial products.[258] Propylene glycol can also be made from lactic acid through the fermentation of glucose.
The current market size for ethylene and propylene glycols are 5.95 billion and 1.1 billion lb/yr respectively including uses as solvents and other nonpolymer applications.[259]

As described below 1,3-propanediol (PDO) and 1,4-butanediol (BDO) are alcohols that can be made by fermentation of sugars and are targeted mainly in polyester copolymers. These materials can also be used as the diol component in polyurethane formulations with isocyanates to give useful polymers.

Polybutylene succinate and other succinate-derived materials
Polybutylene succinate is a copolymer diester that can be made from 1,4-butanediol and succinic acid. Succinic acid, a dicarboxylic acid, is one of the top bio-based platforms moving to market and its production cost has dropped from $2.00/pound in 1992 to approximately $0.50 per pound in 2003.[260] It is made by fermentation of glucose. Succinic acid has the potential to replace maleic anhydride as one of the primary building blocks of the petrochemical industry. Succinic acid is currently made by the hydrogenation of maleic anhydride. As shown in a previous section of this report it can also be used to generate 1,4-butanediol (BDO), 1,4-diaminebutane and used to make polyesters as well as solvents and polymer intermediates such as tetrahydrofuran (THF), gamma-butyrolactone (GBL), n-methyl pyrrolidone (NMP) and 2-pyrrolidone. Succinic acid does not polymerize well in a condensation polymerization with amines to form linear high molecular weight nylon (polyamides) structures, but can form many useful polyesters.

One of these polyesters is polybutylene succinate (PBS). This polymer has properties similar to PET. PBS has applications in packaging and mulch films, and bags. PBS may be blended with the copolymer adipic acid to form polybutylene succinate adipate (PBSA) or terephthalate (petrochemical) to form polybutylene succinate terephthalate.

Producers of PBS include Showa Highpolymer (Japan), KD Chemicals (Korea), and Mitsubishi (Japan). Current production is based on petrochemical feedstocks[233]; however, Mitsubishi and Ajinomoto have developed a biobased route to succinic acid and plan to produce 30,000 metric tons/year of the biobased succinic acid.[259] Mitsubishi expects this to lower the cost of PBS which will compete directly with NatureWorks® PLA.

1,4-butanediol can be used for the production of polybutylene terephthalate (PBT) and is discussed on page 218 Biobased/Synthetic Polymers - Polybutylene

[258] ADM press release Nov 22, 2005 http://www.admworld.com
[259] Nandini Chemical Journal Online. June 2003. www.nandinichemical.com
[260] Werpy, T. and G. Petersen, PNNL, NREL, "Top Value Added Chemicals from Biomass: Candidates from Sugars and Synthesis
Gas" Aug 2004

Terephthalate It can also be used to produce other polymers such as thermoplastic polyurethanes (TPU). These are fully-reacted polymers in pellet or granular form that can be processed on standard extrusion and molding equipment and have significant resistance to abrasion. They are used for coated fabrics (e.g. simulated leather), sheathing for wire and cables, and heels for boots and shoes. Copolyester ethers (COPE) can also be derived from BDO. These polymers have a combination of flexibility, high strength and oil/water resistance even at high temperatures. They are used for automobile hoses, belting, gaskets, grease boots, CV joints, wire and cable insulation, spacer, bushings and specialized recreational and medicinal products.

BDO may be further processed (via dehydration) to produce tetrahydrofuran and (via dehydrogenation) to produce gamma-butyrolactone (GBL). THF can be partially polymerized to give low molecular weight polymers of polytetramethylene glycol (PMTG) that can be used in applications similar to thermoplastic urethanes and copolyester ethers. The company Invista (a subsidiary of DuPont) markets PMTG as Terathane® glycol, an intermediate for both Lycra® elastane and high-value polyurethane. Other producers of PMTG are BASF and QO Chemicals.

Other biobased diacids, such as 2,5-furandicarboxylic acid and itaconic acid, can be made readily by fermentation and have potential uses in polyamides and polyesters. Itaconic acid is made by fermentation of xylose and is used commercially at low levels in Saran polymers to modify properties. Homopolymers of itaconic acid are known, but have limited use due to relatively high costs. At lower production costs, itaconic acid could compete with methyl methacrylate (MMA) and other acrylates as well as in the pressure sensitive adhesives market. These combined markets account for 1.8 billion lbs and are growing.[246]

Polyamides

Polyamides (Nylons) are made at billion pound scales as commercial resins that are used as high temperature engineering materials because of generally high tensile and impact strength, good abrasion resistance and self-lubricating bearing properties. They are generally synthesized from diamines and dibasic (dicarboxylic) acids, amino acids or lactams. The properties can be optimized and tuned to needs by fine tuning the diacids or diamines used. Some common commercial nylons are nylon 4 (polypyrrolidone), nylon 6 (polycaprolactam), nylon 66 (polyhexamethylene adipamide) and nylon 69 (polyhexamethylene azelaamide). The building blocks of caprolactam, adipic acid and azelaic acid can all be made via fermentation and have been studied extensively. Biobased nylons have theoretically 100% substitution potential for their petrochemical equivalents.

3. Biobased/Synthetic Polymers

Polytrimethylene terephthalate

1,3-propanediol (PDO) is used with terephthalic acid to make the copolymer poly(trimethylene terephthalate) PTT which has superior stretch-recovery properties and is used in apparel and upholstery markets. PTT was developed and commercialized by DuPont and Shell in the 1990s when a petroleum based process was found for 1,3-propanediol. DuPont, through a partnership with Genencor International, developed a lower cost fermentation route to 1,3-propanediol through biomass sugars.[261] This has led to commercialization of DuPont's Sorona™ polymers which will transition over to bio-based 1,3-propandiol made via fermentation in a $100 million plant being constructed in Loudon, Tennessee.[262] This product is expected to directly compete with nylon and polyesters which are both currently derived from fossil fuels.

Polybutylene terephthalate

The traditional method of 1,4-butanediol (BDO) production is by the Reppe process, in which acetylene is reacted with formaldehyde. Newer processes use maleic anhydride or *n*-butane as starting points. BDO can also be obtained by hydrogenation of succinic acid, which itself can be made from biomass via fermentation (see page 185 Commodity Chemicals-Succinic Acid). Polybutylene terephthalate (PBT) resin utilizes 1,4-butanediol as a comonomer and is a thermoplastic material that has significant strength and chemical resistance, even at continuous high temperatures. These polyesters are made by Showa Highpolymer, DuPont, Novamont SpA and BASF. PBT can be machined and used with glass fibers in a wide variety of applications and has good color-ability. BDO can also be used in thermoplastic polyurethanes (TPU) which form abrasion resistant coatings or into copolyesters ethers (COPE) used in automotive hoses, belting, gaskets and cable insulation. BDO can also be dehydrated to produce THF which can be polymerized to polytetramethylene ether glycol used in TPU and COPE applications.

DuPont markets a low molecular weight polyol made by partial polymerization of THF under the trade name Terathane™ polytetramethylene ether glycol which is used both in polyesters (including Spandex fibers) and as the polyol segment in polyurethane formulations.

Polyacrylates, Polyamides and Polyacrylonitriles

Polyacrylates are a major class of commercial bulk polymers that are made by the radical polymerization of acrylic acid and its esters. The acid and ester monomers are made by the air oxidation of propylene followed by etherification. Similar vinylic polymers can be made by the radical polymerization of acrylamide or acrylonitrile monomers.

[261] Nieder, A.A. 2002, California Apparel News, Nov 15-22, 2
[262] Green Business News Sept 8, 2005; http://www.greenbiz.com/news

Acrylic Acid
Acrylates (acrylic acid and esters) are a 2 billion pound/year market and are used to prepare emulsion and solution polymers used in coatings, finishes, textiles, paper, paints and adhesives.[246] Acrylic acid can also be obtained from fermentation-based 3-hydroxypropionic acid (3-HP) via dehydration. This can then be used as a monomer or chemically converted to simple esters which can be homo or copolymerized with a variety of vinyl monomers. 3-hydroxypropionic acid can also be used as a precursor to form 1,3-propanediol used in DuPont's Sorona™ polymers. Cargill and Codexis have, over the last 5 years, developed an economical microbial process to this intermediate from corn dextrose.[263]

Acrylamide & Poly(acrylamide)
Acrylamide is used to make water soluble polymers used as flocculants, paper making aids, thickeners and additives for enhanced oil recovery with a current market size of 206 million lb/yr.[246] This monomer was traditionally made by a copper catalyzed chemical route from propylene which has been displaced by an enzymatic process that dehydrates acrylonitrile. Using nitrile hydratase from *Rhodococcus rhodochrous*, Mitsubishi produces over 100,000 tons/year of acrylamide.[264] The biotechnology route developed by Mitsubishi Rayon in Japan gave lower costs, higher selectivity and lower energy consumption and now dominates this market.

Acrylonitrile Polymers
Acrylonitrile (AN) can be made by the dehydration of biobased acrylamide and can be copolymerized with many materials such as synthetic rubbers where it provides resistance to oil and solvents. This technology is now being developed from 3-hydroxypropionic acid, but must come in competitive with current market prices of about $0.31-0.37/lb. The market size for acrylonitrile is about 3.1 billion lbs/yr.[246] The main use is in acrylic fibers, closely followed by copolymers with styrene (poly(acrylonitrile-co-stryene) and terpolymers with rubber modified styrene (poly(acrylonitrile-co-butadiene-co styrene) or ABS resins.

Biodegradability and Recycle
While many polymers are marketed as being biodegradable, a better term would be "environmentally degradable". The American Society of Testing and Materials (ASTM) defines biodegradation as degradation demonstrated to be caused by biological activity, particularly enzyme activity, leading to significant changes in chemical structure. The resulting degradation products must be chemicals such as water, carbon dioxide, methane, inorganic compounds or biomass. Materials may also be environmentally degraded by the following processes:

1. Compostable: The material must be demonstrated to biodegrade and disintegrate in a composting system at a rate consistent with known compostable materials (e.g. cellulose).

[263] Carr, M. The Biobased Revolution. Fall ACS Meeting Oct 11, 2005
[264] Bio-economy.net. 2006

2. Hydro-biodegradable and Photo-biodegradable: Material is broken down in a two-step process; an initial hydrolysis or photo-degradation stage, followed by further biodegradation. Single degradation phase "water-soluble" and "photodegradable polymers also exist.
3. Bio-erodable: This is a misnomer as it involves abiotic (which means it is not the result of biological activity) disintegration, and may include processes such as dissolution in water, and oxidative or photolytic disintegration.

Biobased and synthetic polymers both have a very wide range of degradation rates in the environment dependant on composition, structure, crystallinity, and crosslinking. In general, biobased materials degrade faster than petrochemical based polymers. However, not all biobased polymers are biodegradable. One group of biobased polymers, starch polymers, are easily biodegradable and incinerable and can be fabricated into finished products such as mulch film and loose fills through existing technology. Biodegradable starch foam and packaging materials are designed to replace polystyrene expanded polyethylene and polypropylene resins. Synthetic biodegradable polyesters are made in modified PET polymerization facilities, often from petrochemical based feedstocks. The demand for these materials is growing at about 30%/yr and typically used in packaging which accounts for about half of all disposed plastics. There are many variations including Cargill's Natureworks™ PLA materials, and Eastman Chemical Company's Eastar Bio™ (now produced by Novamont SpA) and BASF's Ecoflex™. Both Eastar Bio™ and Ecoflex™ are aromatic-aliphatic copolyesters based on butanediol, adipic acid and terephthalic acid. These materials have a high moisture and grease resistance, and process much like low density polyethylene LDPE. Uses include lawn and garden bags, agricultural films, netting, and paper coatings. Japan's Showa Highpolymer, part of the Showa Denko group and Korea's SK Chemicals both have small plants producing aliphatic (polybutylene succinate) and aliphatic-aromatic (polybutylate adipate terephthalate) polyesters. These resins are marketed in the US under the trade name Bionelle™ products. Synthetic biodegradable polyesters tend to complement one another's properties, as well as those of PLA, thermoplastic starch, and other organic materials and hence are finding markets in blended resins to increase the performance envelope of both materials. Dow Chemical obtained polycaprolactone aliphatic polyesters from it's' merger with Union Carbide used in adhesives, compatibilizers, modifiers and films. These materials are miscible with numerous other polymers and are inherently biodegradable. Many blends of copolyesters with thermoplastic starch, natural fibers and polycaprolactones give tailored properties and rates of degradation.[265]

Biobased materials, whether feedstocks, monomers or polymers, have different rates of degradation in the environment. A biobased material may be quite degradable, but when combined with a copolymer and extensively cross-linked to attain some specific functionality, the degradability can change significantly. The transition to biobased polymers has the advantage of sustainability when compared to petrochemically-derived polymers. However, the ultimate method of recycle

[265] Plastic Technology, http://www.plasticstechnology.com/articles 2005

and/or disposal of these materials will vary, just as it does today. Some materials will be amenable to recycle, others to biodegradation, and others will be incinerated.

E. Cellulose Fiber Products/Applications

- Research is in the development stage to process cellulose whiskers (very small fibers) from potentially varied sources to be blended with a biobased polymer to form a resin that that can be used as a low cost, biodegradable replacement for glass fibers in polymer composites.

- It is anticipated that this product could be used in the automotive industry, construction and other specialty industrial markets.

- Advantages of this product are reported to include the following.

    - Lightweight – *one half the bulk density of glass*
    - Biodegradable
    - Safe to handle
    - Less energy intensive
    - Less destruction of process equipment
    - High sound absorption
    - No conversion costs for composite production
    - Lower cost

- Research in this field is being sponsored by DOE and conducted by Michigan State University and MBI International, prominently.

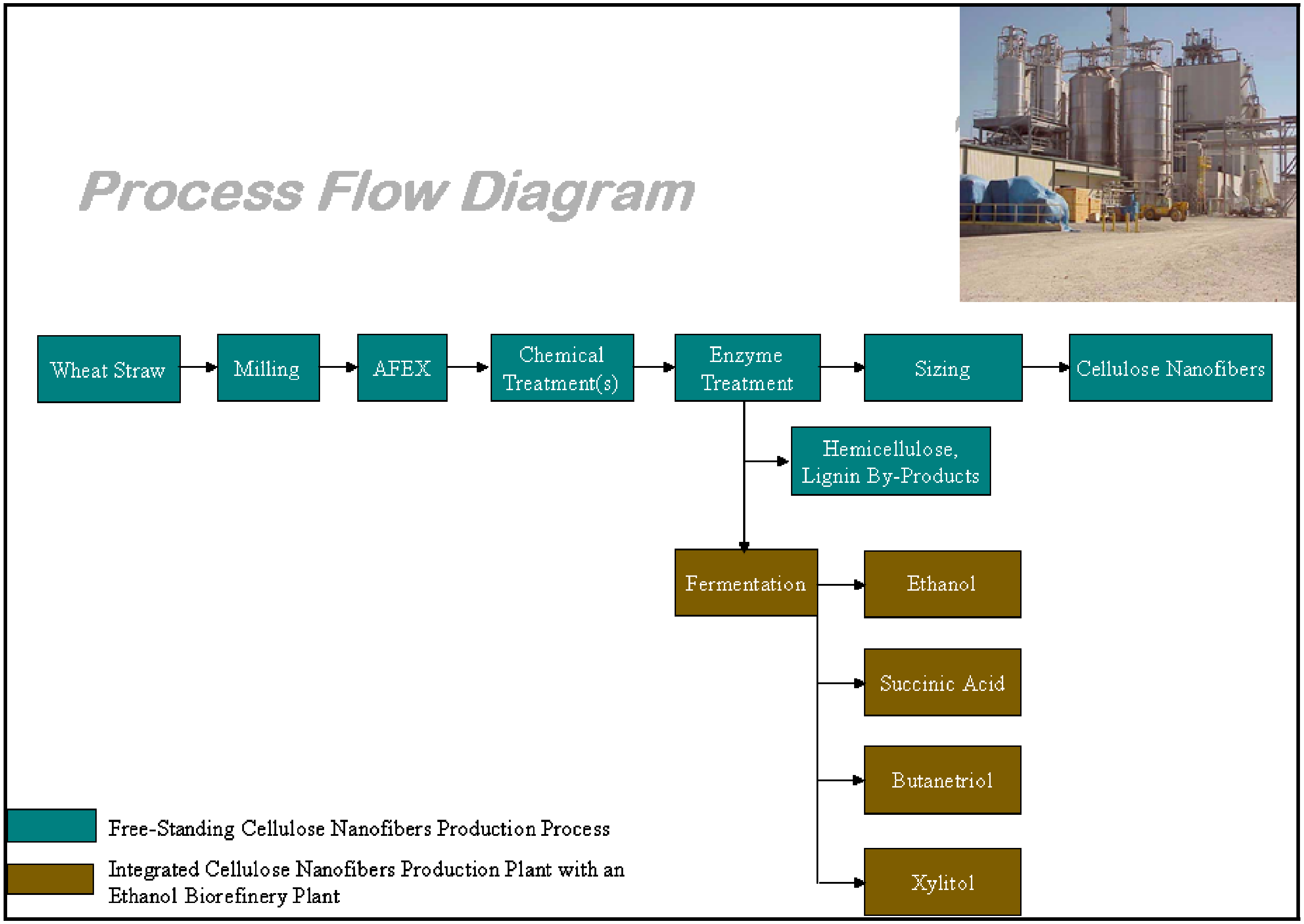
- The manufacture of these advanced composites would address a global market that has been estimated to exceed $3 billion.

- Further, it is expected that that these products could be manufactured in a biorefinery setting, in conjunction with traditional or second wave ethanol production. The related manufacture of fine chemicals is also anticipated (Figure 38).

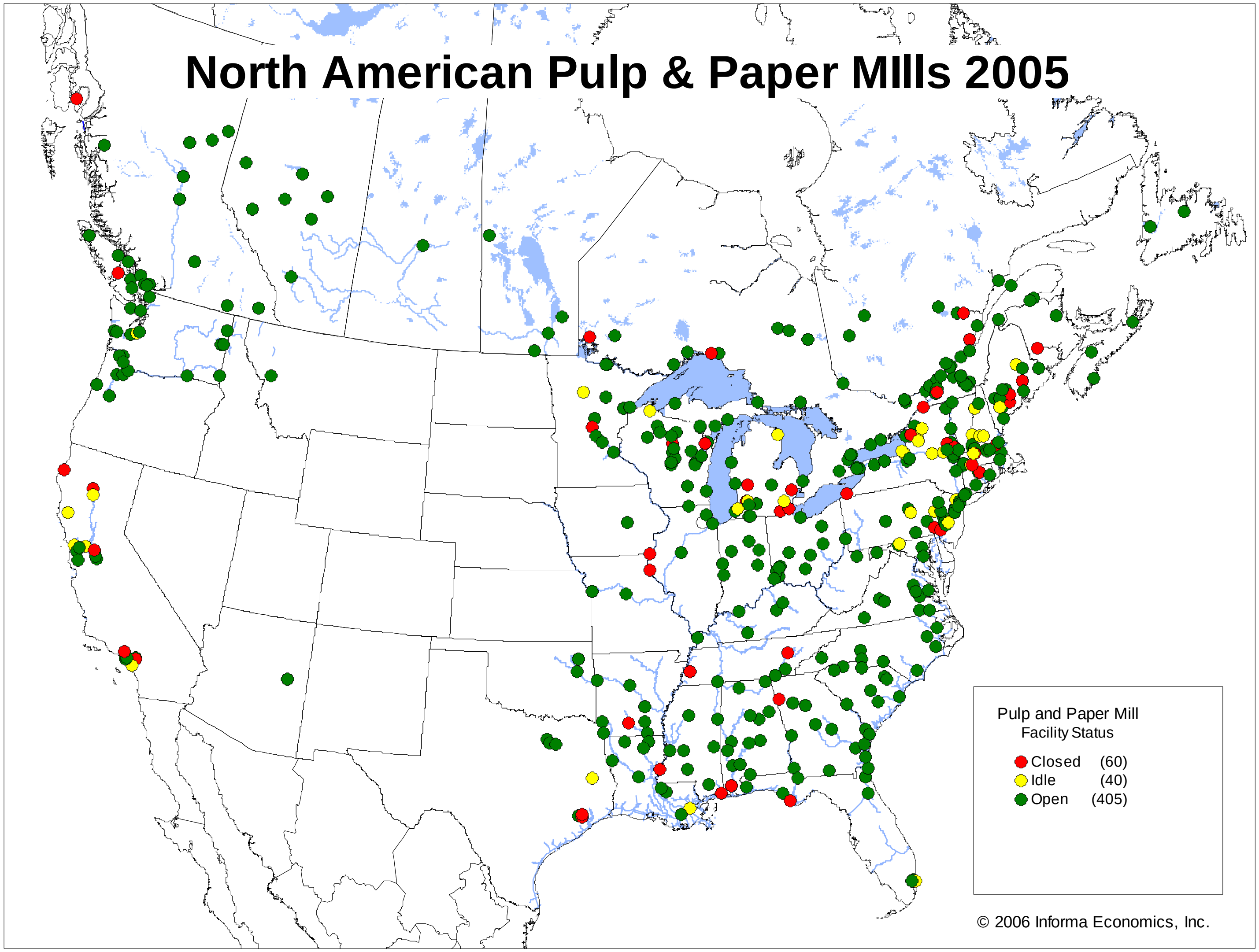
- Since manufacture of based biocomposites would not require the degree of cellulose transformation ethanol production does, it is believed that this technology is potentially available within the medium term.

- The byproduct of industrial conversion of cellulose is lignin. The pulp and paper industry, one of the earliest forms of biorefineries, produces an estimated 26 million tons of lignin annually in the US. Canadian mills add another five million tons to the North American total (Map 12).

Figure 38: Cellulose Microfibers Biorefinery



Map 12: North American Pulp and Paper Mills, 2005



- Industry estimates indicate that at least 95% of byproduct lignin is used as boiler fuel in the mill where produced.

- The lignin not used as fuel, estimated by industry participants at less than two million tons, enters a variety of markets, e.g., binders and dispersants, characterized by the Eurolignin consortium as being either very low value or very small. Further, growth in traditional markets was stated to be very slow.

- The global market for lignin is estimated to be in the range of $250 to $350 million. The leading participants in the Western world are said to be MeadWestvaco, the dominant force, Granit (Switzerland) and Metsaliiton Teollisuus (Finland). Asian suppliers, especially Chinese, are also important. Some reports indicate that MeadWestvaco has arrangements with Chinese manufacturers.

- Industry observers indicate that new technology including lignin precipitation in Kraft mills, Granit's patented process for sulfur-free lignin from non-woody cellulose and improved pulping methods may produce a significantly higher quality product suitable for new markets including cosmetics, pharmaceuticals and other high value uses.

- However, we note that recent literature and the statements of prominent scientists indicate a pessimistic attitude toward lignin as a significant financial contributor to a cellulose biorefinery. Indeed, having surveyed what we believe is the full range of publicly available information, we found that all such plans and feasibility studies treat lignin as a boiler fuel only. All cited the difficulty of separating and refining the product.

- Research sponsored by DOE examining lignin as a gasoline additive is ongoing. The likely commercialization date is unknown.

- There are also reports of proprietary research directed toward high value uses of lignin but the authors were not privy to such efforts.

- A summary assessment of the outlook for expanded use of lignin is presented in Table 49.

Table 49: Summary Assessment of Lignin Market Potential

Market	Market Size	Stage of Lignin Participation	Market Awareness	Potential Market Growth	Overall Attractiveness
On-site Energy	Large	Well Established	Well Established	Slow	Very Attractive
Highways	Small	Well Established	Well Established	Moderately Fast	Moderately Attractive
Binders	Medium	Well Established	Well Established	Moderately Fast	Moderately Attractive
Animal Health	Large	Early Development Stage	Early Development Stage	Moderately Fast	Questionable
Resin	Medium	Early Development Stage	Early Development Stage	Slow	Questionable
Dispersants	Large	Well Established	Well Established	Moderately Fast	Moderately Attractive
Cosmetics	Large	Research/ Conceptual Stage	Research/ Conceptual Stage	Very Fast	Questionable
Gasoline Additive	Large	Research/ Conceptual Stage	Research/ Conceptual Stage	Very Fast	Questionable

Market Size	Stage / Awareness	Growth	Attractiveness
Large	Well Established	Very Fast	Very Attractive
Medium	Initial Commercialization	Moderately Fast	Moderately Attractive
Small	Early Development Stage	Slow	Questionable
Niche/Specialty	Research/ Conceptual Stage	No Growth	Not Attractive

- The key to our assessment is the degree of market awareness that was found regarding non-traditional lignin uses. Our experience with customers in these markets, e.g., animal health, is that they will change formulations or product characteristics only if significant benefits in performance or cost can be demonstrated. Even with such support, the transition is slow. And, consideration/awareness of lignin appears quite limited.

- Further, based on available information, the research and development supporting new lignin uses is generally only at the conceptual development or early development stages.

- Thus, it appears that the biorefinery industry response noted earlier, forecasting lignin use as boiler fuel, is reasonable and that biorefinery financial performance is best estimated assuming no new high value markets for lignin.

- It appears that the research effort toward broadening lignin use has been curtailed and ill-funded. Given the potential value of lignin as a chemical feedstock and as a contributor to biorefinery finance, we see this field as a strong candidate for government research support.

F. Market and Life Cycle Analysis of Biobased Products

- This section concentrates on the status and potential of biobased products. The breadth of the products analyzed has been limited to approximately 21 categories. The list could certainly have been more exhaustive, however, the USDA has identified most of these product categories as areas of interest in their bioindustrial product program. Because of the diversity of the products covered in the analysis, finding consistent data sources proved to be challenging. Ideally, for example, the data for each market would be in "dollars of sales" or "volume of sales" for the most current full year of 2005. Based on our best efforts, we have tried to bridge the gaps in order to tell the most informed story possible for numerous products. Abbreviated citations referencing the information sources used for the analyses are located at the end of the section.

- Each of the biobased product categories are evaluated in a similar manner focusing on three areas of investigation, (1) an industry overview, (2) special comments regarding the product and industry and (3) an outlook of the potential for biobased products within the industry. Predicated on the findings of the research and expert opinion, all of the products are assessed concerning their potential "market attractiveness". A summary matrix of the analysis is presented in Table 50, the products are benchmarked against five different variables as follows,

    - Variable 1: Estimation of the size (based on value) of the conventional product industry that the biobased product resides, for example, the US conventional gasoline industry (biobased product ethanol) is estimated to be over $230 billion, this gives a perspective of magnitude of the conventional industry,
    - Variable 2: When possible the volume/output of the conventional product industry was estimated, for example, the conventional gasoline industry is approximately 139 billion gallons, again, this gives a perspective of the size of the conventional industry,
    - Variable 3: This is a qualitative assessment/estimate of the respective bioproduct and its current stage of product development in the marketplace,
    - Variable 4: This is an estimate of the annual rate of market growth for each respective conventional industry/product categories. For example, the conventional gasoline industry is forecasted to grow at a rate that is less than GDP based on historical patterns of consumption that are linked to the rate of US population growth. This highlights the anticipated relative

strength/growth of the conventional industry that the biobased product is linked,

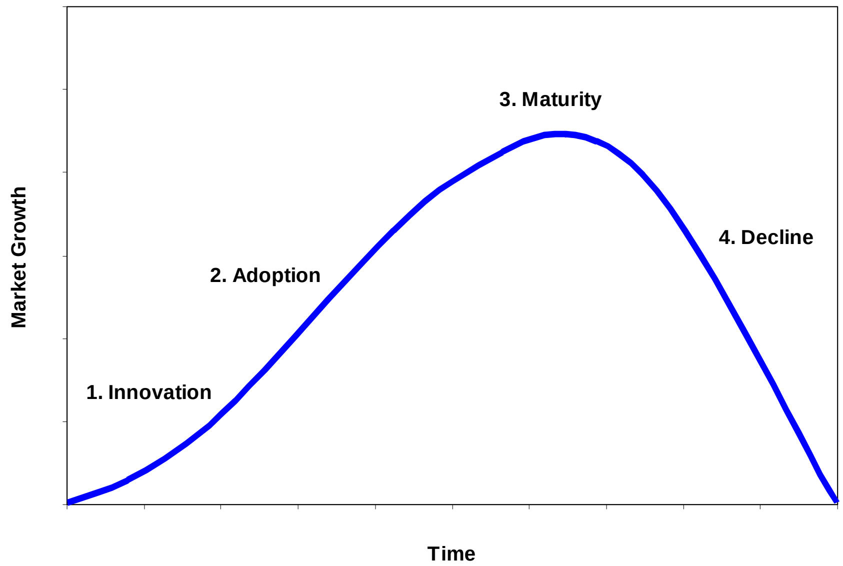
- Variable 5: This is a qualitative estimated of the market share potential of the biobased product relative to all other biobased products by 2015, for example, the pharma sector is expected to show significant growth in product development as the large segment of the US population, the baby boomers age and require/desire greater advancements in pharma products, this bodes well for biobased products. Variable 5 also is an indication of the overall attractiveness of the biobased product growth prospects.

- The results of the four questions then lead to the determination of the "Overall Attractiveness" of the respective product.

- A word is in order regarding the question that pertains to the "Stage of Development." The traditional product life cycle (in a simplified version) is characterized by four distinct phases or cycles (Figure 39). In the first cycle the product is conceived of or innovated. The second movement is the adoption of the product by the marketplace, where sales volumes steadily expand over a protracted period of time. In the third cycle, sales volumes of the product begin to increase but at a decreasing rate. Finally the fourth cycle occurs where the product begins to lose market share and sales start to decline.

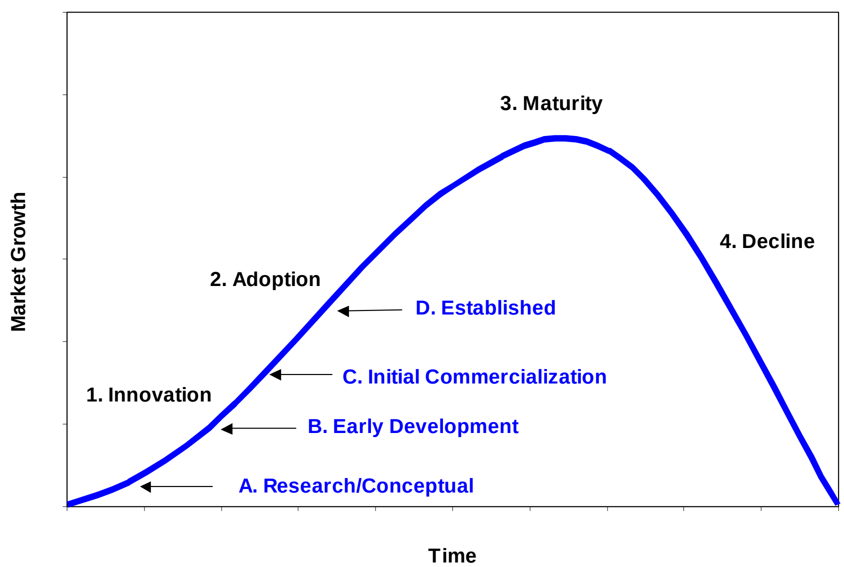
- For purposes of this study the traditional life cycle curve has been expanded to include additional stages that occur between the innovation and adoption cycles (Figure 40). This approach serves to better explain the development of "emerging products" such as the products that form the foundation of the developing biobased economy. The four new cycles are identified as (1) research/conceptual, (2) early development, (3) initial commercialization and (4) well established.

Figure 39: Traditional Product Life Cycle Curve



Source: Informa

Figure 40: Modified Biobased Product Life Cycle Curve



Source: Informa

Table 50: Summary Assessment Matrix of Biobased Products, US Markets

* Based on the value of the convention product market
** Represents the growth rate of the product/sector, e.g., conventional gasoline, not the bio-sector growth rate
*** Represents the % share potential relative to the biobased economy

Rank	Product/Sector	Value $	Volume	Bio-Product Stage of Development	Conventional Market Rate of Growth**	Bio-Product Market Share by 2015***
1	Gasoline (Ethanol)	$230 billion $6.7 billion	139 billion gal. 3.9 billion gal.	Well Established	Flat	Large
2	Pharmaceutical	$113 billion	na	Well Established	Moderately Fast	Large
3	Diesel (Biodiesel)	$110 billion $840 million	62 billion gal. 306 million gal.	Initial Commercialization	Flat	Large
4	Clothing (Biopalstic Blends)	$80 billion	na	Initial Commercialization	Slow	Niche/Specialty
5	Sanitary and Hand Cleaners	$22.3 billion	na	Research/Conceptual Stage	Slow	Niche/Specialty
6	Coatings	$19.5 billion	1.6 billion gal.	Well Established	Moderately Fast	Medium
7	Plastic Films	$17.8 billion	na	Initial Commercialization	Moderately Fast	Medium
8	Carpeting	$14.4 billion	20.8 billion sq. feet	Initial Commercialization	Moderately Fast	Small
9	Fertilizers	$12.5 billion	na	Initial Commercialization	Slow	Niche/Specialty
10	Containers	12.2 billion	na	Initial Commercialization	Moderately Fast	Medium
11	Solvents	$10-15 billion	8-10 billion lbs	Initial Commercialization	Flat	Niche/Specialty
12	Adhesives	$8.4 billion	15.2 billion lbs	Well Established	Moderately Fast	Medium
13	Insulation	$7.8 billion	na	Well Established	Slow	Medium
14	Wood Waste Products	$6.3 billion	317 billion lbs	Initial Commercialization	Moderately Fast	Medium
15	Motor Oils	$3.5 billion	1.2 billion gal.	Research/Conceptual Stage	Slow	Niche/Specialty
16	Janitorial Cleaners	$2.85 billion	na	Research/Conceptual Stage	Slow	Niche/Specialty
17	Wood Substitutes	$1.95 billion	2.26 billion lbs	Initial Commercialization	Slow	Niche/Specialty
18	Hydraulic Fluids	$1 billion	222 million gal.	Research/Conceptual Stage	Slow	Niche/Specialty
19	Sorbents	$400-500 million	na	Well Established	Slow	Small
20	Transformer Fluid	$200 million	40 million gal.	Research/Conceptual Stage	Flat	Niche/Specialty
21	Composite Panels	$100 million	na	Initial Commercialization	Moderately Fast	Medium

Stage of Development	Market Rate of Growth	Market Share
Well Established	Very Fast = > GDP Growth +2%	Large
Initial Commercialization	Moderately Fast = GDP Growth +2%	Medium
Early Development Stage	Slow = Avg GDP Growth	Small
Research/Conceptual Stage	Flat = < GDP	Niche/Specialty

GDP = US Gross Domestic Product, Annual real growth of 3.1%, 20-yr average

1. Motor Oils

a) Industry Overview

- Motor oils have been utilized since the development of steam engines as a buffer between moving and static engine components. The basic jobs of motor oils are to prevent metal-to-metal contact and to transfer heat from friction away from the contact point.
- The U.S. alone consumed 2.5 billion gallons of lubricants in 1997. Fifty-four percent of these were automotive lubricants (such as engine oil and transmission fluid) and forty-four percent were industrial lubricants.
- Researchers state that Americans use a billion gallons of motor oil per year.
- Researchers state that an estimated 15 million gallons of oil are consumed by the recreational boating sector for motor oil purposes in North America alone.

b) Special Comments

- The Department of Energy and Maryland Energy Administration estimate that 350 million gallons of motor oil pollute the envrionment each year.
- Detroit's recommendation of longer oil change intervals is holding down sales. The average drain interval now is 5,200 miles, but on newer models, both Chrysler and General Motors have gone to 7,500 miles for normal driving conditions or 3,000 miles for severe conditions.
- The increasing popularity of light trucks and sport utility vehicles are helping motor oil sales. To increase sticker prices, Detroit loads these vehicles with V-8 engines that may need up to six quarts to fill their crankcases, compared to as few as four quarts for four- and six-cylinder engines.
- Automotive engine oil presents a huge market opportunity, but tough performance requirements and the low price of petroleum alternatives make this a difficult market for biobased to enter. Two companies, however, are selling plant-based automotive engine oils. Agro Management Group (AMG) derives its product (called AMG2000) from canola, soy and various other vegetable oils, and Renewable Lubricants, Inc. (RLI) uses canola, sunflower, soy and corn oils.

c) Outlook and Potential

- Motor oil industry in the United States is expected to see a growth rate of 2.2% from 2000 through 2010.
- Motor oil sales will depend heavily on the quick lubes and car dealers market segment. Independent quick lube operators, which have 14,000, free standing quick lube units and about 7,000 dealers operated quick lube

centers in the United States. Independent quick lube operators, capture as much as 75% to 80% of the motor oil market at the rate they are growing.

Table 51: US Potential Markets for Bio-Based Lubricants

Oil Use	US Market (1000 tons)	Probable % Market acceptance of Bio-Based
Crankcase	3900	24
Marine	189.3	75

(Summarized from National Petroleum Refiners Association, NPRA 1998)

2. Hydraulic Fluids

a) Industry Overview

- Hydraulic fluids are a large group of liquids made of many kinds of Chemicals. Hydraulics are used in automobile automatic transmissions, brakes, power steering; fork lift trucks; tractors; bulldozers; industrial machinery; and airplanes.

- Soybean oil opportunities probability of acceptance for hydraulic fluids is 40%, with a possible market share of 5%. For example, if a market share of 5% is reached, this will provide a possible market share of eight million bushels of soybeans.

- Hydraulic fluids make up 75% of biobased lubricant market. Biobased hydraulic fluids make up 2% of the total hydraulic fluids market.

- Industrial hydraulic fluids represent a 222-million gallon market in the United States.

b) Special Comments

- In 1999, the largest market share of biolubricants was hydraulic oil with 51,000 tons.

- Penetration in soy-based hydraulic fluid market will be limited to niches where environmental and safety concerns are high. (Soybean Board, 2004)

c) Outlook and Potential

- The outlook for soy-based hydraulic fluids is positive if soy can meet performance specifications and any emerging regulatory requirements, while remaining lower in cost.

- Congress officially designated six items for minimum biobased content additives; hydraulic fluid (for mobile equipment) has a 24% content level.

- Some manufacturers now market environmentally acceptable hydraulic fluids in the United States. Exxon Mobil, Chevron, Texaco and E.F.Houghton, a supplier of industrial hydraulic fluids, offer rapeseed-based products. Pennzoil offers a hydraulic fluid made with sunflower oil.

Table 52: US Potential Markets for Bio-Based Lubricants

Oil Use	US Market (1000 tons)	Probable % Market acceptance of Bio-Based
Hydraulic	721.5	60

(Summarized from National Petroleum Refiners Association, NPRA 1998)

3. Plastic Films

a) Industry Overview

- One of the fastest-growing market areas for soy is the manufacture of soy-based plastics.

- The U.S. market for petroleum-based polyols is 3 billion pounds per year and 9 billion pounds worldwide.

- The US Plastic film industry is $17.8 billion, consisting of about 200 firms.

b) Special Comments

- The major end uses are packaging 25% and construction 22%.

- Food packaging will provide growth opportunities in areas such as snack foods, confections and produce. Slower growth in other segments such as textile, apparel and paper product packaging will reflect market maturity.

c) Outlook and Potential

- Packaging will account for three fourths of film uses in 2008 due to cost and source reduction advantages over rigid packaging, as well as potential in areas such as breathable films and stand-up pouches.

- Best film opportunities are anticipated in secondary packaging products such as retail bags and stretch wrap due to growing consumer spending and industrial activity.

- US degradable plastic demand will grow 13.7 percent annually through 2008 as prices and properties become more competitive with conventional polymers. Biodegradable/ compostable types will lead gains, especially polylactic acid (PLA). Film and ring carriers will dominate packaging uses while degradable foodservice items grow the fastest.

4. Containers

a) Industry Overview

- The US Plastic container industry is $12.2 billion.

- The container industry includes producers of metal cans, glass containers, and plastic bottles.

- Plastic container demand in the United States was projected to increase more than 4 percent annually to about 13 billion pounds in 2004.

- The US demand for plastic containers will grow 5.3 percent annually through 2008.

b) Special Comments

- Market share by package type changed slightly from that of 1989, with cans rising to 62.2 percent, glass falling to 20.2 percent, and plastic remaining at 17.6 percent.

- Plastic's expansion of market share has been halted because of end-user concerns about the stability of prices and the environmental consequences of packaging in plastics.

c) Outlook and Potential

- Plastic container demand is forecast to exceed 165 billion units in 2008, which will require over 14 billion pounds of resin as plastics continue to supplant competitive paperboard, metal and glass packaging across a broad range of applications.

- Plastic bottles are expected to log the most substantial growth, according to a study, accounting for 75 percent of all plastic containers by weight.

Table 53: Container Inputs for US Soft Drinks

Container Types	Share 1992	Share 2000
Glass	10%	2%
Plastic	13%	24%
Metal	77%	74%

Source: Salomon Smith Barney

Table 54: Container Inputs, US Packaging Shipments by Material Beer (Billion Units)

Containers	1992	1994	1996	1998	1999	2000	2001(E)
Glass	12.8	15.1	16.7	17.7	18.2	18.4	18.8
Metal	38.2	36.8	34.6	33.4	33.4	32.9	33.2
Plastic					0.05	0.15	0.30
Total	51.0	51.9	51.3	51.1	51.6	51.4	52.3

Source: Salomon Smith Barney

Table 55: Container Inputs, US Packaging Shipments by Material Assorted Liquid food, Fruit, Fruit Juice Packaging (billion units)

Containers	1992	1994	1996	1998	1999	2000	2001(E)
Glass	14.2	16.1	13.2	9.0	9.2	8.6	8.2
Metal	12.5	12.2	11.6	11.7	12.1	11.6	11.8
Plastic	11.4	13.4	16.1	18.8	20.3	22.3	24.2
Total	38.1	41.7	40.9	39.5	41.6	42.5	44.2

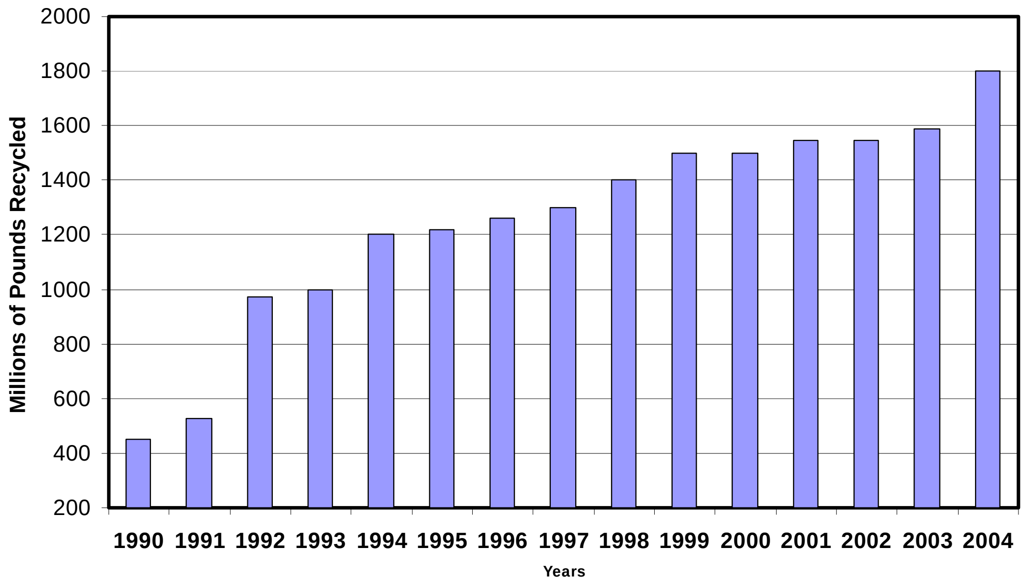
Source: Salomon Smith Barney, industry sources
(*.) Total food containers
(**.) Fruit/fruit juice cans
(***.) Includes water, isotonic, milk and other liquid foods

Table 56: Container Inputs, US Packaging Shipments by Material Soft Drinks (billion units)

Containers	1992	1994	1996	1998	1999	2000	2001(E)
Glass	7.8	4.5	1.6	1.4	1.4	1.4	1.4
Metal	57.4	66.3	64.5	69.4	68.9	67.4	68.1
Plastic	9.8	13.3	16.8	20.6	21.4	22.0	22.5
Total	75.0	84.1	82.9	91.4	91.8	90.7	92.0

Source: Salomon Smith Barney, industry sources.

Figure 41: Growth in Consumer Plastic Bottle Recycling



Source: R.W Beck Incorporated, 2004

5. Composite Panels

a) Industry Overview

- Composite Panels are composed of nonstructural composite material such as highly engineered blends of recycled paper products or agricultural wastes, biobased resins, and color additives that can combine to provide a composite and composite panels.

- Through 2008, demand for composite and plastic lumber in molding and trim applications is projected to expand 7.1 percent per yearly, almost all of which will be plastic lumber.

- Molding and trim was the largest end use for composite and plastic lumber in 2003, at about 47 percent of the total.

b) Special Comments

- Gains will be slower than for most composite and plastic lumber applications, a result of the relative maturity of this market.

- Residential building will remain the largest market for composite and plastic lumber over the 2008 forecast.

- Although prospects for new home construction are expected to moderate through 2008, these materials will achieve growth through increasing market penetration at the expense of alternative materials

c) Outlook and Potential

- The USDA has proposed a minimum biobased content level of seventy percent for composite panels and ten percent for molded reinforced composites.

- Biobased building composites in the United States have grown from 2000-2005, set to increase from an estimated twelve million dollars to over one hundred million dollars, industrial consumer from six million to eight million dollars, automotive from six million to over ten million dollars while infrastructure/ marine will increase from and estimated three million to over six million dollars.

6. Insulation

a) Industry Overview

- Insulation is a conservation measure that can save significant amounts of energy. Standards requiring better insulation in new buildings would reduce the consumption of natural gas and fuel oil and make the use of solar power and electrical heating less costly as the use of oil and natural gas becomes prohibitively expensive.

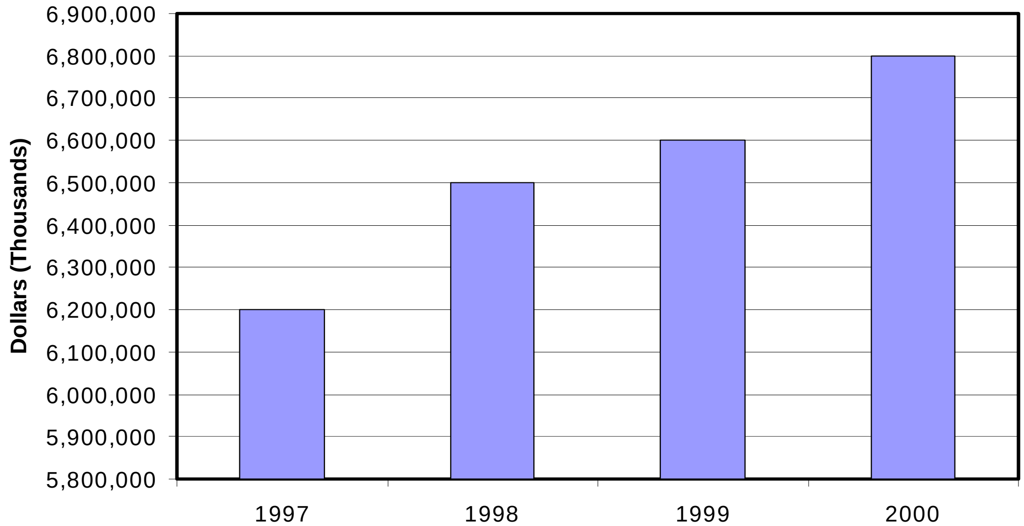
- The insulation industry experienced a 3.1 percent annual growth increase during 1999.

- US demand for insulation will reach $7.8 billion in 2008.

- Fiberglass insulation will remain dominant while foamed plastic, reflective insulation and radiant barriers grow at a faster rate.

- Global insulation demand will reach 18 billion square meters of volume in 2009. The world insulation industry is $22.1 billion.

Figure 42: Insulation Market Size



Source: (National Insulation Association, NIA, 2002)

b) Special Comments

- Researchers state that gains in the insulation market will be based on accelerating durable goods shipments, increasing nonresidential building construction, more insulation per structure and upgrades of insulation for existing buildings.

- Biobased had only four distributors in various parts of the country in 2003.

- Fiberglass dominates the insulation business with 87 percent of the market, and cellulose, which has 7 percent of the market.

c) Outlook and Potential

- The new energy bill passed by 109th Congress offers American builders incentives to build more energy efficient homes, with biobased Insulation, an energy-efficient, soy based foam insulation can help them meet government requirements.

- The new energy bill will allow builders, who use biobased insulation, to receive a $1,000 tax credit for construction of the qualified energy efficient home. If a house is built at the 50 percent efficiency level, with one-fifth of savings coming from a building envelope component, builders will receive a $2,000 tax credit.

7. Clothing with Blends of Bioplastics

a) Industry Overview

- The U.S. textile industry includes about 10,000 companies with combined annual sales of $80 billion. The industry has become more concentrated in recent years, with the 50 largest companies controlling more than 60% of the market. About 100 companies have annual sales over $100 million.

- The industry currently employs an estimated 660,000 people. Approximately 441,000 jobs have been lost since 2000 due to closings of 279 textile plants, according to the National Council of Textile Organizations.

- Textile firms sell to apparel manufacturers, automotive firms, furniture manufacturers, other textile companies and various retailers. The end uses of U.S. textiles (in pounds) are apparel (35%), floor coverings (25%), industrial/other (23%), and home furnishings (16%).

- Annual U.S. textile exports total about $9 billion, a large portion of which goes to Central and South American countries that manufacture apparel for reimport to the United States. Textile imports are $7 billion, with the largest amounts from China, Canada, Korea and Italy.

- On January 1, 2005, the last remaining quotas protecting the U.S. industry (under the Multifiber Agreement) were phased out, in accordance with the General Agreement on Trade and Tariff (GATT). According to the World Bank, upwards of $200 billion in textile manufacturing could shift to China over the next few years.

- Negotiations between the United States and China continue in an effort to work out a new agreement that will balance each country's interests. China is pressing for a 15% growth in textile exports to the United State. The U.S. textile industry wants growth contained at 7.5% through 2008.

b) Special Comments

- A joint venture between DuPont and Tate & Lyle PLC has been formed to produce 1,3-propanediol (PDO), the key building block for DuPont™ Sorona® polymer, using a proprietary fermentation and purification process based on corn sugar. This biobased method uses less energy, reduces emissions and employs renewable resources instead of traditional petrochemical processes.

- Currently, Sorona® polymer is manufactured from petroleum-based PDO and is available commercially from DuPont and its licensees. In 2006, commercial-scale quantities of bio-based PDO from corn sugar will be available from DuPont Staley Bio Products' manufacturing facility in Loudon, Tennessee.

- DuPont Staley Bio Products will contribute to DuPont's goal of deriving 25% of its revenue from nondepletable resources by 2010. DuPont derived 14% of its 2002 revenues from nondepletable resources.

- Cargill's PLA plant at Blair, Neb., turns 14 million bushels of corn into 300 million pounds of PLA per year. Cargill is the original inventor of polylactic acid (PLA), a polymer derived from natural plant sugars and marketed by the joint venture as NatureWorks PLA and Ingeo fibers.

- NatureWorks LLC's proprietary process for manufacturing the polymer used to make Ingeo fiber centers on the fermentation, distillation and polymerization of a simple plant sugar, corn dextrose. The company essentially harvests the carbon stored in the sugars to make polylactic acid resin called NatureWorks PLA. The resulting resin can then be spun or otherwise processed into Ingeo fiber for use in a wide range of textile applications.

- There is some resistance in the market from companies such as Patagonia. That resistance arises from the fact that it cannot be guaranteed that the corn used was free from genetic modifications. Patagonia and other companies campaign against GMOs.

- Further resistance to bio-based textiles is due to past experience in the industry with products such as Ramie Cotton. This bio-based cotton blend rapidly last its properties and became dry. Customers noted a brittle feel and loss of shape in apparel made from this product.

c) Outlook and Potential

- U.S. apparel sales increased 4% in 2004, to $173 billion, according to the NPD Group, a provider of sales and marketing information. At $29 billion, 2004 sales of children's clothing were down modestly (less than 1%). Sales of men's apparel grew 5.4% to $49 billion, and women's apparel sales rose 4.9% to $95 billion. These results compare with a 5.1% overall sales decline in 2003, when sales of men's and women's apparel fell 6.4% and 7.1%, respectively, and children's clothing sales grew 4%.

- The textile industry saw revenue fall at an 8.9% compound annual rate from 2000 through 2004 due to a general slowdown in the economy and broad industry restructuring. Economists expect the industry to grow at an 8.8% CAGR from 2005 through 2008.

8. Fertilizers

a) Industry Overview

- Humans, animals and plants rely on a safe, healthy supply of food and nutrients like nitrogen (N), phosphorus (P) and potassium (K) for proper growth and development. Fertilizer is the 'food' that plants need to produce a healthy and bountiful crop. Experts estimate that without commercial fertilizers, the world would be without one-third of its food supply.

- Eleven private US producers had total agricultural chemical sales of over $100 million in 1999, with another eight generating at least $50 million.

- Total fertilizer sales in 2004 were $12 billion.

b) Special Comments

- In 2003, China imported $478 million in fertilizers and $29.63 million in pesticides from the U.S., accounting for 27% and 22% of total imported fertilizers and pesticides.

- Some 15 million tons of US fertilizer were exported, principally to China, Brazil, Mexico, Canada and Australia in 2004.

c) Outlook and Potential

- The top five nitrogen-producing countries in 2002 were China, India, the United States, Russia and Canada.

- An estimated 15 million tons were exported from the US, to China, Brazil, Mexico, Canada and Australia.

- The fertilizer industry has increased its use efficiency. Nitrogen use on corn, which stood at 5.21 million tons in 1975/1976, fell by 1.3 percent to 5.14 million tons by 2003. Corn production increased from 6.289 billion bushels in 1976 to 10.114 billion bushels by 2003, a 60.8 percent increase. Phosphate use on corn, which stood at 2.55 million tons in 1975/1976, fell by 28.1 percent to 1.835 million tons by 2003.

9. Coatings

a) Industry Overview

- Overall growth of US coatings is forecast at an average annual growth rate of 2.2%.

- The overall market for coatings (which includes paints and surfactants) in the United States tops 1.2 billion gallons. Half of the coatings market consists of architectural coatings for both home and commercial applications.

b) Special Comments

- Total consumption of paint additives was about $710 million in 2002.
- The Paints and coatings industry in the North American Free Trade Agreement (NAFTA) is approximately forty billion in total, including both domestic and export sales, with an annual growth rate of approximately two percent.

c) Outlook and Potential

- The coatings industry is focusing its needs on water-based emulsions with similar characteristics to the soy-based surfactants. (Soy-Based Surfactants can be used to produce to compete technically and economically with much petroleum and oleochemical based commercial surfactants.)

10. Adhesives

a) Industry Overview

- The size of the US adhesive industry is $8.4 billion.
- Demand for adhesives in the US reached an estimated 15.2 billion pound.
- Wood adhesives made from soybeans have been in existence for more than 70 years. However, with the introduction of effective petroleum-based adhesives in the 1930s, soy adhesives were replaced.

b) Special Comments

- Acrylic acid used in adhesives and polymer is an attractive target for new biobased products, at about 2 billion pounds of production annually.
- Six private companies had adhesives and sealants sales of at least $100 million in 2000. Another four private firms had related sales of at least $50 million, and 31 others had total sales of $50 million, including other products.
- Packaging adhesives make up the majority of the market. Assembly and electrical adhesives are beginning to come into greater demand.

c) Outlook and Potential

- Growth of the world market averages about 2-3% per year.
- Adhesives industry reached global sales of $29.5 billion dollars with volume of 21.12 million dry pounds.
- Water-based, hot-melt and reactive formulation adhesives are gradually replacing traditional solvent-based adhesives in response to environmental concerns.

11. Sanitary and Hand Cleaners

a) Industry Overview

- Vegetable oils can be used as surfactants in soaps and detergents.

- Vegetable oils have long been a source of fatty acids for detergents and soaps, but they compete with petroleum-based surfactants.

- In 1988, the U.S. produced 7.3 billion pounds of surfactants, of which approximately 12% was bio-based. In 2000, the U.S. produced 34 billion pounds of surfactants. It is believed that current production of surfactants is at least 43 billion pounds. Assuming 15% growth in the use of bio-based surfactants since 1988, bio-based surfactants are 9.7 billion pounds, 22.5% of the market.

- Ethanol based products are used as sanitizers.

- Citrus-based products are used largely as general cleaners.

b) Special Comments

- The following is a sampling of soy based hand cleaners from the United Soybean Board.

- AA - Liquid Hand Cleaner: Safely removes most organic soils including the toughest automotive lubricants, without caustics, toxic sanitizers or solvents. Does not irritate the skin. Includes jojoba oil and aloe vera. (www.gemtek.com)

- Heavy-Duty Hand Cleaner: Heavy-duty hand cleaner contains vitamin E. It's good for your skin and made from soybeans and corn. (www.naturalsoyprod.com)

- Natural Soy Bio-Clean Heavy Duty Hand Cleaner & Moisturizer: Made from corn and soybeans. Contains Vitamin E. Environmentally safe, clean, orange scent. (www.soyclean.biz)

- Plowman's Pumice: Heavy-duty hand cleaner. www.newuseproducts.com

- SC - Heavy Duty Hand Cleaner: Effective for removing tough automotive mechanic soils, but mild enough for kids and adults. Contains jojoba and aloe vera. (www.gemtek.com)

- Soco Gold: A waterless cleaner that makes it possible to clean your hands, even in the tractor cab. The cleaner removes stains left by herbicides as well as seed dyes and grease. It's safe for use in fertilizer plants, repair stations and maintenance areas. (www.agriliance.com)

- Soy Derm: Tough on grease and grime. A unique, safe and fresh-smelling, waterless hand cleaner made from the finest natural ingredients, including soybeans, aloe vera and imported tea tree oil. (www.soytek.com)

- Soy Scrub: Made from soybeans. Deluxe pump hand cleaner removes ink, stains, grease and oil. Includes fine-ground Missouri pumice for extra cleaning action. No petroleum or citrus solvents. Gentle on your skin. Deep cleans without abusing skin. (www.franmar.com)

- SOYP: SOYP is a new hand cleaner made with American-grown soybeans. (www.newuseproducts.com)

c) Outlook and Potential

- Statistics from the US Department of Commerce show that US Soap and cleaning compound manufacturing (classification of 32561) has grown 3.6% per year the last 2 years. Classification 325611 Soap and other detergent manufacturing which is a subset of 32561 has grown at a rate of 5.4%.

NAICS Code	Industry Group	Year	Value of Shipments ($ million)
32561	Soap and cleaning compound manufacturing	2004	33,057
		2003	30,217
		2002	30,801
325611	Soap and other detergent manufacturing	2002	17,328
		2001	15, 557
		2000	15,115
		1999	14,801

12. Biobased Carpet

a) Industry Overview

- Total industry shipments (2004) totaled 2.3 billion square yards (20.8 billion square feet) or $14.4 billion at mill level. (In 1950 industry shipments were 97 million square yards).

- The United States supplies approximately 45% of the world's carpet.

- Mills located within a 65-mile radius of Dalton, Georgia supply 80% of the U. S. carpet market.

- In 2001, approximately 53% of carpet sales were for residential applications and 47% for commercial applications.

- Commercial installation is broken down into six (6) categories: Corporate (30%); Retail (18%); Educational (15%); Health Care (15%); Hospitality (13%); and "Government and other" (9%).

b) Special Comments

- The carpet industry has a history of innovation to reduce the environmental impact of its products.

- Since 1991, Carpet and Rug Institute (CRI) has administered a voluntary indoor air quality program known as Green Label Certification. It is a cooperative effort between the carpet industry and its suppliers to eliminate and reduce chemicals of concern to levels below the volatile organic compound emission rates of other interior building finishes.

- The National Carpet Recycling Agreement was signed in 2002 and aims to eliminate landfill disposal and incineration of used carpet. With more than 2.5 million tons of carpet discarded each year and landfill capacity declining, there is an environmental need to recycle and reuse carpet.

- Carpet recycling saves 700,000 barrels of oil per year per a Honeywell estimate. Nylon fiber is a valuable polymer that can be recycled and reused to make new products, such as injection-molded auto parts.

- Urethane Soy Systems Company (USSC) has received pioneer US patents for the use of a new “biobased” polyol, made from soybean oil, which can replace many petroleum-based polyols in the manufacture of various polyurethane plastic products. The brand name of USSC’s new biobased polyol is “Soyol™”.

- Polyurethane products are created from the chemical reaction of an isocyanate (“A” component) and a polyol (“B” component). The "B Component" can contain petroleum-based polyols, biobased polyols, cross linkers, catalysts surfactants, blowing agents, flame-retardants and other additives. Depending on the type of components used, polyurethane products can be flexible, rigid, semi-rigid, hard, soft, elastic, etc. Carpet backing and padding is one of the uses of polyurethane than can be made from soy oil.

- In March 2004 Tate & Lyle started a 50-50 joint venture with DuPont, inventor of polyester and nylon, to create a crucial ingredient for the new synthetic fabric Sorona. The product uses 50% less petroleum than competitors', relying instead on a corn-based sugar. ("Turning Corn Into Clothing", Forbes.com, 2005)

- Tate & Lyle uses enzymes to turn corn, grown in abundance in the American Midwest, into the sugar glucose. Glucose is fed into a fermenter where a patented microorganism turns it into a monomer called propanediol. Propanediol is shipped to DuPont polymer plants where it is mixed with terephthalate, a petroleum-based product, creating the polymer Sorona. The polymer is shipped to customers in US and Asian carpet and textile plants, where it's spun into fiber then woven or knitted into materials for carpeting and apparel such as bathing suits.

- Mohawk Industries, Inc. and DuPont announced an exclusive partnership to provide a new line of residential carpet to the flooring industry. Under the terms of this agreement, DuPont will provide its newest polymer technology to Mohawk who will manufacture and market it under the brand SmartStrand(TM) with DuPont(TM) Sorona(R) polymer.

- Cargill has agreed to buy out Dow Chemical's 50% interest in their Cargill Dow polylactic acid (PLA) joint venture. The Minnetonka, Minn.-based partnership, which started in 1997, makes PLA and markets PLA-based fibers and packaging plastics. PLA is made by polymerizing lactic acid that has been fermented from corn-derived glucose. Interface Flooring manufactures carpet with PLA.

c) Outlook and Potential

- Cargill Dow projects a possible market for PLA of 8 billion pounds by 2020.

- By 2010 Sorona sales could hit $300 million to $500 million. ("Turning Corn Into Clothing", Forbes.com, 2005)

- The industry wide goal of diverting 40% of carpet landfill waste by 2012 and increasing the biodegradability of carpet will both promote the use of biobased products as these are more easily returned to nature.

13. Solvents

a) Industry Overview

- The solvent market is estimated at 8 to 10 billion pounds per year, at prices from $.90 to $1.70 per pound.

- The US solvents market will reach $3.4 billion in 2007, with biobased solvents growing six percent annually to nearly 25 percent of the overall market.

b) Special Comments

- Tetrahydrofuran is a solvent and key ingredient of adhesives, printing inks, and magnetic tape. The current annual U.S. markets for these uses are estimated at 255 million pounds.

- Conventional solvents will post modest gains, largely by replacing hydrocarbons and other problematic solvents.

c) Outlook and Potential

- The global demand for solvents is forecast to increase 2.3 percent per year through 2007 to 19.7 million metric tons. This represents a considerable improvement over the 1997-2002 period.

- Market value is expected to increase to $3.5 billion, due to faster growth for higher value products, and the ongoing replacement of traditional solvents with alternatives that are less damaging to the environment.

14. Biobased Pharmaceutical Products

a) Industry Overview

- The demand for new pharmaceutical, nutraceutical and industrial products is being driven by fundamental shifts in demand for improved health and quality of life and renewed concern about the long-term availability of petroleum-based products that replaced bio-based materials in the last century.

- In 2000, 25% of the active components of prescribed pharmaceuticals had their origin in flowering plants and this was expected to increase to 30% over the next decade. This was a $30 billion global market, growing at 6% per year in 2000.

- Herbal supplements, minerals and vitamins, were a $45 billion global market in 2000, and were expected to continue to experience growth of 10% or more in many segments. To this market add cosmeceuticals, growing at 8% and with sound prospects for sustained development.

- Products for the cardiovascular market stand at $30 billion/year, with potential to be supplied by plants such as Digitalis spp., Strophanthus fratus, Cinchona spp. and Rauwolfia serpentina. Ginkgo biloba, ginseng, garlic and echinacea are likely to continue to experience strong growth in demand in Europe and the USA.

b) Special Comments

- The world's per-capita spending on pharmaceuticals has increased steadily from $72 in 2000 to $87.1 in 2002.

- Some of the factors leading to increased consumption of nutraceuticals include the positive research results from nutrient supplements; increased clinical studies being performed to establish the efficacy of natural remedies; increased distribution and promotion by retailers; and growing interest in alternative medicine and self-medication. Nutraceuticals are emerging as an important part of the health care industry. This demand is being fuelled by growing awareness of the role of anti-oxidants in enhancing the quality of life and reducing the prevalence of degenerative diseases. Agricultural plants are the essential source of raw material in the manufacture of anti-oxidants, which typically contain vitamin C, vitamin E and beta-carotene in balanced product formulations. Raw materials used in supplying anti-oxidants range from grains through to horticultural crops such as cabbage, broccoli and grape seeds. Added to this is growing awareness of the need to limit consumption of foods with high levels of saturated fats. This is creating opportunities for plant seeds such as Canola and genetically modified plants with high levels of saturated oil in their natural state such as peanuts.

- The fastest growing nutraceutical market is weight-loss products, according to the Nutrition Business Journal. With more than 120 million overweight Americans and 17 million diabetics, demand is growing for foods or supplements that increase metabolism, suppress or satiate appetite, and control blood sugar.

c) Outlook and Potential

- The world pharmaceutical industry stood at $593 billion in 2003, or 24% of the healthcare sector. Rising at an average annual growth rate (AAGR) of 8.8%, this market is expected to reach $901 billion in 2008.

- Biopharmaceuticals are growing at double the rate of the ethical sector. The sector was valued at $40.1 billion in 2004 and is growing at double the rate of the ethical sector.

- If the term “nutraceutical” is taken in its broadest sense, including health foods, dietary supplements and natural foods, the global market has been put at $504 billion. $500 billion of this market is split equally between the US and Europe. This contrasts with another study, valuing the market for functional foods at $32 billion in 1997, rising to $45 billion by 2002, divided primarily between Japan ($14 billion rising to $19.5 billion), the US ($10.5 billion rising to $15 billion) and Europe ($7.5 billion rising to $10.5 billion).

- If nutraceuticals are defined in a stricter sense as dietary and nutritional supplements the market was $46.7 billion in 2002 and is expected to reach $74.7 billion in 2007.

15. Wood Substitutes

a) Industry Overview

- Concerns about the sustainability of present forest practices have lead to changes in forest harvesting in the US. As a result, the US wood products sector has lost a substantial market share to non-wood substitutes and foreign wood product imports

- The United States is the world's second largest forest products exporter, totaling $17 billion worth of exports in 1997 (including paper products). However, the value of imports actually exceeded exports, making the US the world's biggest forestry importer, at $22 billion in 1997.

- In 1998, US softwood lumber imports hit a record high of 44 million m3. Canada is the main source of imported softwood lumber, with a 95% share. Annual Canadian lumber are more than a third of the U.S. market.

- Recycled-plastic lumber first became available in the 1980s. Unlike most new products, its development was driven not so much by end-use needs, but rather by the need to deal with the growing mountains of plastic in landfills: 19 million tons a year, more than 120 pounds per person.

- There are 3 main choices for lumber substitutes: recycled plastic only, wood-plastic composites and fiberglass-plastic composites. These products are manufactured from various combinations of plastic and other materials.

- Recycled plastic only. In North America, about 30 manufacturers currently produce lumber products out of 100% recycled plastic. Most of these companies use only high-density polyethylene (HDPE) though some producers use commingled plastic. The past several years have seen considerable consolidation among manufacturers. U.S. Plastic Lumber Company Ltd., a publicly traded company based in Chicago, has bought up nearly a dozen other manufacturers and is now the largest of these companies. One of their products is Carefree Decking.

- Manufacturers of recycled plastic lumber are able to control their products structural properties by using just HDPE. In fact, a consortium has developed testing procedures that standardize the structural testing of their products, a key step in getting recycled-plastic lumber recognized in building codes. Recycled-plastic lumber has some shortcomings. The products are heavy, slippery, and lack wood's strength, and they heat up and soften somewhat in the sun. Fluctuations in temperature cause them to expand and contract significantly.

- Wood-plastic composites. Products made from a mix of recycled plastic and wood fiber are the other main category. These usually contain 50% HDPE and 50% wood waste. The wood reduces the weight of the lumber, improves its strength and stiffness, and reduces thermal expansion and contraction. Mobil Chemical developed Rivenite, the first wood-plastic composite, later called Timbrex, and finally Trex. At plants in Virginia and Nevada, a spin-off company called Trex produces its namesake wood-plastic lumber that matches the dimensions of conventional lumber (such as 2-by-4s).

- AERT, Inc., of Junction Texas, produces decking and handrails marketed as ChoiceDek. These have deep corrugations on the underside that reduce weight without significant loss of rigidity. ChoiceDek is made using a mix of HDPE and low-density polyethylene (LDPE). For the wood fiber, the company uses oak or red cedar chips left over after extracting the aromatic oils. Because a consistent type of wood is used (rather than wood waste), ChoiceDek ages to a uniform silvery gray.

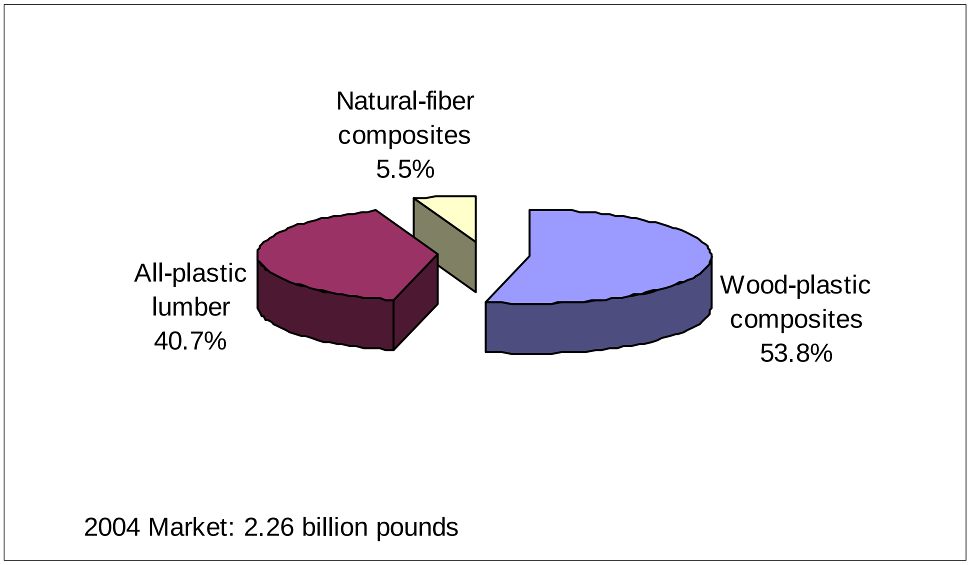
- Several other composite products rely on highly engineered designs. SmartDeck, manufactured by U.S. Plastic Lumber, is a complete decking system, with planks, posts, railings, stair treads, trim, and fascia boards.

- Another entry into this field is Nexwood, from Composite Technology Resources Ltd., in Quebec. This product is similar to SmartDeck, but it uses rice hulls--the very strong fiber left over after threshing rice. Wood products giant Louisiana-Pacific Corporation is expected to introduce a wood-plastic composite.

- Fiberglass-plastic composite. U.S. Plastic Lumber introduced recycled-plastic lumber designed to carry structural loads. Carefree Structural Lumber incorporates fiberglass into recycled HDPE to greatly increase its strength. As a result, this product can be used as support structures for decks.

- Wood-plastic composites are the largest segment of the market (Figure 43).

Figure 43: North American Composite and Plastic-Lumber Market



Source: PlasticsNews

b) Special Comments

- Although not as common as pressure-treated or cedar lumber, more and more recycled-plastic lumber is being used around homes. Decking is the most common use. Plastic lumber replaces pressure-treated wood, and premium rot-resistant woods such as cedar, redwood, and teak.

- In landscaping, recycled-plastic lumber, including commingled plastic products, can be used in retaining walls to stabilize steep slopes. The landscape timbers are bolted together or pinned into the ground. In gardens, plastic lumber is an alternative to preservative-treated lumber, for providing stakes, garden edging, and support for raised beds.

- Another important application is for outdoor furniture such as picnic tables, garden benches, and lawn chairs. This furniture may be heavy, making it difficult to move around, but it will not rot and should last for years.

- Some wood substitute products are initially more expensive. Longer life and less maintenance offset this initial price difference. Others, such as Oriented Strand Board (OSB) are less expensive. Wood substitute products are also perceived as more environmentally conscious than traditional lumber products.

- Compared to wood, plastic and composite lumbers are heavier and more subject to thermal expansion and contraction. Depending on the kind of wood being compared, plastic can weigh two to three times as much.

- Marketers are positioning their wood-oriented companies to integrate all, or at the very least a large portion, of their architectural window and sash components, doors and moldings, toward the opportunity wood substitutes offer.

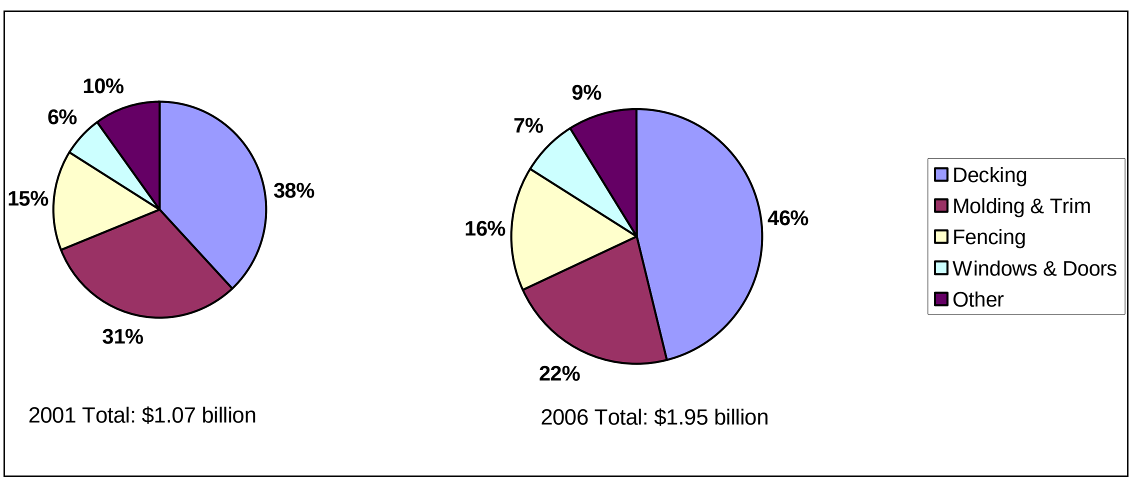
- Softwood lumber continues to be displaced by substitute materials in segments of the residential construction industry that it traditionally dominated: wall, floor, and roof framing. To a large degree, this loss of market share can be attributed to a perception among residential builders that the value of softwood lumber has declined: a direct result of rising prices and a perceived drop in lumber quality. Much of the loss in market share can be attributed to the increased use of engineered wood products. Many would argue that this is a normal process of product evolution within the forest products industry that is due to technological advances in manufacturing processes driven by the changing forest resource. However, two trends should concern managers in the forest products industry. First, the use of non-wood substitute building materials has increased significantly since 1995. Second, there is a growing perception among homebuilders that using non-wood building materials (including steel and reinforced concrete) is better for the environment than using softwood lumber.

c) Outlook and Potential

- Wood substitute products are growing rapidly, by as much as 20% or more per year, and this trend is expected to continue for many years.

- The largest growth in wood substitute products has been in decking. (Figure 44)

Figure 44: Plastic and Wood-Plastic Lumber Demand



Source: PlasticsNews

- Independent research has shown that the combined minimum revenue from exterior wood and wood-substitute trim sold per year is approximately $5 billion. (US Glass)

- The pace of material substitution in the residential construction industry has moderated since 1998. To a large degree this might be attributed to lower lumber prices, less volatility in lumber prices, and the fact that builders have become more accepting of the decreased softwood lumber quality that has been attributed to the younger, faster grown plantation resource. The exception to this trend is in floor framing applications where wood I-joists continue to expand their market share at the expense of softwood lumber.

- Residential builders have steadily increased their use of substitute structural materials since 1995.

- The most commonly used products in residential construction are softwood lumber, OSB, steel framing, fingerjointed lumber, wood trusses, laminated veneer lumber (LVL), and wood I-joists.

- In 1980, North American OSB panel production was 751 million square feet (3/8" basis) (0.7 million cubic meters). By 1990, this figure was 7.6 billion square feet (7.0 million cubic meters). In 2001, this figure had grown to 22.0 billion square feet (19.4 million cubic meters).

- Plywood has lost market share to OSB. The US consumption gap between OSB and Plywood is expected to grow as OSB emerges as the dominant structural panel consumed in the US. In 2000, for the first time, OSB production marginally exceeded plywood production. By 2004, OSB production had grown to nearly 60% of the North American panel market share.

- Wall framing- Softwood lumber dominated wall framing in 1998, with an 83% market share, but it has lost market share since 1995 (down from 93%), particularly among large firms.

- Floor framing- Softwood lumber’s share of the floor framing market declined from 59% in 1995 to 42% in 1998. While it is still the most widely used product, the market share of wood I-joists increased from 23% to 39% in the same period.

- Roof framing- Softwood lumber framing is no longer the dominant material in residential roof systems. Survey data show that wood trusses increased slightly from 46% to 48%, while softwood lumber declined from 51% to 40%.

16. Products from Wood Waste, Forest Cleaning, and Managed Woodlots

a) Industry Overview

- Wood waste is defined as end-of-life products, failed products, off-cuts, shavings and sawdust of all timber products. This definition of wood waste excludes forest residues, often referred to as primary wood waste and green or garden waste materials such as branches, bushes and tree stumps.

- There are three different categories of wood waste as follows:

    - Untreated Timber includes hardwoods and softwoods
    - Engineered Timber Products include particle board, medium density fiber board, plywood, (ETP) hardboard, low density fiber board, oriented strand board, finger jointed timber and glulam beams
    - Treated timbers include timbers treated with copper chrome arsenate (CCA), light organic solvent preservative (LOSP) and creosote preservative

- Dependent upon the level of contamination of materials, wood waste can be a valuable resource suitable for recycling / processing into secondary products.

- Suitable wood waste is utilized in the manufacture of products such as feedstock to industrial processes, amended soil and compost products, landscape mulch, animal bedding, firewood and impact absorbing playground material.

- The separation of wood waste by category is therefore an important aspect of the recycling process.

b) Special Comments

- The timber industry has been using wood residues from primary wood processing mills for decades for fuel, pulpwood, and feedstock for products such as particleboard, the recovery and reuse of wood from two other major waste streams, municipal solid waste and construction and demolition waste, is only now being seriously considered.

- Municipal solid waste (MSW) is waste from residential, commercial, institutional, and industrial sources. Paper and paperboard is the single largest component of MSW, constituting 75 million metric tons or about 36% of all MSW. Just over 12.0 million metric tons of solid wood waste is generated in the wood component of MSW in 2002

- An estimated 34.5 million metric tons of wood products was used for new residential construction in 2002. Wood waste was about 11% of all wood used to build residential structures.

- In 2002, an estimated 5.6 million metric tons of wood waste was generated from all residential repairs and remodeling activities; about 3.8 million metric tons was recoverable.

- The following is a sampling of products that can be made from wood waste.

  - Boiler Fuel
  - Chunkrete
  - Compost Amendment
  - Erosion Control
  - Ethanol
  - Fireplace Log
  - Hardboard/Fiberboard
  - Landfill Cover
  - Landscape Mulch
  - Methonol/Syngas
  - Oriented Strandboard/Waferboard
  - Packaging Filler
  - Particleboard
  - Pet Litter
  - Playground/Handicapped Access Groundcover
  - Potting Soil
  - Pulp and Paper
  - Road Stabilization
  - Soil Amendment
  - Topsoil
  - Wood Pellets
  - Wood-Plastic Composites

c) Outlook and Potential

- Nearly 63 million metric tons of wood waste material is generated in the manufacture, use, and disposal of solid wood products each year.

- Of the total amount generated, about 27.1 million metric tons (43%) is deemed suitable for further recovery for recycling or reuse.

- In 1999, an estimated 299 million pallets were recovered for recycling. These recovered pallets were recycled into new pallets or related products, or were ground for fuel or mulch. Less than 1% of recovered pallet material was returned to the landfill. Thus, nearly 7 million metric tons of pallet material was diverted from the MSW stream.

17. Janitorial Cleaners

a) Industry Overview

- The cleaning industry employs 2 to 3 million janitors.

- US demand for janitorial services and supplies grew 5.6 percent (including price increases) to $37 billion in 2005.

- The US janitorial services and supply industry was $28 billion.

b) Special Comments

- The cleaning supply industry will offer the best growth, driven by demand for commercial cleaning equipment.

- Under the Farm Security and Rural Investment Act of 2002, the U.S. Department of Agriculture will designate biobased products for Federal agencies to purchase. Until USDA designates products, the Office of the Federal Environmental Executive (OFEE) and the Office of Federal Procurement Policy have encouraged agencies to buy and test biobased products to see if they meet the agencies' needs.

c) Outlook and Potential

- Yellowstone is the first park in the country to replace existing cleaning and janitorial products used by park and concessionaire personnel with environmentally preferable cleaning products.

- Researchers state that the cleaning products used, switched from more than 130 products with certain health or environmental risks, to less then 10 products that are environmentally friendly.

18. Sorbents

a) Industry Overview

- According to industry estimates, the size of the sorbent products market for the types used to clean up oil and solvent spills is $400 to $500 million per year, with an annual growth rate of 30%.

- Absorbents and adsorbents (referred to as "sorbents") are used in environmental, industrial, agricultural, medical, and scientific applications to retain or release liquids and gases.

b) Special Comments

- According to one lumber producer, and as previously noted, recovered sawdust is commonly used for sorbent products, particularly for animal bedding

- Sorbents can be manufactured using recovered paper, textiles, plastics, wood, and other materials.

c) Outlook and Potential

- Researchers estimates that the lumber industry contributes between 600 - 1,000 tons of waste each year for sorbent related usage.

- One-researcher estimates that approximately 8,000 tons of fines (wood waste) recovered from paper mill sludge each year.

Figure 45 Environmental Protection Agency Recommended Miscellaneous Product Level

Miscellaneous Product	Material	Post Consumer Recovered Content	Total Recovered Content
Sorbents	Paper	90 – 100	100%
	Textiles	95 - 100	--
	Plastic		25 – 100%
	Wood		100%
	Other Organic Multi materials		100%

(Environmental Protection Agency, 2004)

19. Transformer Fluid

a) Industry Overview

- Transformer oil, a highly refined mineral oil that is stable at high temperatures and has excellent electrical insulation properties.

- Most electricity passes through thousands of petroleum oil filled power and distribution transformers, more than 1.06 billion kilowatt-hours of electricity a year for residential purposes alone.

- The Tennessee Valley Authority (TVA) estimates that there is and estimated 151.4 million liters or 40 million gallons of transformer oil used in the U.S. each year. This number includes new transformer and replacements.

b) Special Comments

- Public awareness has grown about PCB-based transformer oils and their environmental hazard from damage or leak.

- Researchers state that FR3, with soy oil as base vegetable oil is becoming environmentally preferred solution.

- In 2004, Cooper Power partnered with Cargill to launch vegetable based transformer oil.

c) Outlook and Potential

- A three-way collaboration linking Cargill Industrial Oils and Lubricants, Electric Research and Manufacturing Cooperative (ERMCO), and Waverly Light and Power will provide an earth friendly alternative to petroleum-based transformer oil that will more widely available to electric utilities.

- Most PCB oil-filled transformers have been collected or replaced with PCB-free mineral oil or alternate fluids.

- Discussions with the Transformer Association point to the continued interest of the industry to move completely away from liquid based fluids for use in transformers. One company, Acme Electric Corporation, have eliminated liquids altogether and now only use a silicon-based substance in their transformers.

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G. Pharmaceuticals and Nutraceuticals

- Because of the importance of the pharmaceuticals and nutraceutical industries in the biorevolution, an individual section is presented in the study.

- Interest by the general public is growing worldwide in the prospect that food and food products can promote and maintain good health. Predictions are that the value of the functional foods and nutraceuticals industry will expand significantly over the next decade, promising to become a major segment of the agri-food industry. The Richardson Centre for Functional Foods and Nutraceuticals at the University of Manitoba estimates that the value of the industry will reach $300 billion globally by 2010. Other studies estimated that $250 billion, or 50% of the US food market of $503 billion may be attributable to nutraceutical products if taken at its broadest definition. Globally the market is estimated to be $300 billion to $500 billion.

- Functional food: a food that is similar in appearance to conventional foods and is consumed as part of a usual diet, but also has demonstrated physiological benefits and/or reduces the risk of chronic disease beyond nutritional functions.

- Nutraceutical: a product produced from foods but sold in pill, powder, potion or other medicinal form not generally associated with food, but demonstrated to have physiological benefit or to provide protection against chronic disease.

- Sharp shifts in demand and supply of new pharmaceutical, nutraceutical and industrial products using bio-based materials may have as much impact on the structure of agriculture as did many of the major events and discoveries of the last century – including, plant breeding and new information and communication technologies.

- Few agricultural industries will escape the impact of the 21st century revolution in biological and chemical sciences, process engineering and growing consumer demand for improved quality of life.

- The implications for producers and research organizations will be significant as markets and influential manufacturers will demand more differentiated products with more consistent content for more sharply segmented markets.

- New farm management challenges will be presented in the form of a continuing demand for improved product quality with increased nutrient content, which new technology and expert farm management may be able to deliver at lower cost and prices.

- The demand for new pharmaceutical, nutraceutical and industrial products is being driven by fundamental shifts in demand for improved health and quality of life and renewed concern about the long-term availability of petroleum-based products that replaced bio-based materials in the last century.

- It is expected that there will be increasingly differentiated products for polarized market segments, driven by the demand of various consumer groups, each motivated by different priorities such as health benefits, cost, ecological benefits, ethical issues, food safety and sustainability of supply.

- Demand for natural products as raw material for new pharmaceutical, nutraceutical and industrial products seems assured, but there will be increased interest in the composition and active ingredients of materials for specific end uses.

- New technologies that offer specific and reliable traits for specific end uses, lower costs and higher quality will lead the way and offer a competitive advantage for those enterprises ready enough to adopt them when they become available. Traditional, organic and GMO production systems all have opportunities for these markets.

- In 2000, 25% of the active components of prescribed pharmaceuticals had their origin in flowering plants and this was expected to increase to 30% over the next decade. This was a $30 billion global market, growing at 6% per year in 2000.

- Herbal supplements, minerals and vitamins, were a $45 billion global market in 2000, and were expected to continue to experience growth of 10% or more in many segments. To this market add cosmeceuticals, growing at 8% and with sound prospects for sustained development.

- Products for the cardiovascular market stand at $30 billion/year, with potential to be supplied by plants such as *Digitalis* spp., *Strophanthus fratus*, *Cinchona* spp. and *Rauwolfia serpentina*. *Ginkgo biloba*, ginseng, garlic and echinacea are likely to continue to experience strong growth in demand in Europe and the USA.

- For consumer products such as nutraceuticals, genetic engineering may increase the nutritional values of certain plants and, regulations permitting, this has significant potential to meet the demands of a high growth market. The discovery and development of "Golden Rice" with high levels of Vitamin A is a current example. 'Golden Rice' is genetically modified rice with high levels of beta-carotene and other carotenoids, which the body turns into Vitamin A as needed. Vitamin A is a fat–soluble vitamin that is essential for normal vision, mucous membranes, immune system and the skin.

- Major pharmaceutical companies are examining the scope for incorporating antioxidant specific-trait genes in a range of food crops. Identification of scenarios and incorporation in research project allocation procedures is likely to improve risk management and pay-offs to research projects.

- Pharmaceutical companies are taking renewed interest in the potential for discovery of new compounds from plants. Nutraceutical manufacturers are looking for herbs and natural product based vitamins to meet the needs of a growing demand for supplementary foods and preventive medicine.

- These developments are impacting the demand for raw materials made from plants and to a lesser extent, animals, though improved feeds for animals and animal products themselves are equally important for these industries.

- The underlying desire for better health, improved quality of life and concern about the availability of non-renewable resources are driving this demand. The quality and content of information about products and processes is likely to have a significant influence on supply and demand.

- To illustrate, scientific research suggests that 400-1200 IU of vitamin E per day will contribute to long-term health in significant ways, including reduced heart attacks, diabetic control, better immunity and reduced cancer. This level of intake is 40 times higher than the recommended dietary intake of 10IU. Some health professionals argue that complete nutrition is best obtained from diet alone and without supplements. Many physicians remain skeptical about the real effect of the whole range of nutritional supplements including vitamins, minerals, amino acids and herbs in particular. But supplement manufacturers claim it is simply not possible to consume the optimal amount of 450 IU of vitamin E through natural foods without upsetting the overall balance of nutrients required.

- Some of the factors leading to increased consumption of nutraceuticals include the positive research results from nutrient supplements; increased clinical studies being performed to establish the efficacy of natural remedies; increased distribution and promotion by retailers; and growing interest in alternative medicine and self-medication. Nutraceuticals are emerging as an important part of the health care industry. This demand is being fuelled by growing awareness of the role of anti-oxidants in enhancing the quality of life and reducing the prevalence of degenerative diseases. Agricultural plants are the essential source of raw material in the manufacture of anti-oxidants, which typically contain vitamin C, vitamin E and beta-carotene in balanced product formulations. Raw materials used in supplying anti-oxidants range from grains through to horticultural crops such as cabbage, broccoli and grape seeds. Added to this is growing awareness of the need to limit consumption of foods with high levels of saturated fats. This is creating opportunities for plant seeds such as Canola and genetically modified plants with high levels of saturated oil in their natural state such as peanuts.

- The term "nutraceutical" was only coined in the 1980's, as a marketing label to distinguish certain foods and food ingredients, usually from natural sources, which confer specific health benefits. The term (an amalgamation of "nutrition" and "pharmaceutical") has been used interchangeably with "functional food" or, less commonly, "pharmafood".

1. Pharmaceuticals

- The world pharmaceutical industry stood at $593 billion in 2003, or 24% of the healthcare sector. This market is expected to reach $901 billion in 2008, growing at a CAGR of 8.8%, (Figure 46 and Figure 47).

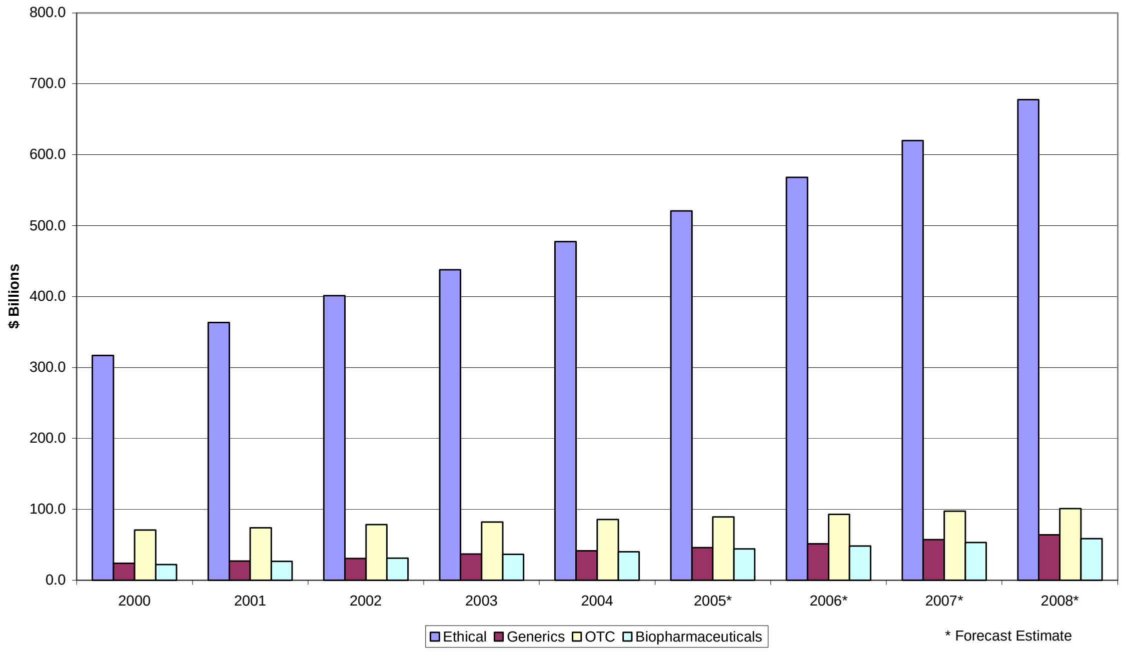
Figure 46: Worldwide Pharmaceutical Market by Sectors, through 2008 ($ Billions)

	2000	2001	2002	2003	2004	2005*	2006*	2007*	2008*
Ethical	317.1	363.4	401.0	437.6	477.4	520.9	568.3	620.0	677.8
Generics	24.0	27.0	30.5	37.0	41.3	46.1	51.4	57.4	64.0
OTC	70.5	73.8	78.5	82.0	85.5	89.2	93.0	97.0	101.0
Biopharmaceuticals	22.1	26.3	31.0	36.5	40.1	44.1	48.4	53.2	58.6
Total World Market	433.7	490.5	541.0	593.1	644.4	700.2	761.2	827.7	901.4

* Forecast Estimate

Source: BCC, Inc., IMS Health

Figure 47: Worldwide Pharmaceutical Market by Sectors, through 2008 ($ Billions)



Source: BCC, Inc., IMS Health

- Ethical pharmaceuticals account for 74% of the market. Ethical pharmaceuticals are only available by prescription and are name brand as opposed to generic. This sector is under increasing pressure from generics and biopharmaceuticals.

- The generic industry is expected to increase its penetration in the world market to 7% by 2008, reaching $64 billion.

- Biopharmaceuticals are growing at double the rate of the ethical sector. The sector was valued at $40.1 billion in 2004 and is growing at double the rate of the ethical sector.

- The top 10 pharmaceutical companies share has improved from 28% in 1990 to 46% in 2002. Companies are increasingly focusing on mergers and acquisitions, in-licensing activities, co-development, and co-marketing activities in order to remain competitive and create value for their shareholders. Leading ethical pharmaceutical companies are increasingly venturing into biopharmaceuticals, generic pharmaceuticals, etc. as a mode for organic growth. Biopharmaceutical companies like Amgen and Genetech are competing head-on with the big pharma in the market place.

- North America is the biggest market for pharmaceuticals with about 50% share of the total world pharmaceutical market. Overall, the 10 leading markets cover 70% of the ethical pharmaceutical market. Some key markets like Japan and Latin America are declining owing to the economic crises affecting their countries. Asia in particular is emerging as a leading pharmaceutical market. The WTO/GATT implementation in 2005 is aligning the world pharmaceutical market into one global market.

- The world's per-capita spending on pharmaceuticals has increased steadily from $72 in 2000 to $87.1 in 2002.

- The main categories of disease, in terms of sales are drugs for cardiovascular conditions, alimentary or metabolic disorders, the central nervous system (CNS), respiratory problems and infections.

- 25 % of the active components of drugs prescribed in 1996 had their origins in higher (flowering) plants, with an additional 10% derived from fungi.

- The drugs with botanical origins, which are available today, can be divided into a number of categories. These include long-known products, which still remain the drug of choice today, such as the cardiotonic digitoxin, and newer drugs, such as the taxoids from *Taxus* spp. And artemisinin, and its derivatives from *Artemisia* spp. There is growing demand for natural-based medicines; therefore these medicines will take an increasing proportion of the existing (largely synthetic) drug markets.

- In 1980, none of the top 250 pharmaceutical companies had research activities involving higher plants, but by the early 1990’s, more than half of them had introduced such programs

Table 57: Classic Plant Drugs Obtained from Higher Plants

Drug	Clinical action or use	Primary botanical origin
Atropine	Anticholinergic	Atropa belladonna
Caffeine	CNS stimulant	Camellia sinensis
Camphor	Rubefacient	Cinamomum camphora
Chymopapain	Chemonucleolysis	Carica papaya
Cocaine	Local anaesthetic	Erythroxylum coca
Codeine	Analgesic/anti-tussive	Papaver somniferum
Colchicine	Anti-gout	Colchicum autumnale
Digitoxin	Cardiotonic	Digitalis purpurea
Digoxin	Cardiotonic	Digitalis lanata
Emetine	Amoebicide	Cephaelis ipecacuanha
Ephedrine	Sympathomimetic	Ephedra sinica
Galanthamine	Cholinesterase inhibitor	Lycoris squamigera
Gossypol	Male contraceptive	Gossipium spp.
Hyoscamine	Anticholinergic	Hyoscamus niger
Kawain	Tranquiliser	Piper methysticum
Levodopa	Anti-Parkinsonian	Mucuna deeringiana
Menthol	Rubefacient	Mentha spp.
Methoxsalen	Psoriasis/vitiligo	Ammi majus
Methyl salicylate	Rubefacient	Gaultheria procumbens
Morphine	Analgesic	Papaver somniferum
Nordihydroguaiaretic acid	Antioxidant	Larrea divaricata
Noscapine	Anti-tussive	Papaver somniferum
Ouabain	Cardiotonic	Strophanthus fratus
Physostigmine	Cholinesterase inhibitor	Physostigma venenosum
Pilocarpine	Parasympathomimetic	Pilocarpus jaborandi
Podophyllotoxin	Topical treatment for condylomata acuminata	Podophyllum peltatum
Quinidine	Anti-arrhythmic	Cinchona ledgeriana
Quinine	Anti-malarial	Cinchona ledgeriana
Reserpine	Antihypertensive	Rauwolfia serpentina
Scopolamine	Sedative	Datura metel
Sennosides A and B	Laxative	Cassia spp.
Tetrahydrocannabinol	Antiemetic	Cannabis sativa
Theophylline	Bronchodilator	Camellia sinensis
Tubocurarine	Muscle relaxant	Chondodendron tomentosum
Vinblastine	Anticancer	Catharanthus roseus
Vincristine	Anticancer	Catharanthus roseus
Yohimbine	Aphrodisiac	Pausinystalia yohimbe

Source: RIRDC

2. Nutraceuticals

- Nutraceuticals were defined in 1994 by the Institute of Medicine's food and nutrition board as "any food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains." The main focus has been on phytochemicals — biologically active chemicals such as glucosinolates in cruciferous vegetables (cole crops), lycopene in tomatoes, limonoids in citrus fruits, lignans in flaxseed and catechins in tea — all purported cancer fighters.

- The fastest growing nutraceutical market is weight-loss products, according to the Nutrition Business Journal. With more than 120 million overweight Americans and 17 million diabetics, demand is growing for foods or supplements that increase metabolism, suppress or satiate appetite, and control blood sugar.

- While many claims have not been replicated in clinical trials, research facilities are going up around the country to study the medicinal qualities of food components, such as the Nutraceuticals Institute, a partnership between Rutgers University, St. Joseph's University and the State University of New Jersey.

- In an article in *Nutraceutical World*, the president of California Functional Foods states, "The functional food and beverage market is continuing to grow, including the FOSHU (Foods for Specified Health Uses) category. There are now over 540 active approved FOSHU products, with new products approved on a regular basis."

- Three main product categories make up the nutraceutical group: minerals and nutrients, vitamins and herbal extracts.

- Nutraceuticals can be seen as the latest in a succession of health foods, the evolution of which can be summarized as follows:

Era	Food-health concept/Catalyst for change	Effect on/Product types
1950's-1960's	"Refined"	Fiber Cod liver oil
1970's	"Green"	"Natural" ingredients Pesticide-free
1980's	"Low" and "Lite"	Calorie intake Fat/salt/sugar Fish oils Cholesterol
1990's	"Nutraceuticals"	Dietary fibers Oligosaccharides Polyunsaturated fatty acids Cholines/phospholipids Glycosides Dietary vitamins/minerals Peptides Lactic acid bacteria
Until 2010	Disease-fighting foods Health-optimizing foods	Genetically engineered plants and fruits: e.g. bananas to give pediatric vaccines Tomatoes with elevated nicotine content to aid smoking cessation Foods with disease prevention function, studies on modes of action and benefits. e.g. terpenes, carotenes, limonoids, xanthophylls, phytosterols, isoflavones, oligosaccharides and vitaminenriched foods

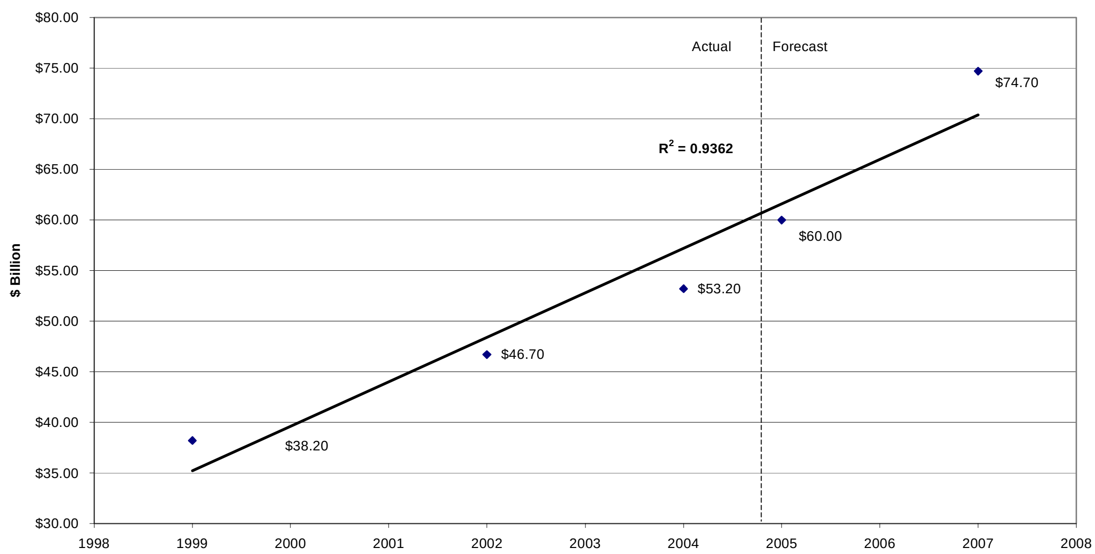
Source: Mertens/Financial Times Healthcare, 2000

- The precise market value for nutraceuticals is not clear, reflecting the difficulty with which the market is defined. Depending on exactly what is included within the broad definition of “nutraceuticals” or “functional foods”.

- If the term “nutraceutical” is taken in its broadest sense, including health foods, dietary supplements and natural foods, the global market has been put at $504 billion. $500 billion of this market is split equally between the US and Europe. This contrasts with another study, valuing the market for functional foods at $32 billion in 1997, rising to $45 billion by 2002, divided primarily between Japan ($14 billion rising to $19.5 billion), the US ($10.5 billion rising to $15 billion) and Europe ($7.5 billion rising to $10.5 billion).

- If nutraceuticals are defined in a stricter sense as dietary and nutritional supplements the market was $46.7 billion in 2002 and is expected to reach $74.7 billion in 2007 (Figure 48).

Figure 48: Nutraceutical Market ($ Billion)



Source: RIRDC, BCC, Informa Forecast

- There are more than 85 supplement manufacturers in the United States. 20% of them account for 70% of the income in the US market. The top 5 manufacturers and sales in 2000 are as follows.

    - Royal Numico $939 Million
    - American Home Products $480 Million
    - Leiner Health Products $463 Million
    - Unilever (Slim Fast) $385 Million
    - Pharmavite $360 Million

- There is a huge diversity of herbal products offered globally for self-medication covering a wide range of complaints. The best selling plant species used in herbal preparations are as follows.

  - *Garlic:* Garlic (Allium sativum) is primarily used to combat infections, reduce cholesterol levels, and treat circulatory disorders, including high blood pressure and high blood sugar levels. Garlic sales accounted for 16- 18% of the US market during 1996-1999. Approximately 1000 tons of fresh garlic is required annually for the production of Kwai® N by Lichtwer Pharma AG – this material is sourced exclusively from China.

  - *Ginkgo:* Ginkgo (*Ginkgo biloba*) is taken to improve microcirculation, especially to the brain and central nervous system, with the aim of improving mental function and concentration, especially in cases of dementia and Alzheimer's disease. In many market surveys, Ginkgo is commonly the single most popular herbal remedy, reflecting the public concern over maintaining cerebral function. Ginkgo accounts for 19-21% of sales in the United States

.

  - *Ginseng:* Ginseng (Panax ginseng) is most commonly taken as a general tonic, an adaptive (helping the body to combat stress, fatigue and cold) and stimulant. Ginseng is frequently in the top three most commonly purchased herbs, accounting for 12-20% of the herbal market between 1996 and 1999.

  - *Spirulina:* Spirulina (Spirulina platensis) is a microalga, containing high concentrations of gamma-linolenic acid, Vitamins B12 and E, provitamin A (beta-carotene) and protein. Claims made for Spirulina include immunostimulant activity, stabilization of blood sugar, anti-allergen, appetite suppressant and cancer preventative.

  - *Chamomile:* German Chamomile (Chamomilla recutita, syn. Matricaria recutita) and Roman Chamomile (Chamaemelum nobile, syn. Anthemis nobilis) are used largely interchangeably to treat digestive problems, combat tension and reduce irritation (such as sore skin and eczema).

  - *St John's Wort:* A European native, St John's Wort (Hypericum perforatum) is amongst the most extensively studied plants used in herbal medicine. It is mainly taken to counter depression, and has been used as a natural alternative to synthetic anxiolytics, such as Prozac. This herb accounted for between 11-14% of herbal sales in Europe and the United States between 1996 and 1999.

- *Echinacea:* Echinacea (mainly Echinacea purpurea, but also E. angustifolia and E. pallida) is widely used as an immunomodulator, for treatment and prevention of upper respiratory tract infections.

- *Saw palmetto:* The primary claim made for Saw Palmetto (Serenoa repens) is for treatment of benign prostatic hyperplasia (BPH), a condition likely to increase in incidence with the general ageing of the population. Sales of Saw Palmetto range from 4-6% of the total herbal market in the United States.

- Herbal teas are an area of rapid growth.

- Lycopene, an acyclic carotenoid found mainly in tomatoes (and also red peppers and red cabbage), is one of the major carotenoids in Western diets. It has the potential to become a major player in the nutraceutical market if studies continue to show it to be anti-carcinogenic. The anti-carcinogenic activity is thought to arise from the antioxidant properties of the carotenoid, which decrease oxidative damage to DNA. Currently the only supplier of lycopene to the nutraceutical market is the Israeli company LycoRed Natural Products, which is a subsidiary of Makhteshim-Agan Industries.

- Another emerging antioxidant is resveratrol (3,5,4'-trihydroxystilbene), which is found in green vegetables, citrus fruit and in particular in red wines, the latter being the main source of resveratrol in the diet. Resveratrol may be responsible for the health benefits attributed to drinking red wine as it has been shown to have antioxidant effects as well as anti-carcinogenic and anti-inflammatory effects.

- Materials like distiller's dried grains (DDGs), an ethanol byproduct, can yield such high-value extracts as follows.

  - Xylose: a low-calorie sweetener and fluoride replacement; current market price of $6.60 to $7.00/kilogram.

  - L-arabinose: used in a Hepatitis-B treatment and as a sucrose inhibitor for diabetic and weight loss applications; current price $100 to $140/ kilogram.

  - Galactose: plant-based, low-calorie sweetener and an energy additive in sport drinks and bars; current price $125 to $150/kilogram.

  - Galacturonic acid: a nutrient for functional foods, a replacement for phosphates in detergents and a biodegradable surfactant; current price $150 to $280/kilogram.

VI. Integration of Products and Technologies: Biorefinery Concept

A. Existing Biorefinery (players, technologies, products, and markets)

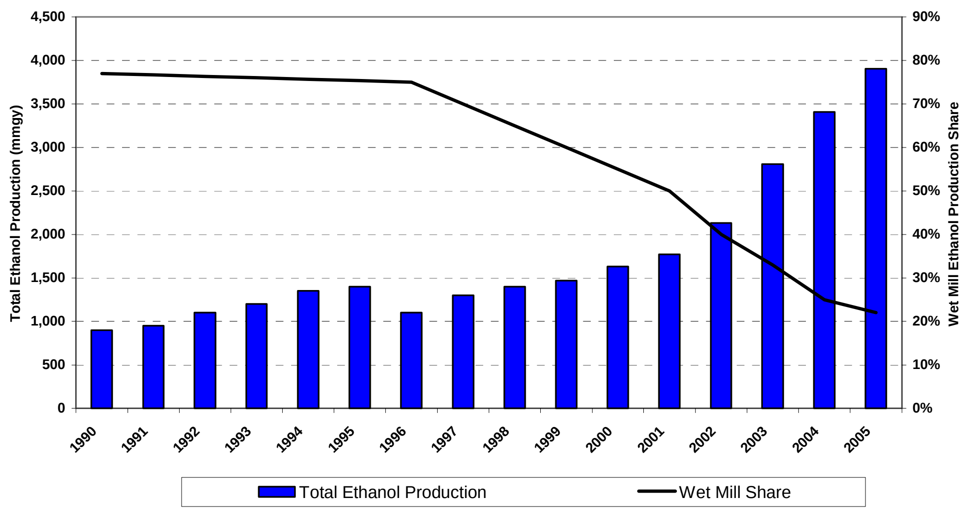
1. Introduction

- There are two basic technologies that are currently being utilized in the US to produce ethanol from corn. The most widely utilized (approximately 78% if US ethanol production capacity) is the dry-mill process (also called dry-grind process) that utilizes the entire kernel to produce ethanol. The other technology is the wet-mill technology that utilizes the concentrated starch fraction of the kernel to produce ethanol.

2. Production History

- When the Clean Air Act Amendments of 1990 were passed, a majority of US ethanol was produced in wet mills (Figure 49). These plants are generally quite large; some with capacities well over 100 million gallons per year (mmgy). In 1990, when only 900 million gallons of ethanol were produced, wet mills accounted for 77% of total output. This production share remained relatively flat through 1996. After 1996, virtually all new plants that were built were dry mill facilities due to lower capital costs and slightly higher ethanol yields. Until recently, dry mill plants have been modest in size compared to wet mill facilities, with maximum capacities around 50 mmgy. However, there are a few newly constructed and proposed dry mills with capacities in excess of 100 mmgy.

Figure 49: US Ethanol Production and Wet Mill Production Share 1990-04



3. Dry Mill Ethanol Process

- Dry milling is an eight step process (Figure 50):

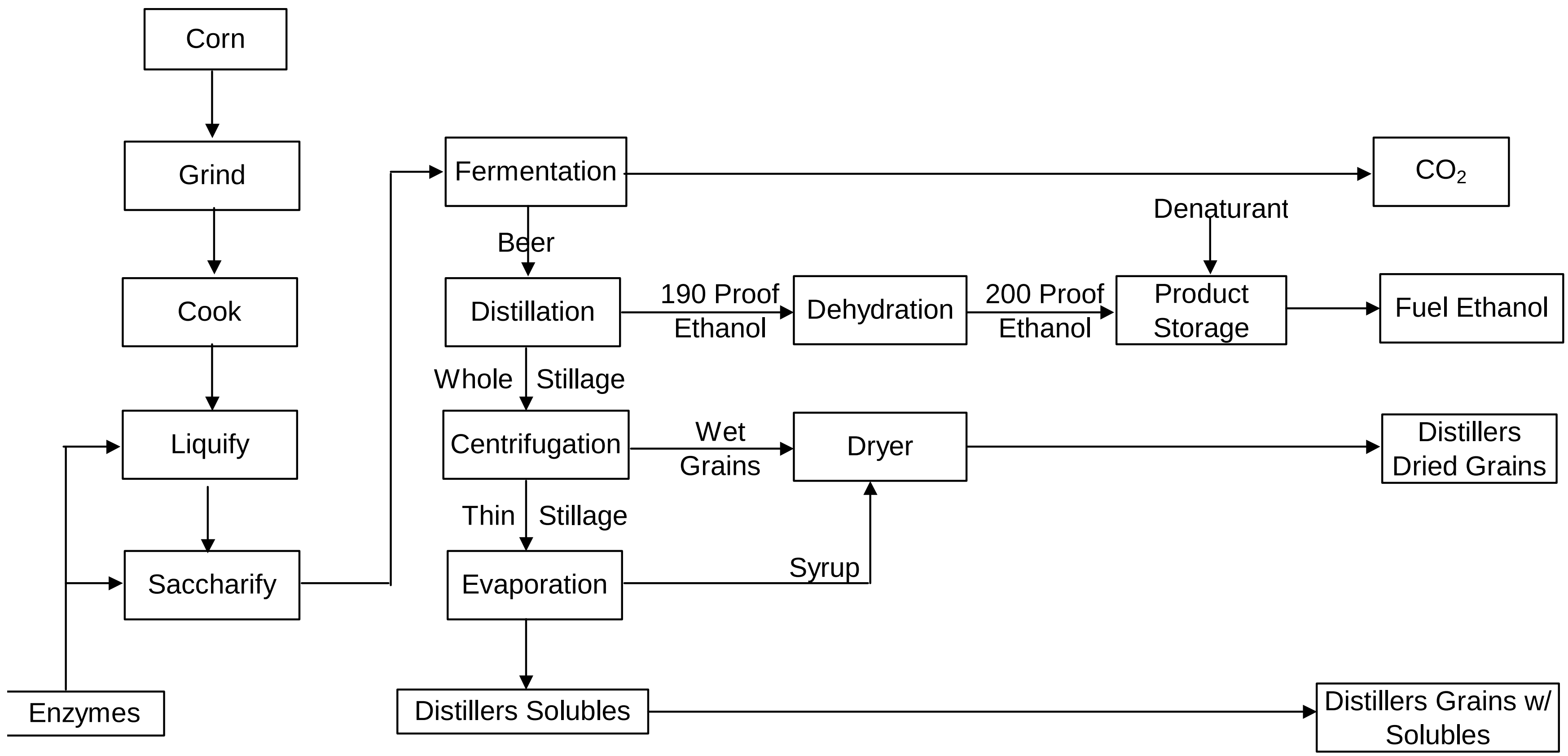
  1. Milling
  2. Liquefaction
  3. Saccharification
  4. Fermentation
  5. Distillation
  6. Dehydration
  7. Denaturation
  8. Co-Product Processing

- In the milling step, the entire corn kernel (or other grain feedstock) is ground into flour called “meal” using a hammer mill without first separating the component parts of the grain. In the liquefaction step, enzymes (alpha amylase) and water are then added to the meal to form mash. The enzymes begin to break the cornstarch into simple sugars. To complete the liquefaction step, the mash is heated to between 250 and 300 degrees to reduce the level of bacteria in the mixture. In the saccharification step, another enzyme (gluco-amylase) is added to the mash to complete the breakdown of the starch into dextrose.

- To begin the fermentation process, the mash is cooled and yeast is added to break the dextrose down into ethanol and carbon dioxide. The mash generally remains in the fermentation tank for between 40 and 50 hours at which point it is called beer. The beer consists not only of ethanol, but also the solids from the original corn feedstock that is not fermented. After fermentation, the beer is transferred to distillation columns where the ethanol is separated from the rest of the beer. At this point, the ethanol is 96% pure ethanol (190 proof). It can then be dehydrated to 200 proof using a molecular sieve. The ethanol is then blended with 2-5% denaturant (conventional gasoline), which renders the product undrinkable.

- After the distillation of the ethanol, the remaining portion of the beer is called stillage. The stillage is centrifuged to separate the coarse grain from the liquid. The liquid contains soluble material and is dried to approximately 70% moisture by evaporation. The resulting product is called condensed distillers solubles (CDS). The CDS is usually added back to the coarse grains, although it can be sold separately. This product is called wet distillers grains with solubles (WDGS), which can be shipped to local livestock feeding operations (primarily cattle). WDGS, however, cannot be transported over long distances due to problems with rancidity, as well as the prohibitive economics of transporting material that is approximately 65% water. WDGS can be dried further to produce distillers dried grains with solubles (DDGS), which can be shipped locally via truck or further distances via rail. DDGS is a middle-protein feed with a minimum crude protein content of approximately 30% (for older facilities, the crude protein content is roughly 27%), fat content of 11%, and fiber content of 4%. The remaining co-product of the fermentation process, carbon dioxide, can be used in beverage manufacture, dry ice production, or in flash freezing, although in locations where there is a surplus of carbon dioxide, the economics might not support capturing the carbon dioxide output.

Figure 50: Ethanol Dry Milling Process



Source: American Coalition for Ethanol

4. Wet Mill Ethanol Process

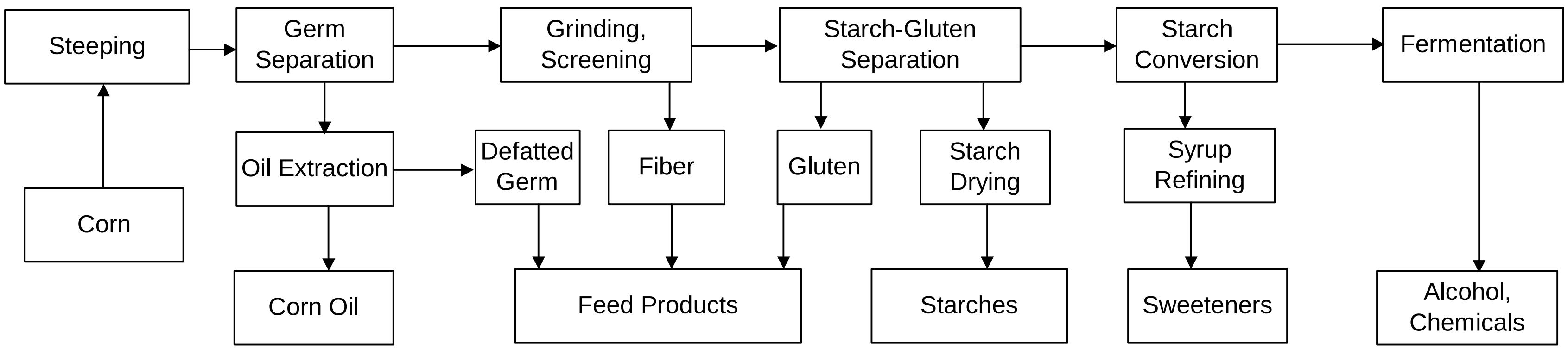
- Whereas the dry mill process is relatively straightforward and has historically been focused on only one primary product, ethanol, the wet mill process is a step closer to the concept of a biorefinery, separating the corn kernel into several valuable components (Figure 51). In the beginning of the wet-mill process, the entire corn kernel is steeped in a weak solution of sulfur dioxide for 24 to 48 hours at around 125°F to prepare it to be broken into its component parts. After steeping, the corn kernel is ground to recover the germ, which is further processed to remove the corn oil. The remaining portion of the germ is called corn germ meal and is either sold as a feed ingredient or often included in corn gluten feed (at wet mills that have captive oil extraction units). Corn germ meal is typically 20% protein, 2% fat, and 9.5% fiber and, when sold separately, is fed primarily in swine and poultry rations.

- The rest of the corn kernel is screened to remove the bran (fiber), which is mixed with the steep water and then sold in wet form as wet corn gluten feed (WCGF) or is dried to produce corn gluten feed (CGF). CGF is approximately 21% protein, 2.5% fat, and 8% fiber and is used primarily in cattle rations.

- The remaining unprocessed portion of the corn kernel is centrifuged to separate the gluten, which is concentrated and dried to produce corn gluten meal (60% protein, 2.5% fat, 1% fiber), from the starch, which can then be processed into a number of products. Corn gluten meal is primarily used as broiler (chicken) feed, but is also used in pet foods. Corn gluten meal also can be sold to further processors for the manufacture of concentrated vegetable proteins, which are used in applications such as meat replacers and extenders.

- The starch resulting from the wet milling process can be sold or further processed into other value-added products. Fermentation into ethanol is somewhat similar to the process described above for dry milling (excluding the initial treatment). Starch can also be dried and sold or can be processed into modified starches, tailored to specific food and industrial applications. The starch also can be converted into high fructose corn syrup, which is mainly used in soft drinks, or glucose, which is standard corn syrup used in a variety of food applications. In the past, some wet mills with the requisite equipment would shift from ethanol production in the winter months to high fructose corn syrup in the summer months, when soft drink consumption increased.

Figure 51: Corn Wet Milling Process



Source: Corn Refiners Association

B. Emerging Biorefineries (players, technologies, products, and markets)

1. Corn Fractionation in Dry Mills

- The current petrochemical industry is built on the concept of multiple products extracted from crude petroleum in a refinery. The production of multiple chemicals results in multiple revenue streams and a reduction in waste streams from petroleum processing. Corn wet mills producing ethanol operate in a similar manner, producing value-added products such as corn oil, gluten feed, gluten meal, high fructose corn syrup, dextrose, glucose syrup and ethanol in a biorefinery. To be competitive in the absence of government subsidies, corn dry mill ethanol producers must adopt the same strategy and develop value-added products to enhance their profitability and sustainability. To do this, new technologies are needed for integration into corn dry milling.

- As previously discussed, corn processing for ethanol production is generally accomplished by wet and dry mills. Corn wet mills have a major advantage in producing high value coproducts, for instance, germ and corn gluten meal, but are relatively capital intensive. Corn dry mills, on the other hand, have lower capital investment requirements but suffer from low coproduct value, distillers dried grains with solubles (DDGS) and carbon dioxide. In order to compensate for this downside, a number of technological advances have been made to decrease processing costs, and increase the value of coproducts resulting from the process.

a) Raw Starch Hydrolysis Technology

- The cooking step[266], necessary to gelatinize and liquefy the starch in the dry grind ethanol process, is highly energy consuming and has some undesirable side effects, such as the Maillard reaction (which somewhat limits the availability of sugar and protein), and can result in the yeasts producing higher levels of wasteful product, such as glycerol (the high humectancy of glycerol limits the drying process of DDGS).

- The cooking step can be substituted by a raw starch hydrolysis method, also referred to as cold hydrolysis, where enzymes are used to hydrolyze starch that has not been cooked into fermentable sugar. The main reported benefits of raw starch hydrolysis are as follows:
  - o Energy saving;

[266] In a typical dry grind ethanol process, the five basic steps are grinding, cooking, liquefaction, saccharification and fermentation. The whole corn kernels are generally milled without separating out the various components of the grain, and the milled grain is slurried with water and alpha amylase before cooking.

  - Increased ethanol yields (due to higher sugar availability and higher concentration of alcohol obtainable;
  - Reduced side effects; and
  - Increased protein content of the coproduct.

- Compared to traditional dry mills, the dry grind ethanol process using the raw starch hydrolysis technology results in DDGS of higher quality and increased protein content, and lower energy cost during drying. Due to the higher protein content, this "modified" DDGS can be sold at a premium compared to "regular" DDGS; premium that would be established based on the exact protein content.

- Broin Companies, with "Broin Project x" (BPX), and Genencor International Inc., with Stargem™, have both recently commercialized technology solutions to realize raw starch hydrolysis. The method is still in its infancy but is promising. In its January 2006 edition, Ethanol Producer Magazine[267] reported that nine plants are currently using BPX.

b) Modified Dry Grind Ethanol Process

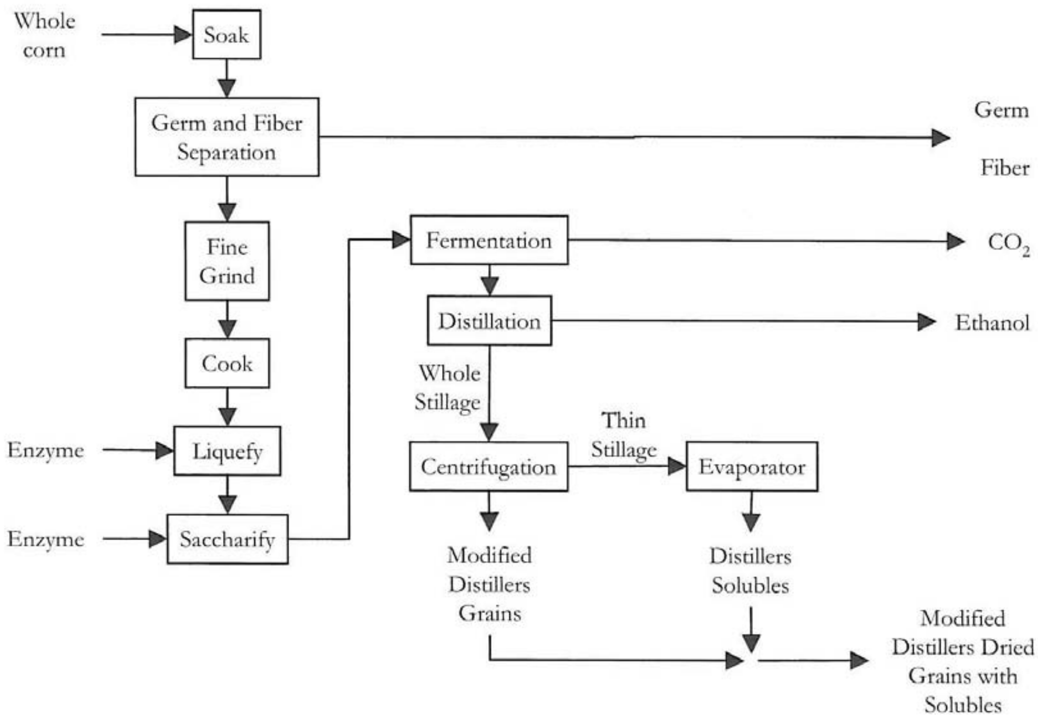
- The modified dry grind ethanol process was initially developed at the University of Illinois at Urbana-Champaign during the 1990s as an attempt to increase the value and quantity of coproducts made from traditional corn dry mills (Figure 52).

- In this process, the germ and fiber from the corn are separated at the front end, before the commencement of fermentation. The endosperm is then fermented to produce ethanol, while the remaining fractions are converted into value-added coproducts. Thus this biorefining technology separates the corn into three fractions including fiber, germ and endosperm.

- Because much of the germ and fiber consist of materials that are not fermentable into ethanol, efficiency of the overall process is improved over conventional dry mill. In addition, removing the non-fermentable components at the front-end enables to obtain a DDG of better quality with higher protein content.

[267] Williams, Jessica. "Break It Down Now" Ethanol Producer Magazine, January 2006, p. 26-30.

Figure 52: Modified Dry Grind Ethanol Process with Germ and Fiber Recovery



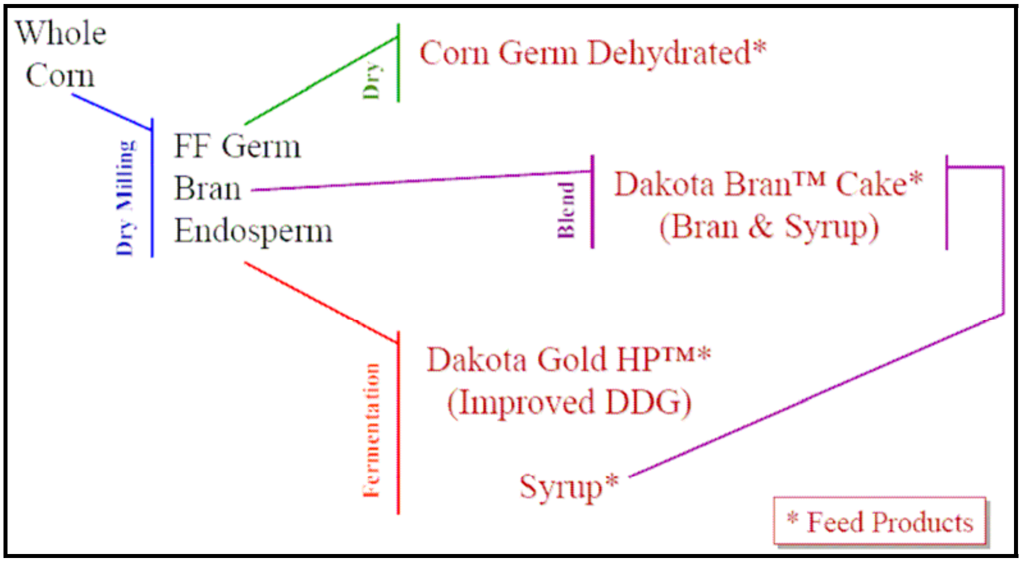
Source: Singh, Vijay, Kent D. Rausch, Ping Yang, Hosein Shapouri, Ronald L. Belyea, and Mike E. Tumbleson. "Modified Dry Grind Ethanol Process" Publication of the Agricultural Engineering Department, University of Illinois at Urbana-Champaign UILU No. 2001-7021, July 18, 2001, p.41.

- Several modified dry grind ethanol processes have been developed where fermentation rates, yields and coproduct composition vary. These processes can generally be grouped into two "families": the first one using a dry milling process[268], and the second one a wet fractionation technology[269]. These two families of processes diverge based on the quality of the coproducts and the capital costs. Thus, with the former, germ recovered has a lower oil content, and fiber a lower quality, whereas the latter requires higher capital costs.

- The modified dry grind ethanol process is becoming increasingly more popular. Cargill and Badger State Ethanol LLC (Monroe, WI), among other players, have been reported having plans to implement this emerging biorefinery process. Broin, also, has presently two operations and a third one under construction using this process. Broin's process, which employs a dry milling technology to retrieve germ and fiber, has been trademarked under the name BFRAC™ (Figure 53)

[268] The whole corn is soaked in water and then ground.
[269] The whole corn is soaked in water before conventional wet milling degermination, and germ and fiber recovery.

Figure 53: Broin's BFRAC™ Process Flow



Source: Broin, Dakota Gold Marketing™

The following sections will develop various coproduct uses for the germ, fiber and DDG.

Fiber

- Corn fibers recovered through the modified dry grind ethanol process have the advantage of being of relatively good quality. The utilization of the fibers however is ultimately determined by the type of recovery process used; hence, wet fractionation technology enables the recovery of very high-quality fibers, allowing their use to produce dietary fibers.

Dietary Fiber

- The term "dietary fiber" encompasses a wide variety of fibers of very high quality. The most widely accepted definition in the food industry is that put forth by the American Association of Cereal Chemists (AACC): "Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibers promote beneficial physiological effects include laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation."

- The demand for dietary fibers has been especially high in countries where consumers' awareness regarding food-related health is important: North America, Europe, and Japan. It is currently reported that the demand for dietary fibers is growing at an annual rate of 12%, making it a very attractive market. However, because the market for dietary fibers is relatively new, there is no available record of the supply and demand of fiber products in the US.

- It is a highly specialized and heterogeneous product that is not traded or quoted on any commodity exchange. Due to a tight offer and a relatively large demand, food grade corn fibers are currently relatively expensive. The price of dietary corn fibers can range from $0.20 to $0.70 /lb or more depending on the exact type of fibers, for instance, soluble or insoluble.

- To the best of our knowledge, there is currently no plant producing dietary corn fibers in the US (one plant though has been reported in project). One should note, however, that a number of other corn products rich in fibers, such as corn grits, are currently available and marketed as food-grade fibers. These corn products are typically enriched in fibers and have a total dietary fiber level similar to high-quality dietary corn fiber products.

Feed Products

- Fibers can be used in a number of pet food applications. Broin for example has trademarked a feed product made of bran and corn condensed distillers solubles, Dakota Bran™ Cake.

Germ

- Corn germ can either be sold as a high energy feed product or as a source of corn oil. Corn oil usually trades at a premium to soybean oil by $0.02 to $0.025/pound because of desirable qualities/attributes such as its favorable flavor profile.

- Although both applications are possible, it is preferable to trade the germ recovered using a dry milling process as a feed product, since the oil level is significantly lower than with a wet fractionation technology.

Distillers Dried Grains

- The concentration of proteins in the DDG is increased as fiber is decreased and enhances the potential for including DDG in non-ruminant livestock diets.

- In the modified dry grind ethanol process, there is less relative mass fermented, as compared to a dry mill. This results in DDG that is higher in protein (40-48%) than the “regular” DDG produced in dry mills.

- The protein feed market is well defined concerning the issue of substitutability between different products. The various protein products all trade in a similar price pattern, with premiums or discounts established based on the protein concentration. Ultimately, the price of soybean meal (SBM) dictates the pricing for all of the major protein feeds. The modified DDG is expected to be traded at the same level as high protein SBM.

- Broin has trademarked its improved DDG as Dakota Gold HP™.

c) Raw Starch Hydrolysis Technology

- The modified dry grind ethanol process can finally be coupled with a raw starch hydrolysis technology, which could decrease processing costs and potentially increase the quality of the DDG. This technology allows for the saccharification of corn starch without the usual higher temperature hydrolysis step. It saves energy and reduces time in the process because the hydrolysis and fermentation are performed at similar temperature and pH. This process requires the corn to be milled to a smaller particle size and is especially adaptable to plants corn endosperm feedstock. Broin has filed patents for such a process (BTX) and the use of enabling enzymes. Broin has teamed with Novozymes to introduce this technology into Broin's ethanol plants.

d) Corn Oil Extraction

- Corn oil of food grade quality can be extracted from corn germ produced by corn fractionation technologies. Both solvent extraction processes and expeller extraction can be used. Additional technology is being marketed to extract corn oil from dry millers fermentation residues, usually from "thin stillage". Thin stillage is extracted from the fermentation residue by centrifugation. It has high oil content and the oil can be removed by different separation technologies. This oil has an increased level of free fatty acids making it an unlikely candidate for food grade corn oil and a likely source of oil for biodiesel production. New technologies are being investigated for oil extraction including enzymatic extraction. The USDA-ARS is developing a process based on cellulase hydrolysis of the germ for release of the oil.[270] Currently, most oil is extracted using hexane. Using enzymes would eliminate the hexane, a chemical with health and safety issues for food production.

2. *Lignocellulose Based Biorefineries*

- One of the essential elements in the economical and efficient production of cellulosic ethanol is the development of biorefineries. The concept of a biorefinery is analogous to a petroleum refinery where a feedstock, crude oil, is converted into fuels and co-products such as fertilizers and plastics. In the

[270] Moreau, R.A., et al., 2005. Aqueous enzymatic extraction of corn oil from corn germ. Meetin Abstr. 96th AOCS Annual Meeting & Expo. Salt Lake City, UT, May 1-5, 2005

case of a biorefinery, plant biomass is used as the feedstock to produce a diverse set of products such as animal feed, fuels, chemicals, polymers, lubricants, adhesives, fertilizers and power.

- While similar to oil refineries, biorefineries exhibit some important differences. First, biorefineries can utilize a variety of feedstocks. Consequently, they require a larger range of processing technologies to deal with the compositional differences in the feedstock. Second, the biomass feedstock is bulkier (contains a lower energy density) relative to fossil fuels. Therefore, economics dictate decentralized biorefineries closer to feedstock sources.

- As with grains, processing cellulosic biomass is directed toward extracting fermentable sugars from the feedstock. The sugars in cellulose and hemicellulose are locked in complex carbohydrates called polysaccharides (long chains of monosaccharides or simple sugars). Separating these complex polymeric structures into fermentable sugars is essential to the efficient and economic production of cellulosic ethanol.

- Two processing options are employed to produce fermentable sugars from cellulosic biomass. One approach utilizes acid hydrolysis to break down the complex carbohydrates into simple sugars. An alternative method, enzymatic hydrolysis, utilizes pretreatment processes to first reduce the size of the material to make it more accessible to hydrolysis. Once pretreated, enzymes are employed to convert the cellulosic biomass to fermentable sugars. The final step involves microbial fermentation yielding ethanol and carbon dioxide.

- Grain based ethanol utilizes fossil fuels to produce heat during the conversion process, generating substantial greenhouse gas emissions. Cellulosic ethanol production substitutes biomass for fossil fuels, changing the emissions calculations.

- The Department of Energy (DOE) Biofuels program has identified the high cost of cellulose enzymes as the key barrier to economic production of cellulosic ethanol. Two enzyme producers, Genencor International and Novozymes Biotech, have received research funding from DOE to engineer significant cost reductions and efficiency improvements in cellulose enzymes.

- Another major thrust of R&D efforts is devoted to improving pretreatment technologies. Pretreatment is required to break apart the structure of biomass to allow for the efficient and effective hydrolysis of cellulosic sugars.

- Pretreatment technologies utilize dilute acid, steam explosion, ammonia fiber explosion (AMFE), organic solvents or other processes to disrupt the hemicellulose/lignin sheath that surrounds the cellulose in plant material. Each technology has advantages and disadvantages in terms of costs, yields, material degradation, downstream processing and generation of process wastes.

- One of the most promising pretreatment technologies, Ammonia Fiber Explosion (AMFE), employs liquid ammonia under moderate heat and pressure to separate biomass components.

- The economics of biorefineries are dependent upon the production of co-products such as power, protein, chemicals and polymers to provide revenue streams to offset processing costs, thus improving cellulosic ethanol profit margins. Generation of co-products also results in greater biomass and land use efficiencies along with a more effective use of invested capital

- Lignin and protein, two important co-products, have the potential to significantly improve the economics of biorefineries. Lignin is a non-fermentable residue from the hydrolysis process. It has energy content similar to coal and is employed to power the operation, thereby reducing production costs.

- Iogen is operating a facility in Ottawa, Canada, utilizing proprietary enzyme hydrolysis and fermentation techniques to produce 260,000 gallons/year of ethanol from wheat straw.

- Two companies are exploring new technologies and processes to integrate cellulosic biomass in existing corn ethanol and wet grain milling facilities. Broin Companies has received a $5.4 million grant from DOE to investigate employing fiber and corn stover in the production of ethanol

- A $17.7 million grant from DOE is funding Abengoa's research on processes to pretreat a blend of distillers' grain and corn stover to produce ethanol. The project calls for the building of a pilot-scale facility in York, Nebraska

- BC International is applying a proprietary acid hydrolysis technology to agricultural residues and forest thinning feedstocks to produce ethanol. The company is developing facilities in Louisiana, California and Asia and claims their process produces ethanol at costs lower than conventional ethanol plants.

- Historically, the only cellulose to ethanol plant operating continuously in North America, of which we are aware, is owned by Georgia Pacific and located in Washington State. Reportedly, the plant capital was largely Federal based on needs of the World War II era. We understand the plant has been mothballed.

- There is an emerging body of thought among leading industry participants and observers that the initial breakthrough in cellulosic conversion to ethanol will be the transformation of corn kernel cellulosics in traditional dry mill ethanol plants (Tiffany and Eidman, Bothast, Stowers).

- The benefits of this process would be substantial. The plants would have an immediate yield increase of 5% to 10 % with minor variable cost increase. In addition, the volume of distillers dried grains (DDGS) would be substantially reduced. The profitable disposition of DDGS has emerged as one of the most vexing problems facing the fuel ethanol industry.

- Capital costs for converting a dry mill ethanol plant to utilize corn kernel fiber are not fully understood but industry sources indicate that the financial parameters are likely to be attractive.

- If corn kernel fiber conversion is successful, the learning from this research and development is expected to be applicable to the commercialization of processes to produce ethanol from other cellulose raw materials, e.g., corn stover.

- There is also significant support for the concept of utilizing existing biorefineries, specifically pulp and paper mills as test sites. Many of these facilities in North America are underutilized and possess infrastructure that may allow their economic conversion to initially grain based ethanol production with a long run strategy to manufacture with cellulosic raw material.

3. DuPont's Emerging Biorefinery Concept

- Another example of the biorefinery concept, which has been discussed previously at length in the report, is DuPont "Integrated Corn-Based Biorefinery" (ICBR). Figure 54 and Figure 55, displays the concept in a visual representation.

Figure 54: Integrated Biorefinery Industry

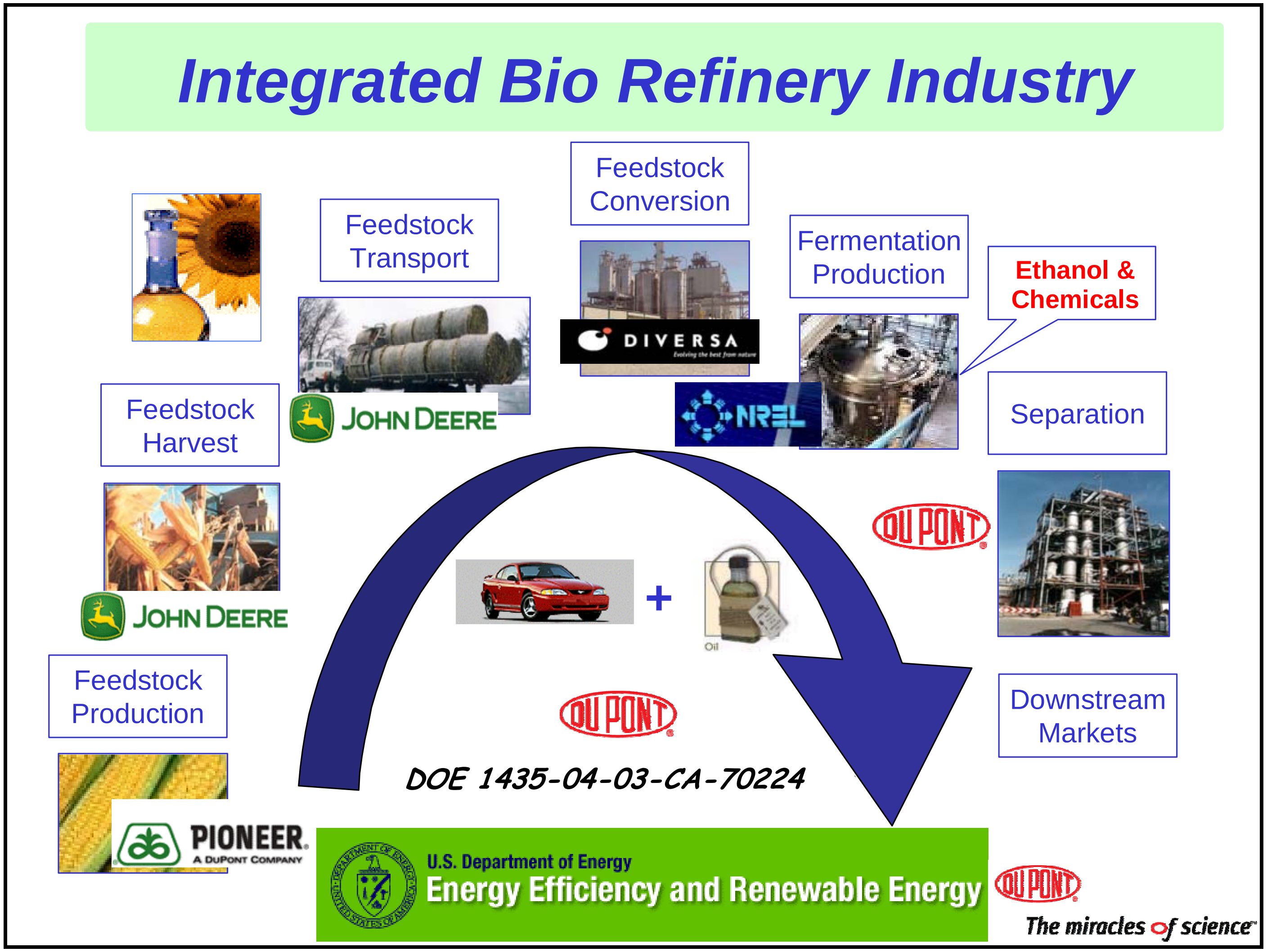
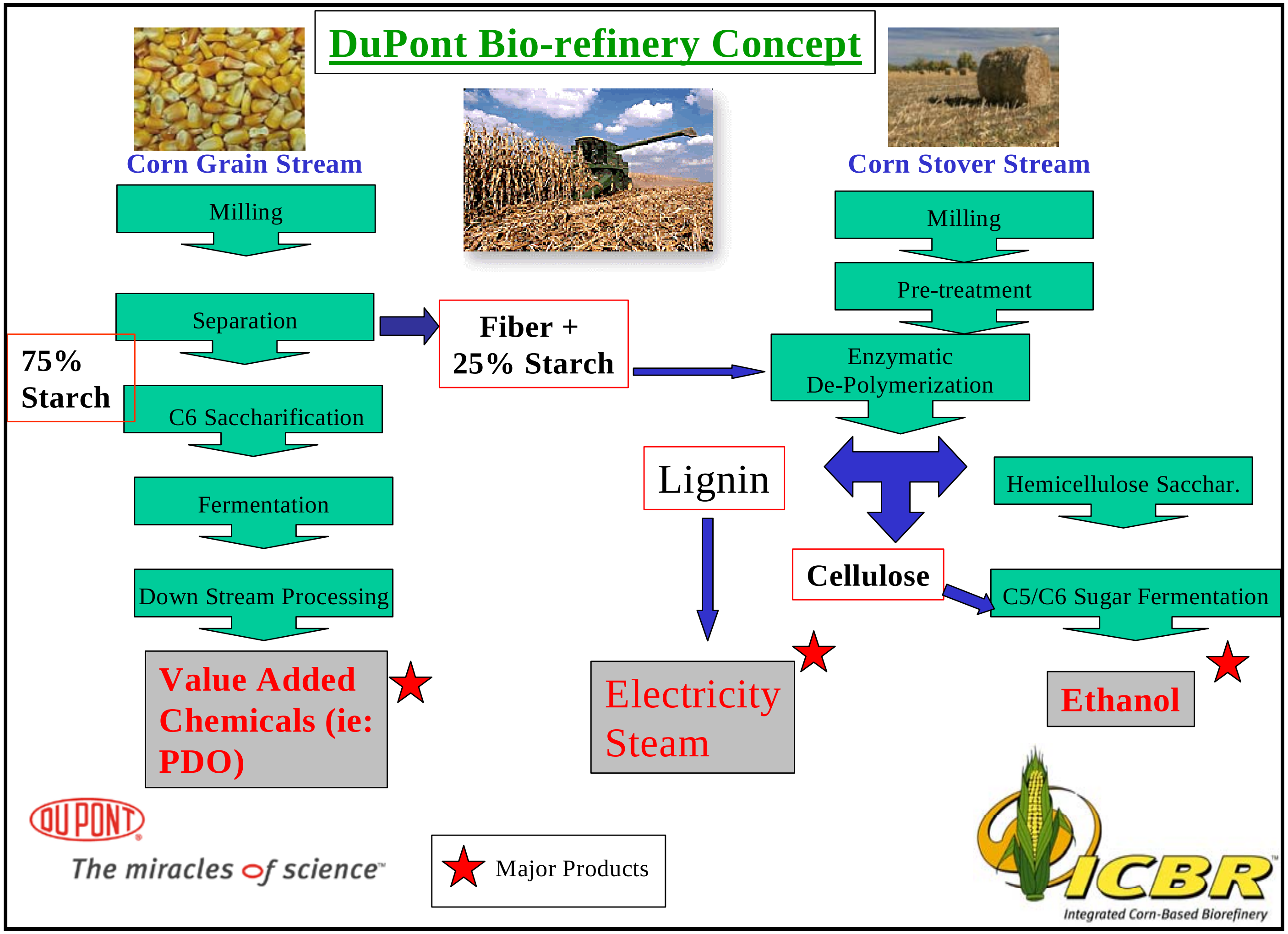


Figure 55: DuPont's Biorefinery Concept, Corn Based



VII. Evaluation of the Critical Demand-Side and Supply-Side Issues and Concerns: Role of Agricultural Land in the Bioeconomy

- A summary assessment of key North American biobased feedstocks is presented in Table 58. Within the set of traditional crop outputs, “Primary Feedstocks,” not surprisingly the present raw material sources, corn, soybeans and canola are expected to continue to dominate.

- Considering the new generation of raw materials, “Residual Feedstocks,” corn stover, wheat straw and timber waste are clearly seen as most attractive.

- The needs of the new biorefinery industry dictate that raw material from substantial, stable and well-established sources are its foundation. The efficient handling and assembly systems in place for these biomass resources cements their desirability.

- It is not likely, within the 2015 time frame, to see any commercial cropland conversion from traditional crops to dedicated biomass, e.g., switchgrass.

- However, the use of biomass from cropland in the Conservation Reserve Program (CRP) would be a natural raw material supply if the concerns of wildlife interests were met and appropriate financial terms were set.

- The systems are already in place for harvesting hay from CRP, historically on an emergency basis and more recently on a more lenient schedule.

- Several analyses have been conducted of this resource, which indicate that the grass species in place are generally suitable for biorefinery use and capable of significantly greater biomass yields if intensive cultural practices were economically warranted.

- The CRP acreage is also relatively concentrated, further simplifying use of this resource (Map 13).

- As with the corn based ethanol industry, a biorefinery based on biomass, whether agricultural residue, CRP or wood, will locate in proximity to the raw material. A collection of maps (Map 14 to Map 25) have been generated in order to better understand where the primary cropping feedstocks and residues are produced in the US and Canada. Additionally, two maps, (Map 26 and Map 27) have been presented to show geographical regions that will focus on animal biomass waste streams from dairies and feedlots and the likely use in methane capture conversion processes.

- Given the low value of biomass as a raw material, generally estimated in the range of $30.00 to $45.00, logistics will be a critical consideration. Many industry observers believe that a system of terminals, analogous to the grain elevator system will be required. At such terminals, bulk could be reduced physically and possibly chemical pretreatment would occur before transport to the biorefinery.

- There is an argument that straw, wheat, other small grains and rice, will be the initial raw material of choice over the more abundant corn stover. The basis of this logic is that handling systems are in place and easily accessible and that there is often a need to remove the residue from the field.

- Countering this argument is the fact that corn stover can be gathered with machinery and techniques nearly identical to straw handling and that the agricultural machinery industry has proven ability for quick response to market needs.

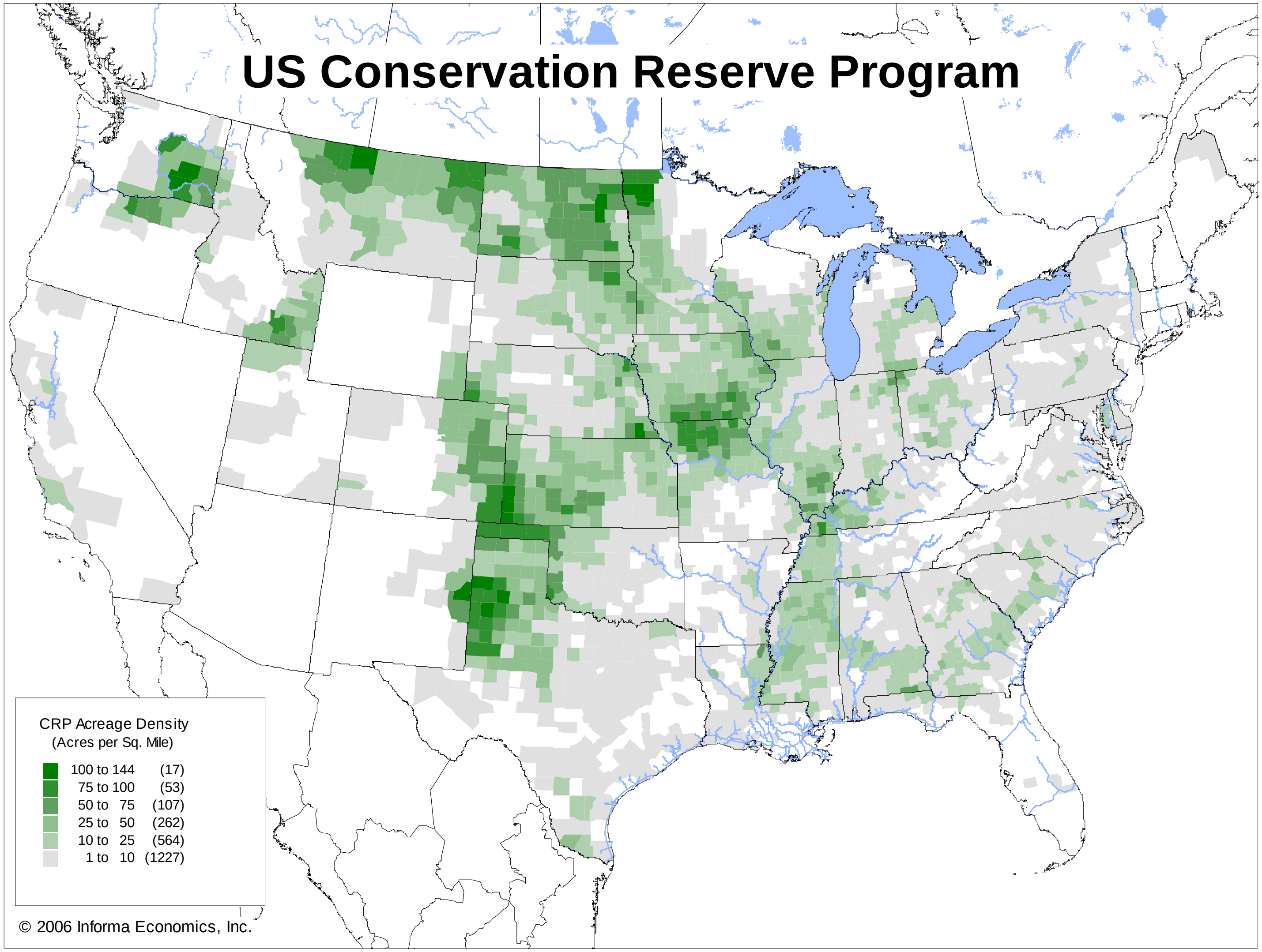
- A significant unknown when considering biomass harvest is the perishability of the various raw materials and the requirements for handling and storage when destined for a biorefinery.

Table 58: Summary Assessment of US & Canadian Biobased Crop Feedstocks

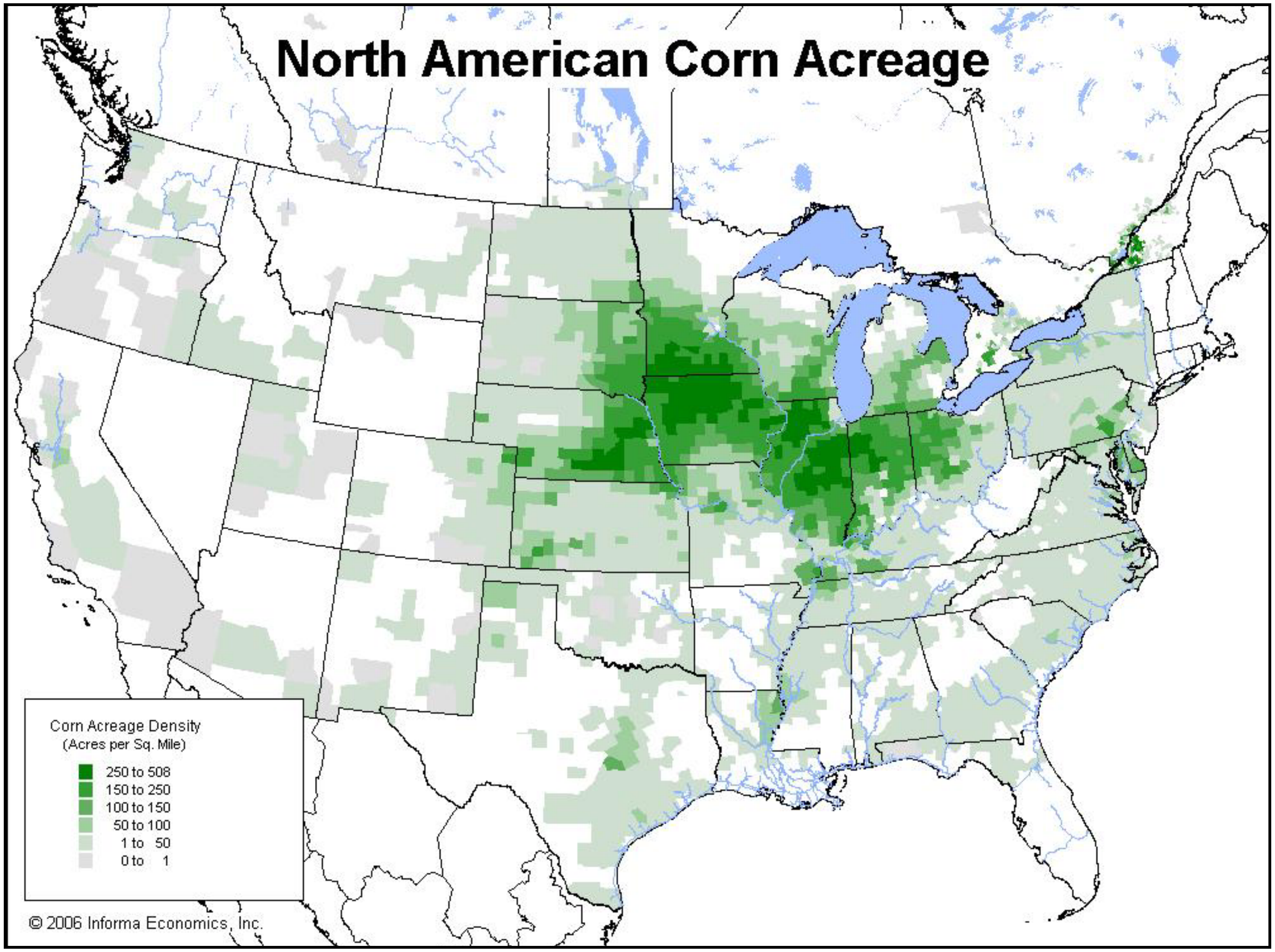
Feedstocks	Current Scale of Resource Base	Complexity of Assembling	Stage of Development in BioEconomy	Potential Market Growth	Overall Attractiveness
Primary Feedstocks:					
Canola	●	●	◕	●	●
Corn	●	●	●	●	●
Wheat	◕	●	◑	◑	◑
Sorghum	◔	●	◔	◑	◑
Soybeans/Soybean Oil	●	●	◕	●	●
Switchgrass/Conservation Reserve	◕	◕	◑	●	◕
Grasses (other sources)	◔	◕	◑	◔	◕
Cultivated Trees (willows/poplars)	◑	●	◕	●	◕
Manged Timber Tracts	●	●	◑	◕	●
Residual Feedstocks:					
Corn Stover	●	◕	◑	●	●
Corn Fiber	●	◕	◑	●	●
Wheat Straw	◕	◕	◑	●	●
Barley	◔	◕	◑	◑	◑
Oats	◔	◕	◑	◑	◑
Rice Straw	◔	◕	◑	◑	◑
Rye	◔	◕	◑	◑	◑
Timber Waste	●	●	◑	◑	◕

Large	●	Well Established	●	Very Fast	●	Very Attractive	●
Medium	◕	Initial Commercialization	◕	Moderately Fast	◕	Moderately Attractive	◕
Small	◑	Early Development Stage	◑	Slow	◑	Questionable	◑
Niche/Specialty	◔	Research/ Conceptual Stage	◔	No Growth	◔	Not Attractive	◔

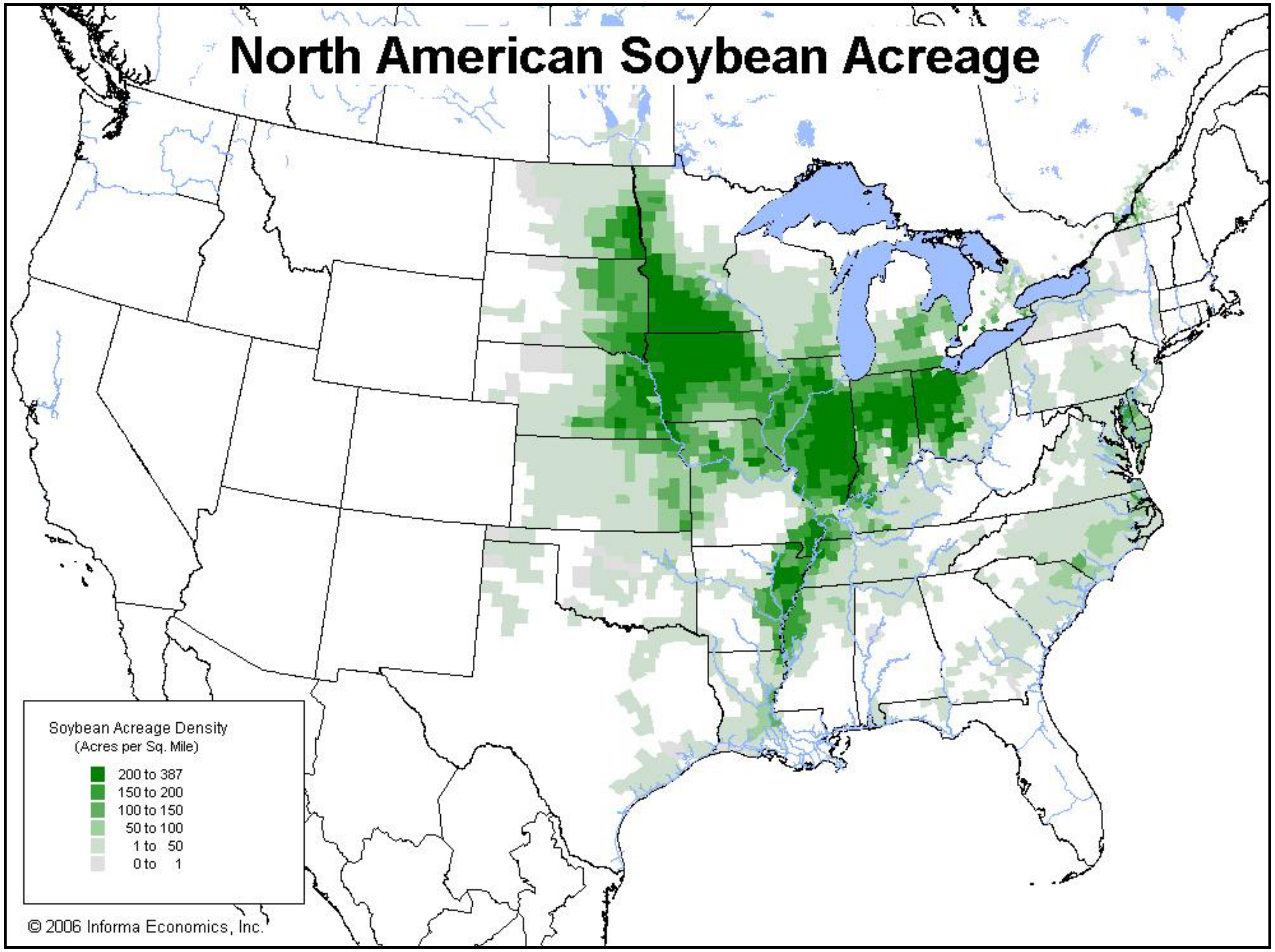
Map 13: Land in the US Conservation Reserve Program



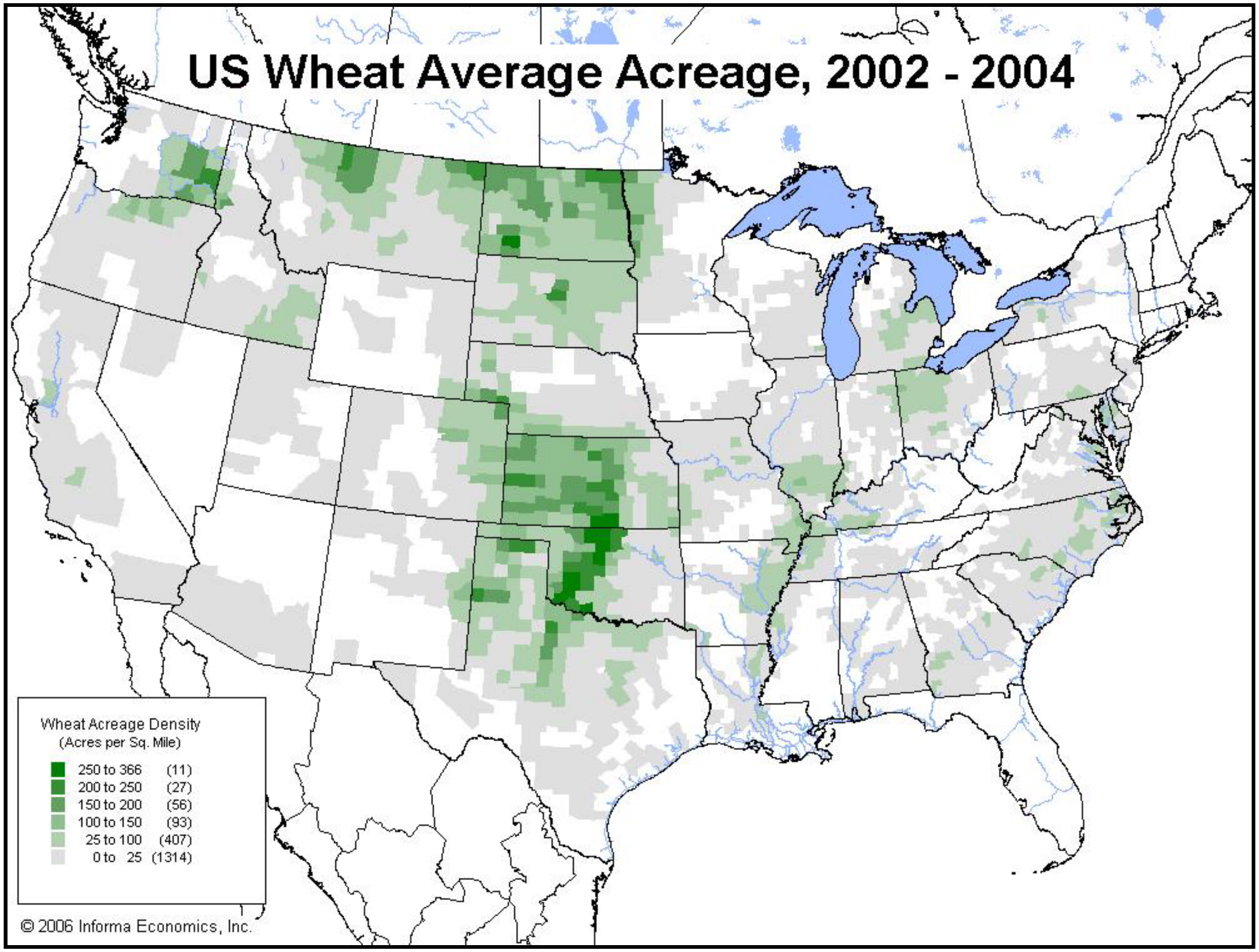
Map 14: North American Corn Acreage, 2002 – 2004



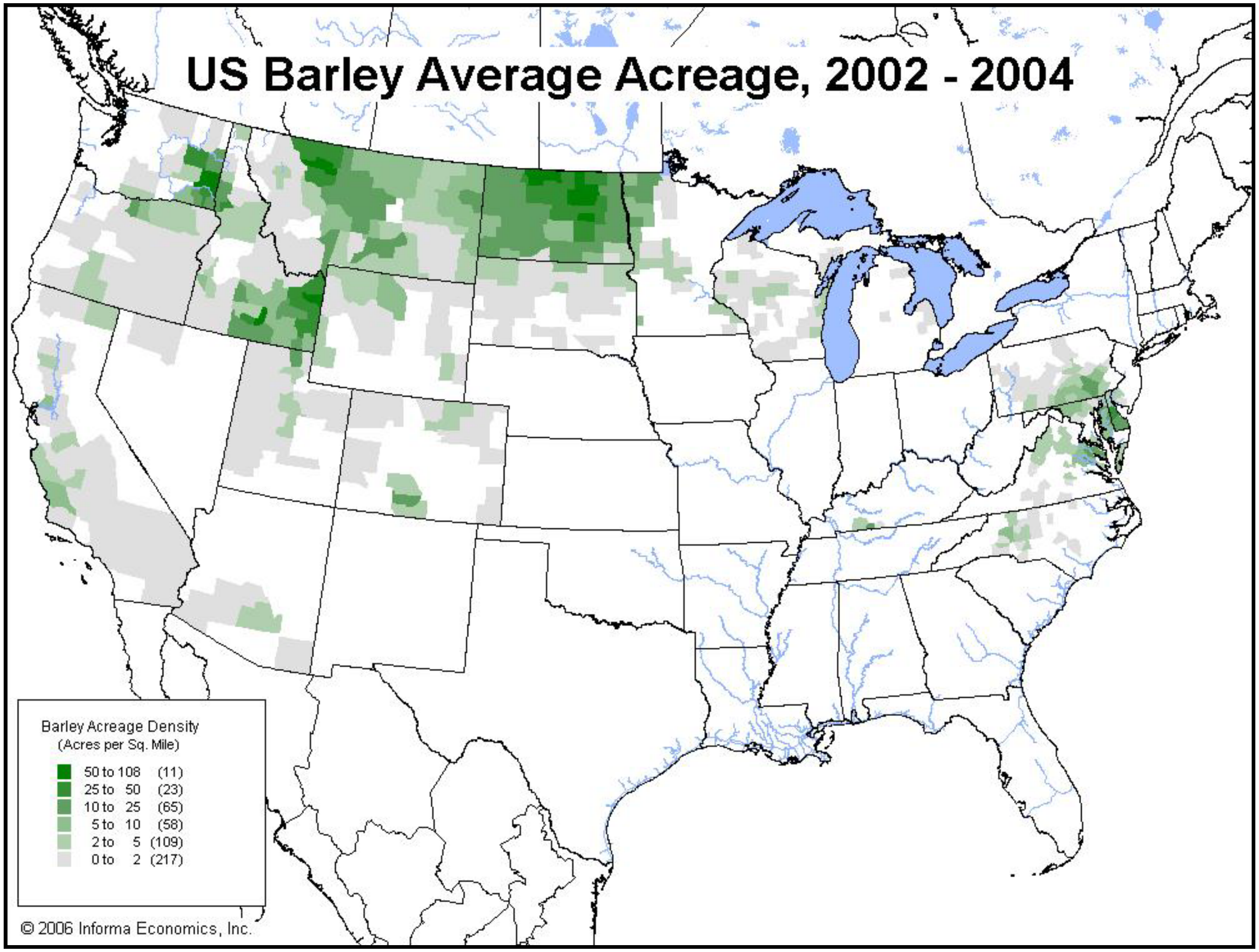
Map 15: North American Soybean Acreage, 2002 – 2004



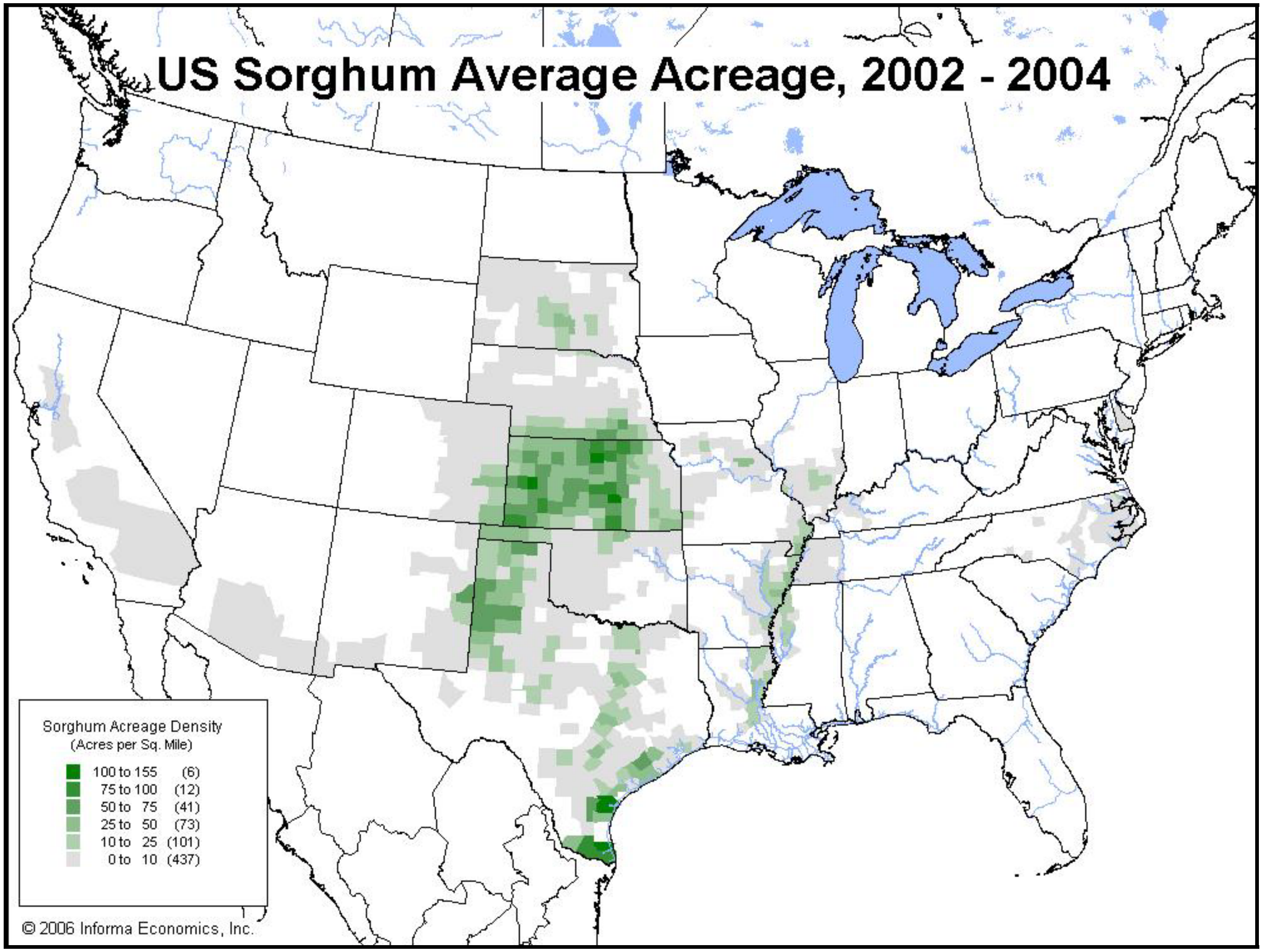
Map 16: US Wheat Average Acreage, 2002 – 2004



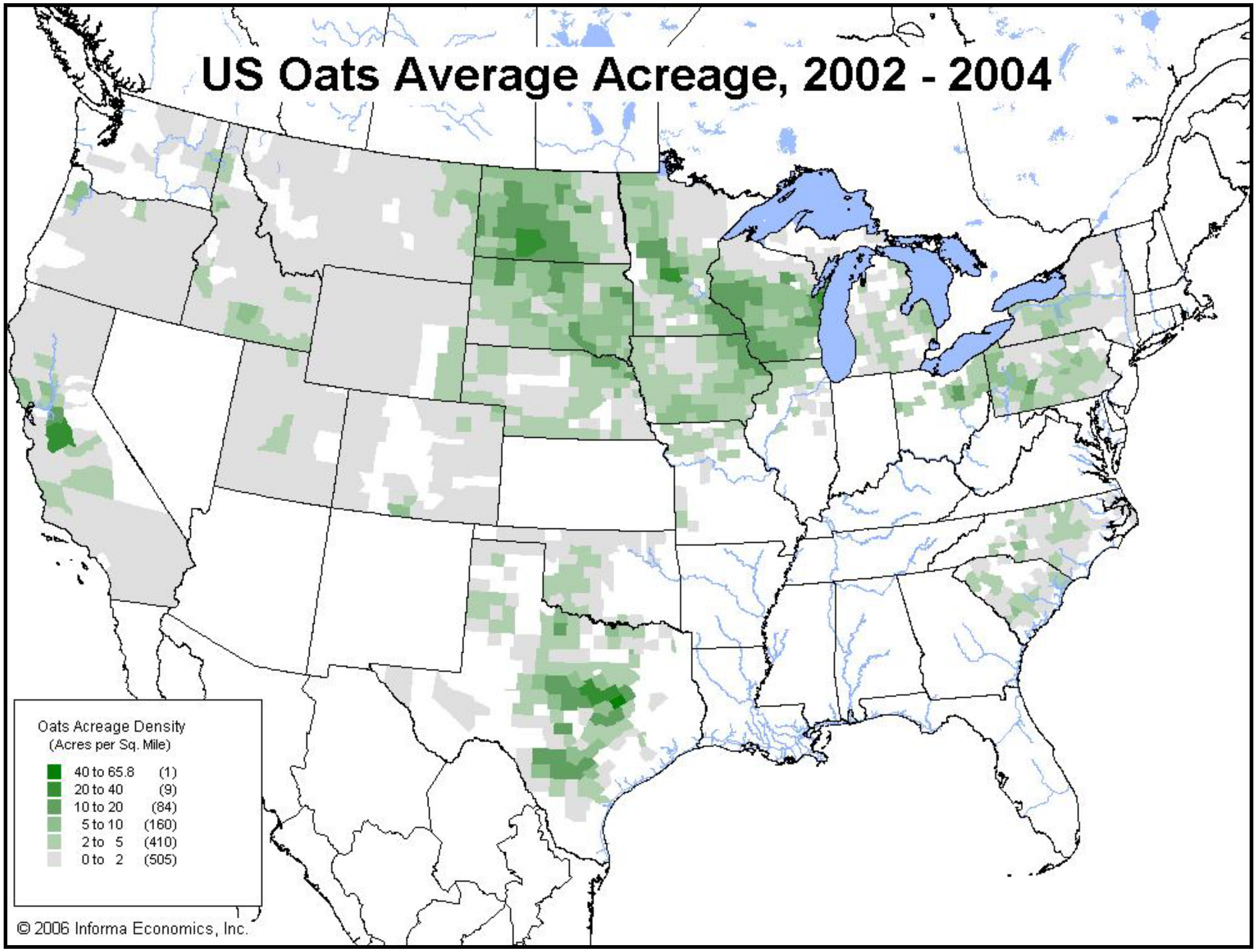
Map 17: US Barley Average Acreage, 2002 – 2004



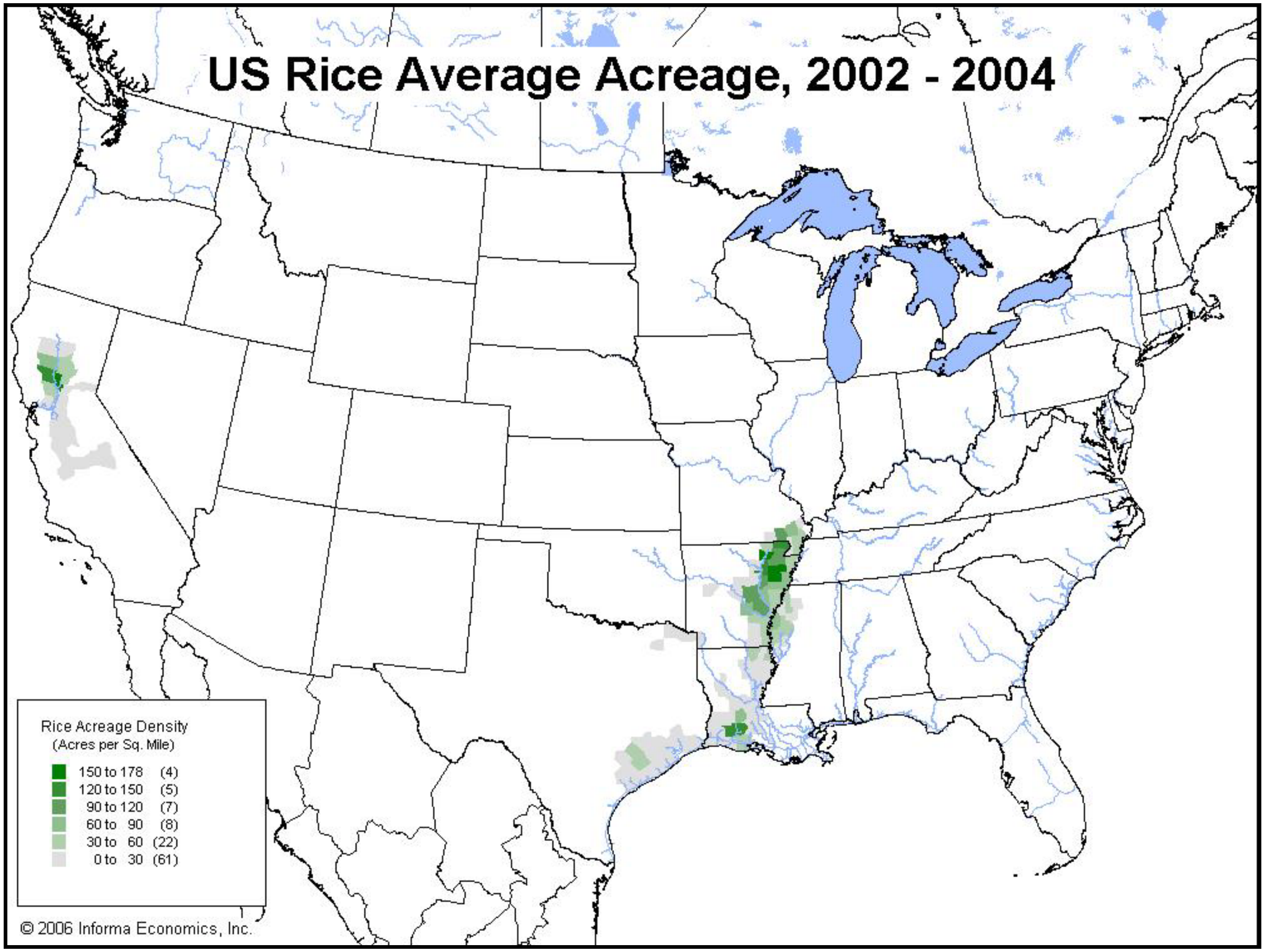
Map 18: US Sorghum Average Acreage, 2002 – 2004



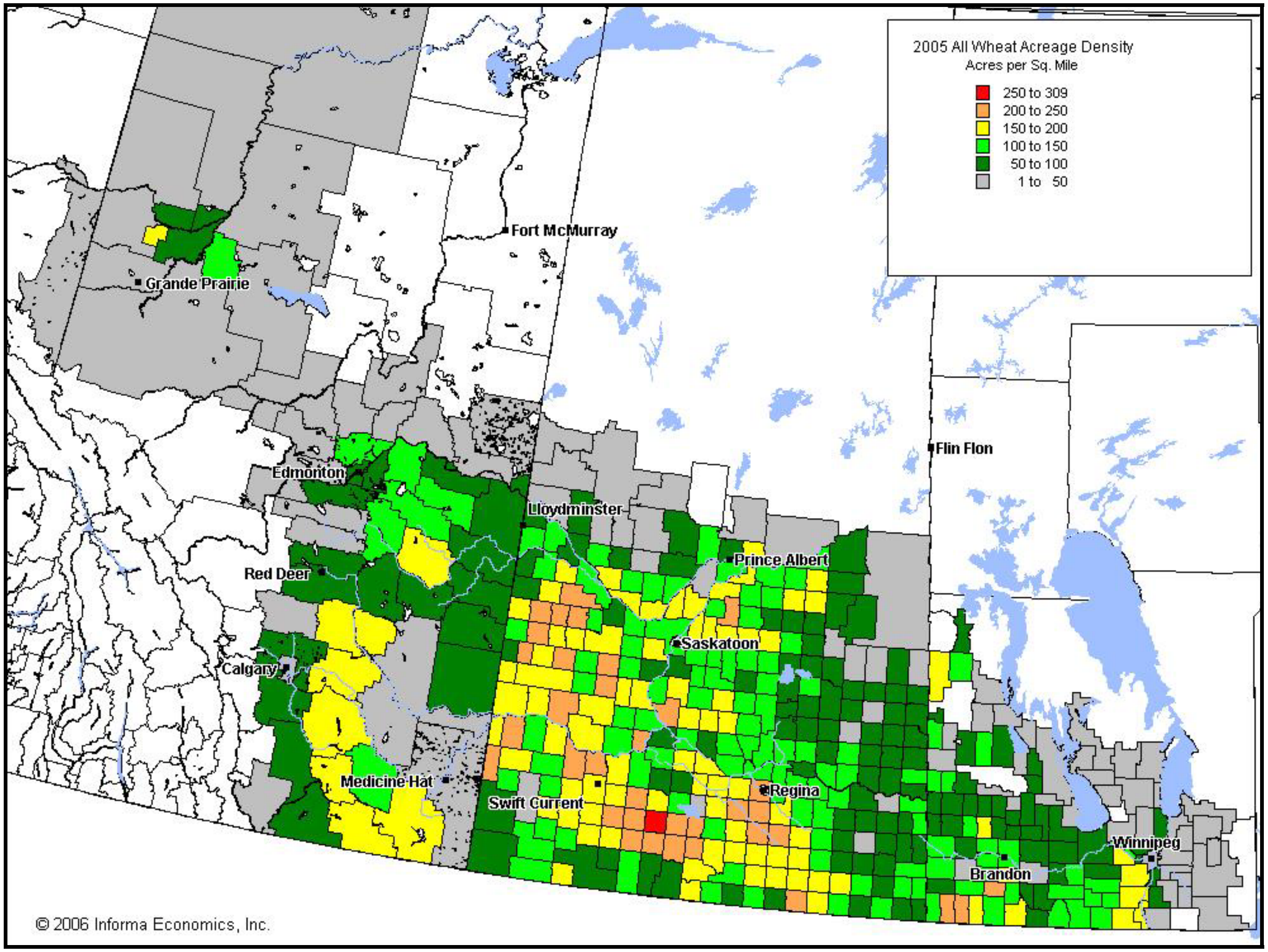
Map 19: US Oats Average Acreage, 2002 – 2004



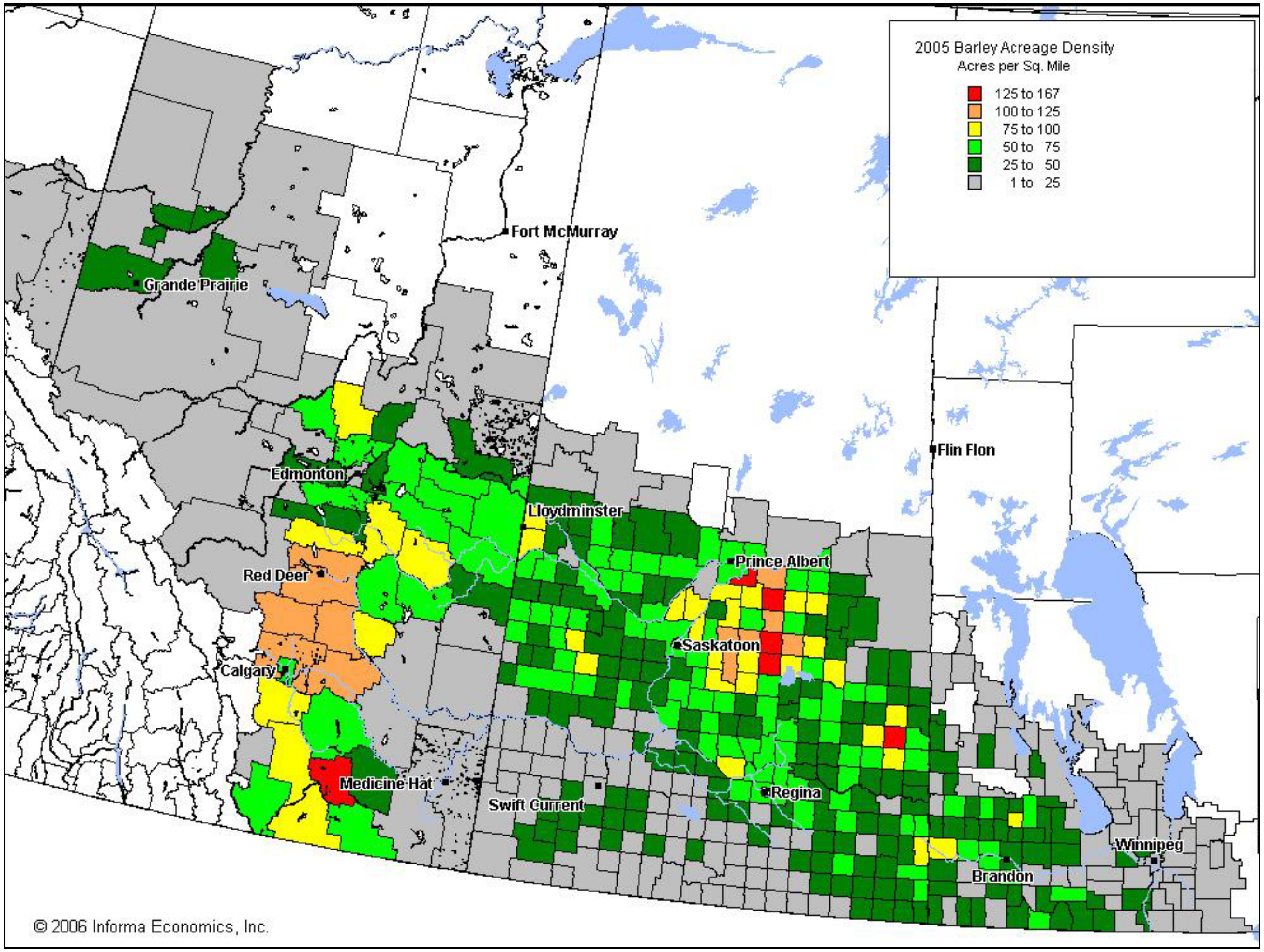
Map 20: US Rice Average Acreage, 2002 – 2004



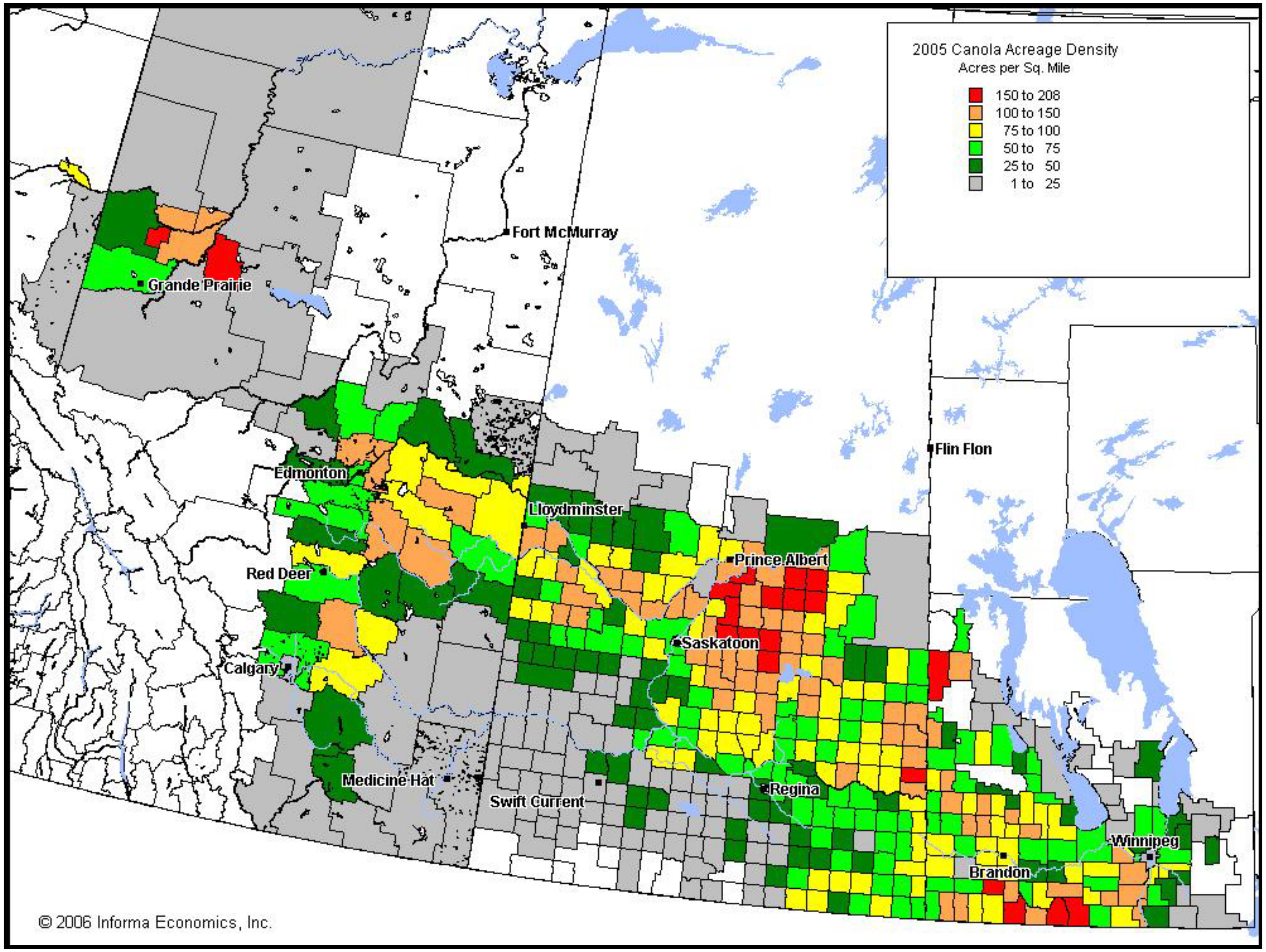
Map 21: Canadian, Wheat Production, 2005



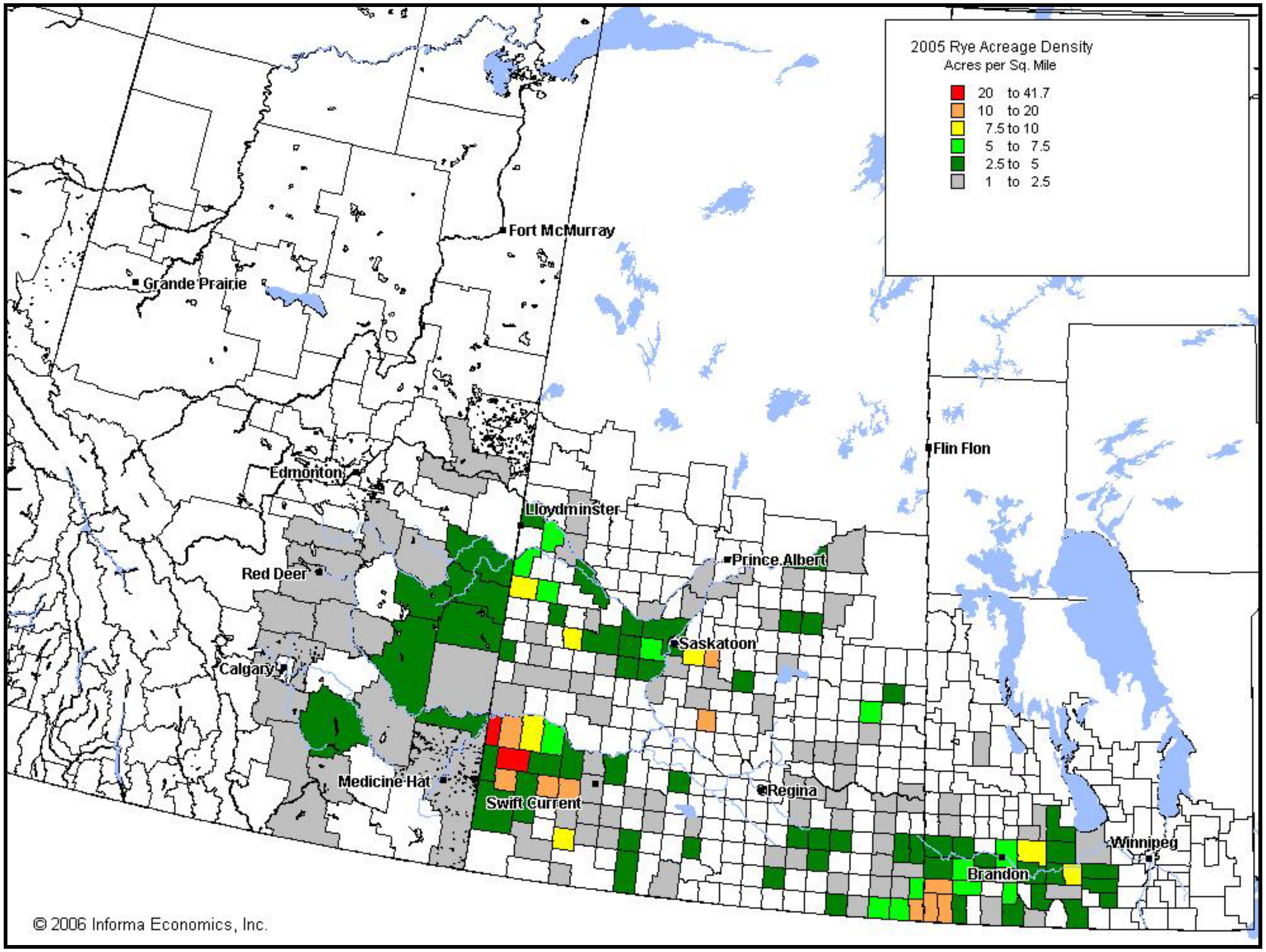
Map 22: Canadian, Barley Production, 2005



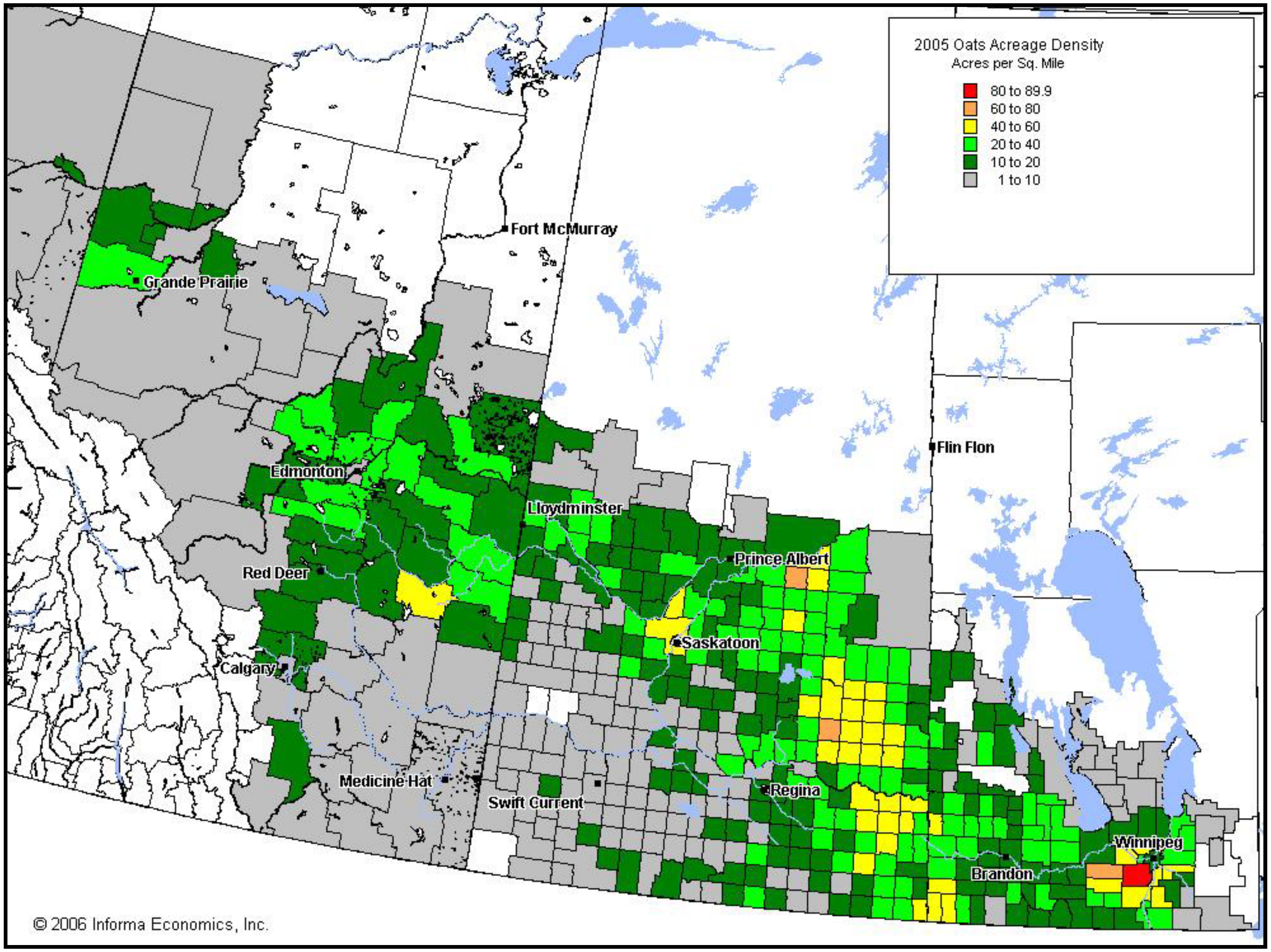
Map 23: Canadian, Canola Production, 2005



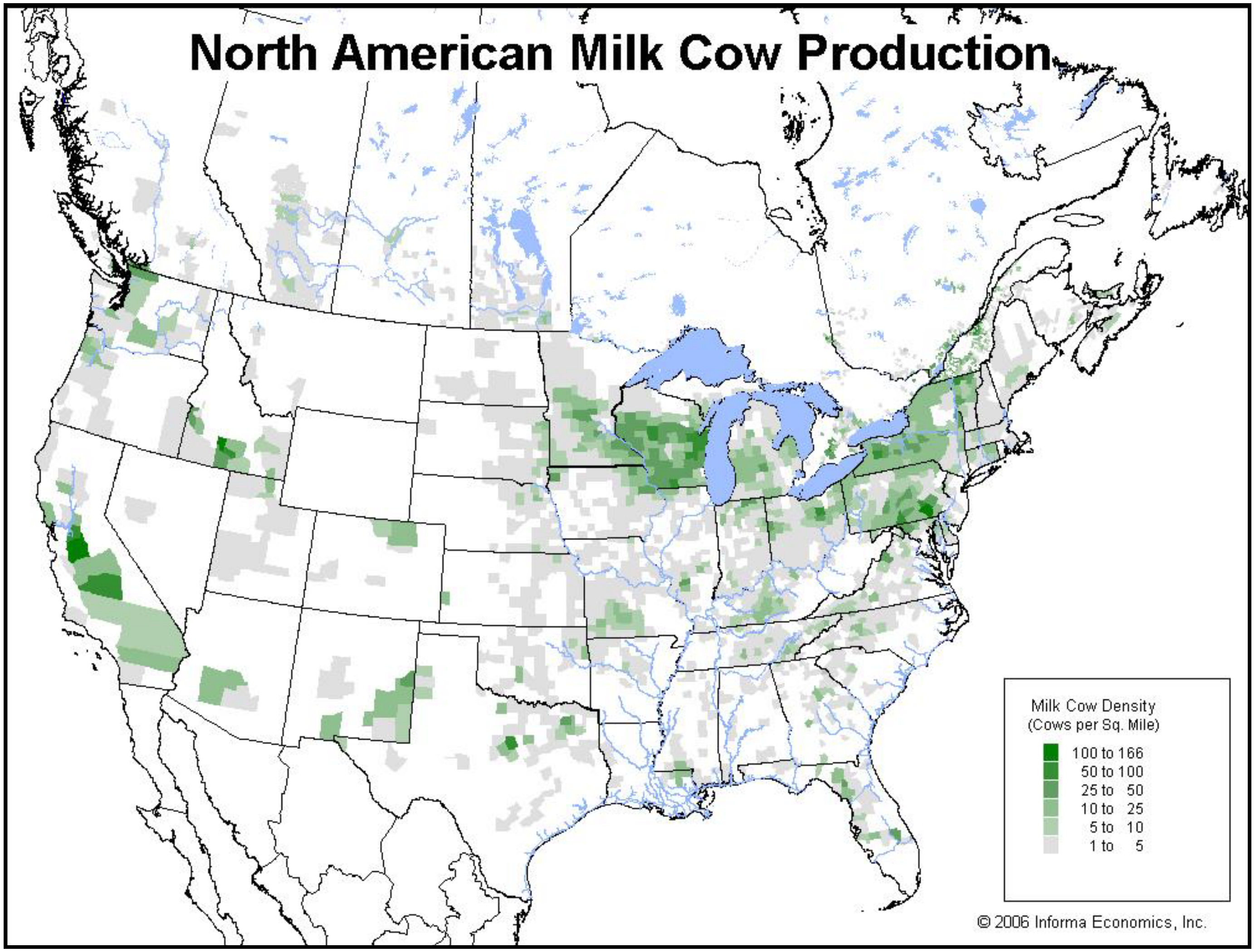
Map 24: Canadian, Rye Production, 2005



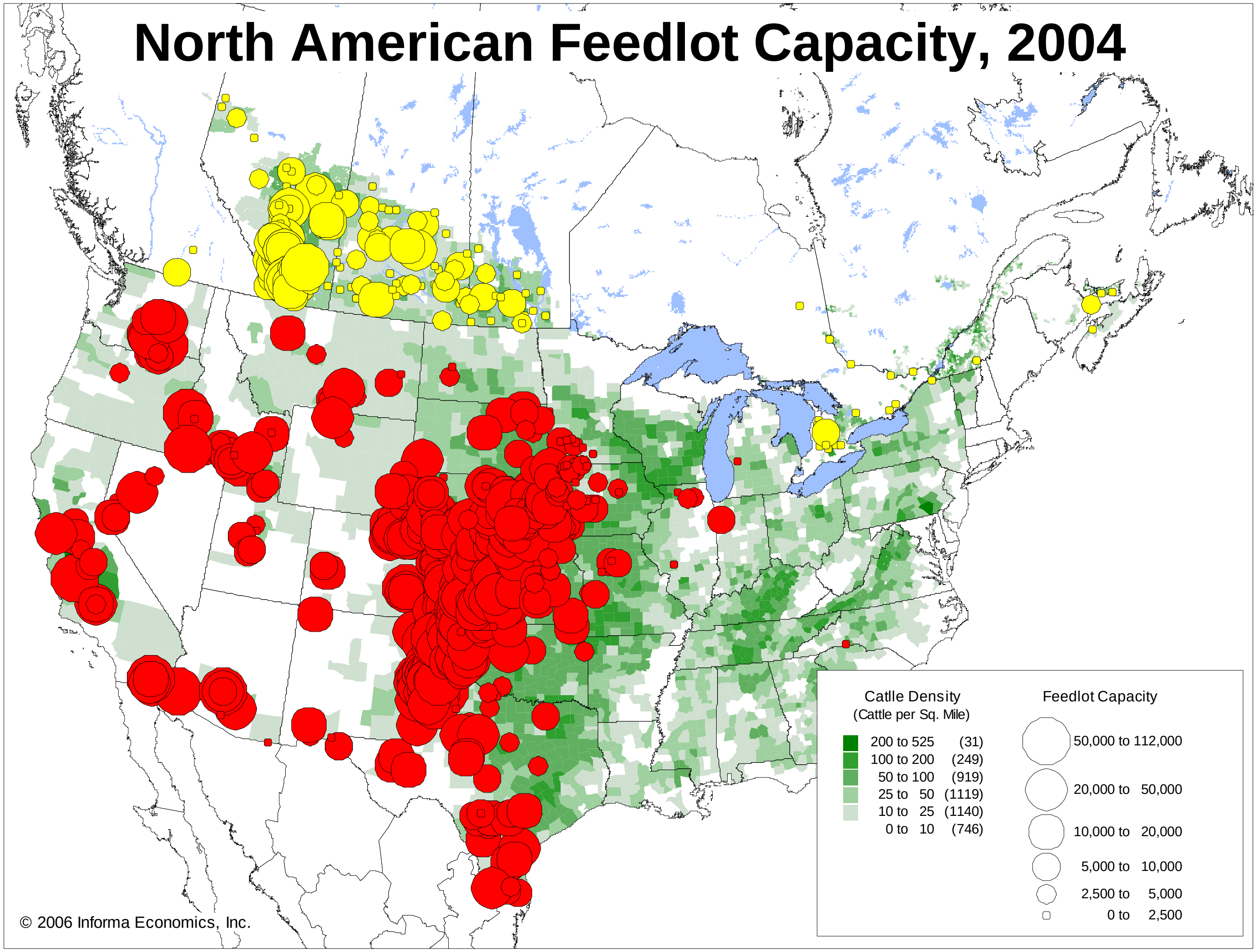
Map 25: Canadian, Oats Production, 2005



Map 26: North American Milk Cow Production



Map 27: North American Feedlot Capacity, 2004



VIII.Impacts and Implications of Oil Prices and Government Support on Biomass and the Agricultural Sector

A. Impact Matrices

- Moving forward, the two most decisive forces that will dictate the direction and rate of progression of the bioeconomy will be the impact of oil prices and the level of government support (US and abroad). For purposes of this study we have developed an assessment matrix that compares the price of oil at three levels relative to the degree of US federal and state government support at three levels (Table 59 and Table 60). Two different time periods are also evaluated, the short-run 1-3 years and the intermediate-run until 2015.

- The crude oil prices are set at three levels,
  - $25/barrel – this is the level where oil traded for a protracted period of time during the 80's and 90's (Figure 1).
  - $45/barrel – the level that many economic organizations are using as a benchmark price for crude oil for the next 10 years, including Informa.
  - $105/barrel – this represents an extremely bullish outlook on crude prices. The investment house Goldman Sachs said that we may have entered into a period where "super spikes" could occur with oil reaching $105/barrel.

- Government support and incentives (state and federal)
  - Low government support/incentives – this would be <u>below</u> current federal and state levels of assistance.
  - Medium government support/incentives – this would be at current federal and state levels of assistance.
  - High government support/incentives – this would be <u>above</u> current federal and state levels of assistance.

Highlights

<u>Short-run</u>

- Below $25/barrel, the ethanol industry begins to consolidate as margins tighten.
- If oil stays at $45/barrel, and government support remains constant or higher, downstream product development within the public and private sector will progress.
- If oil moves to levels of $105/barrel, private research and development and capital investment expands significantly.
- With oil prices near $105/barrel, corn acreage increases swiftly to meet the demand for greater supplies of ethanol production

Intermediate-run

- With oil at $25/barrel and medium government support, the ethanol industry rate of growth slows and reaches approximately 8 billion gallons annually.
- At $45/barrel and medium government support, there becomes the potential for a permanent shift towards corn production at the expense of soybeans.
- At $45/barrel and high government support, new breakthroughs in biomass conversion technology start occurring.
- At $105/barrel and low government support, the agriculture sector experiences significant revenue impacts as the ethanol and biodiesel industries move into high gear, thus increasing the demand for corn and soybean oil for feedstock.

B. Additional Impact Discussion

- Perhaps one of the more challenging and interesting questions that the agricultural sector faces is as follows, what is the ability of the sector to supply the necessary volume of feedstocks to meet the potential growth in such biomass activities as ethanol production? In Figure 56 and Figure 57, two different "what-if" scenarios are presented to show how the growth of the ethanol industry might radically impact the demand for corn, causing shockwaves throughout the agricultural economy. A summary of the three different scenarios is described as follows:
    - Approximately 15% of the US corn crop will be utilized to make ethanol in 2006. Given a potential growth trajectory of the ethanol industry in which production reaches 12 billion gallons in 2015 and 16 billion gallons in 2025, and attaining a 15% utilization level (and all other variables held constant), the US corn crop would have to be almost 30 billion bushels in 2015 and 39 billion bushels in 2025 as depicted in Figure 56.
    - Another scenario would include the long-run trend for US corn production (in anticipation that more corn will be produced as yields expand) and ask how much of the corn crop would be required to meet the 12 billion gallon and 16 billion gallon ethanol target? In 2015, and estimated 37.6% of the crop would be required to produce 12 billion gallons of ethanol and in 2025, 44.4% of the corn crop would be required to produce 16 billion gallons of ethanol.
    - Both of these scenarios are at the extreme of the continuum, however, they portray the likelihood that significant structural changes in the US agricultural community could occur if ethanol production continues to grow rapidly and there are no major breakthroughs in conversion technologies (especially cellulose to ethanol conversion).
    - A more plausible scenario regarding the future balance of ethanol growth and the need for more corn is offered in Figure 58, Table 61,

Table 62 and Table 63. In this scenario, the need for more corn is supplemented by an industry supply response where corn acreage is increased at the expense of soybean acreage and wheat acreage and corn yields expand from current levels. US planted corn acres in 2005 equaled 81.8 million acres; this is expected to climb to 92.5 million acres in 2015, a growth of 13.1%. Corn yield are forecasted to increase to a level of 172.4 bushel per an acre, up approximately 16.6% from current levels.

Table 59: Short-run (1-3 Years) and the Impact of Oil Prices and Government Support on Biomass and the Agricultural Sector (Dollar Impact, Annual Revenues Agriculture, Not Counting Manufacturing Revenues)

	Petroleum at $25/Barrel	Petroleum at $45/Barrel	Petroleum at $105/Barrel
Low Government Support & Incentives (below current level)	• Revenue negatively impacted • The ethanol industry begins to feel margin pressure • The biodiesel industry slows to a drip • Good price risk managers will benefit • Ethanol industry will consolidate rapidly, low cost producer survives	• Modest (-) revenue impact ($0-2 bil.) • Ethanol production grows but at a modest rate • Ethanol industry consolidates at a deliberate pace • Biodiesel economics are questionable	• Modest (+) revenue impact ($4-6 bil.) • Biodiesel industry grows much slower relative to the ethanol industry • Corn acreage expands • Distribution of ethanol/biodiesel will be critical
Medium Government Support & Incentives (current level)	• Minimal revenue impact • The ethanol industry will consolidate • Large scale firms will develop downstream products	• Modest revenue impact ($2-4 bil.) • Move towards more US corn acreage for ethanol: especially if corn yields lag • Reduction in soybean acreage • Strong returns to ethanol producers • Biodiesel interest perks up	• Modest (+) revenue impact ($4-6 bil.) • Biodiesel industry sees a large inflow of private capital • Corn acreage expands rapidly • Distribution of ethanol/biodiesel will be critical
High Government Support & Incentives (above current level)	• Minimal revenue impact • The low cost ethanol producers remain profitable • The seeds are planted for future technological breakthroughs in biomass	• Modest revenue ($2-4 bil.) • Development of downstream products will accelerate • Biodiesel grows rapidly • The seeds are planted for future technological breakthroughs in biomass private sector willing to take risks	• Modest (++) revenue impact ($5-7 bil.) • Biodiesel industry sees a massive inflow of private capital • Corn acreage expands very rapidly • Significant research and development push by private sector

Table 60: Intermediate-run (2015) and the Impact of Oil Prices and Government Support on Biomass and the Agricultural Sector (Dollar Impact, Annual Revenues Agriculture, Not Counting Manufacturing Revenues)

	Petroleum at $25/Barrel	**Petroleum at $45/Barrel**	**Petroleum at $105/Barrel**
<u>Low</u> Government Support & Incentives (below current level)	• Negative revenue impact • Private sector biomass investments dry up • Ethanol industry consolidates rapidly – margins squeezed • High cost ethanol plants exit industry	• Modest (+) revenue impact ($4-6 bil.) • Ethanol industry becomes more concentrated • Industry is driven purely by petroleum/fuel prices/economics • Chemical companies pursue niche biobased products	• Significant (+) revenue impact ($7-10 bil.) • Fuel driven industry • Ethanol industry maintains rapid growth • Biodiesel becomes more prominent • Private research and development accelerates dramatically in biobased products
<u>Medium</u> Government Support & Incentives (current level)	• Negative revenue impact • Private sector biomass investments dry up • Ethanol industry consolidates • An 8 bill. gal. ethanol industry	• Significant revenue impact ($5-7 bil.) • Potential for long-run shift in US corn production away from soybean production • Industry is fuel driven with modest downstream product development • A 12 bill. gal. ethanol industry • Chemical companies pursue niche biobased products	• Major revenue impact ($10-15 bil.) • Exceptional returns to ethanol producers • Fuel driven industry with rapid breakthroughs in biomass technology (e.g., cellulose to ethanol) • Private research and development accelerates dramatically • Fuel driven industry with rapid breakthroughs in biomass technology (e.g., cellulose to ethanol) • An 18 bill. gal. Ethanol industry
<u>High</u> Government Support & Incentives (above current level)	• Modest (+) revenue impact ($4-6 bil.) • Biomass investments are negligible from the private sector • Technology breakthroughs in biomass are slowed down	• Significant (+) revenue impact ($7-10 bil.) • US exports of soybeans slow in order to meet biodiesel demand • Industry is fuel driven with rapid downstream product development and new breakthroughs in conversion technologies • Chemical companies pursue niche biobased products	• Remarkable revenue impact ($12-20 bil.) • Fuel driven • The potential for US to import soybeans/soybean oil from Brazil • Private research and development accelerates dramatically industry with rapid breakthroughs in biomass technology (e.g., cellulose to ethanol)

Figure 56: Total Corn Crop Required for 12 and 16 Billion Gallons of Ethanol Produced Maintaining a 15% Utilization Level

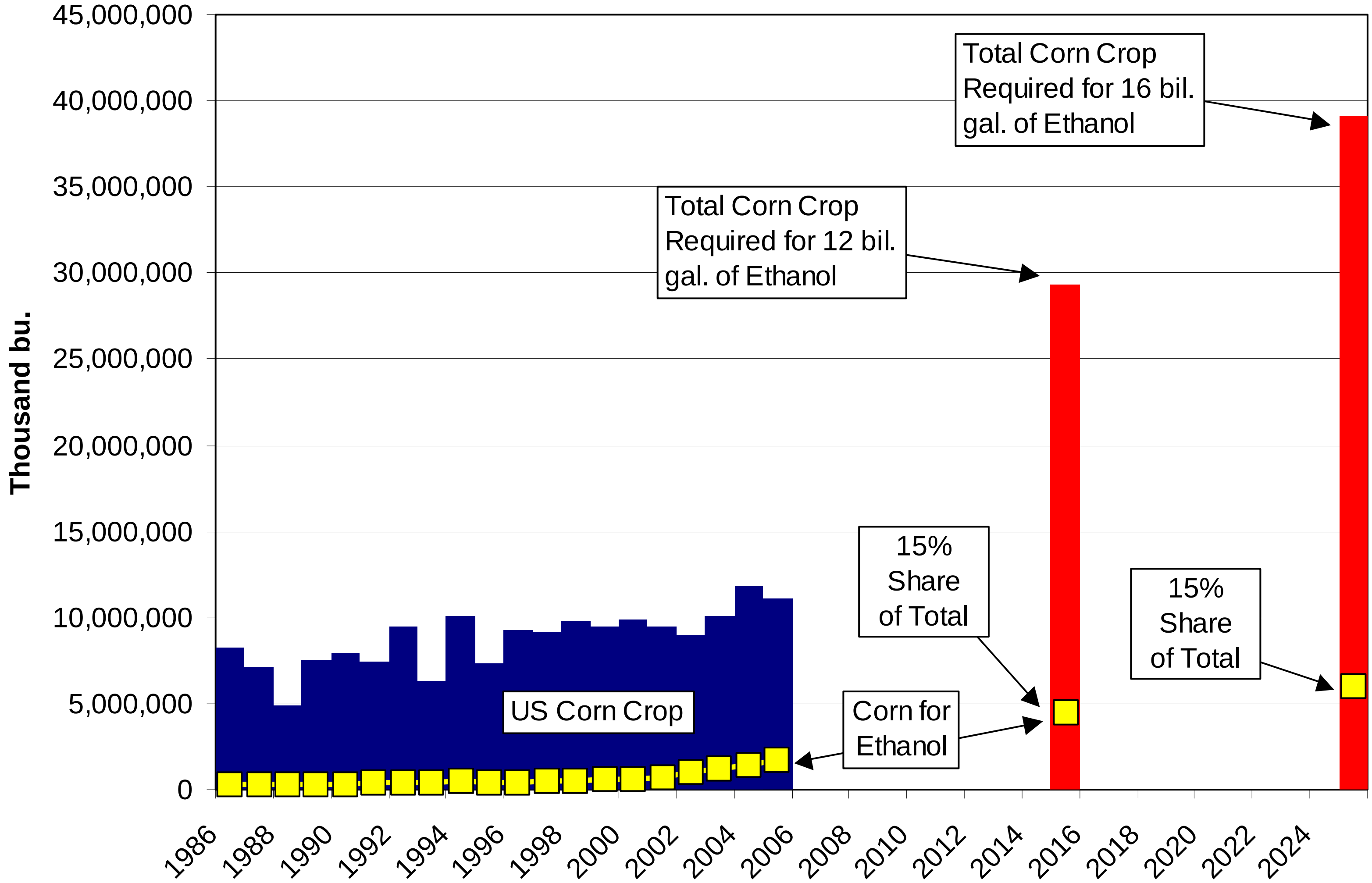


Figure 57: US Corn Requirements for 12 and 16 Billion Gallons of Ethanol Production and the Percent Share of the Total Crop used for Ethanol

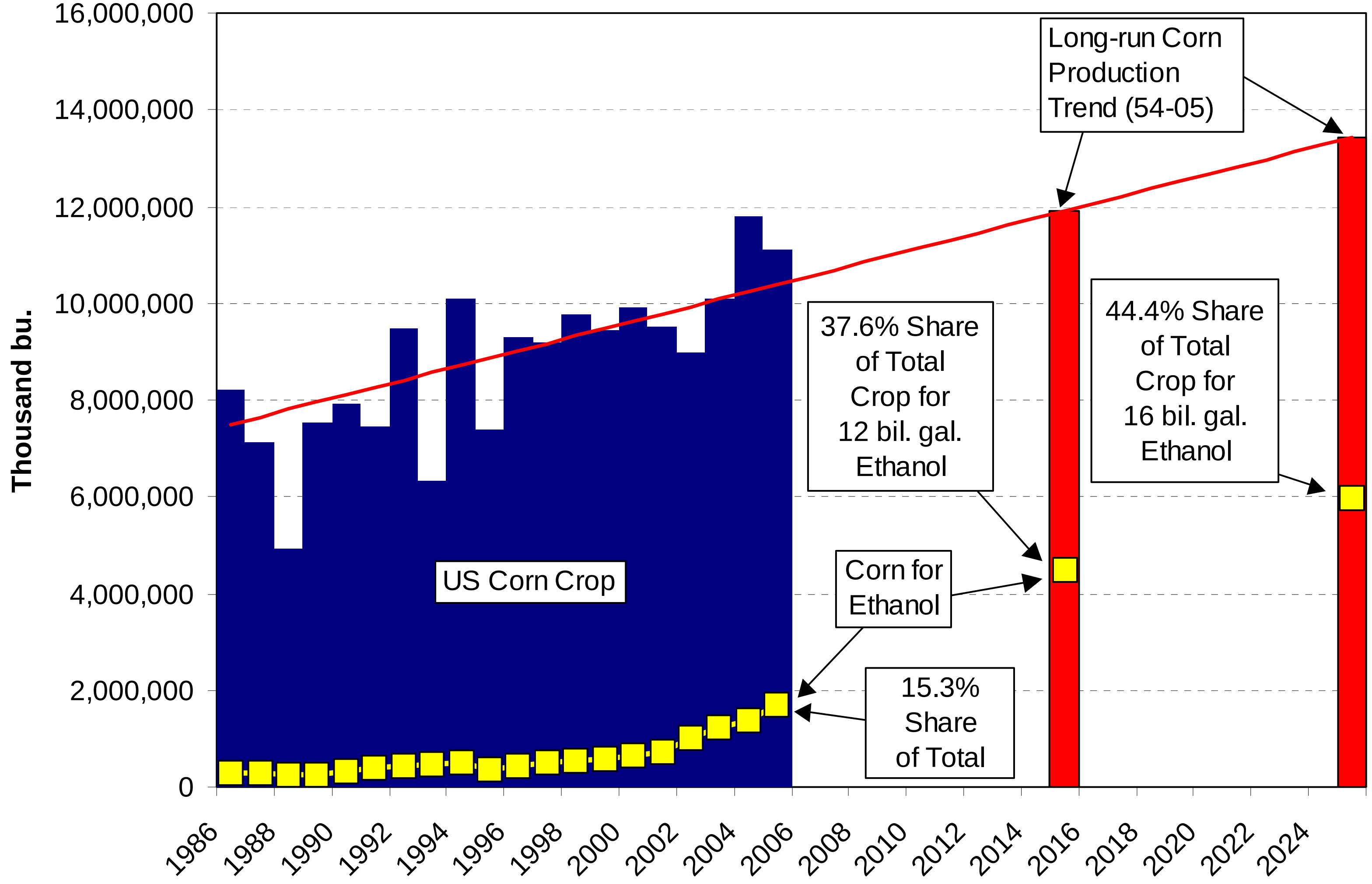
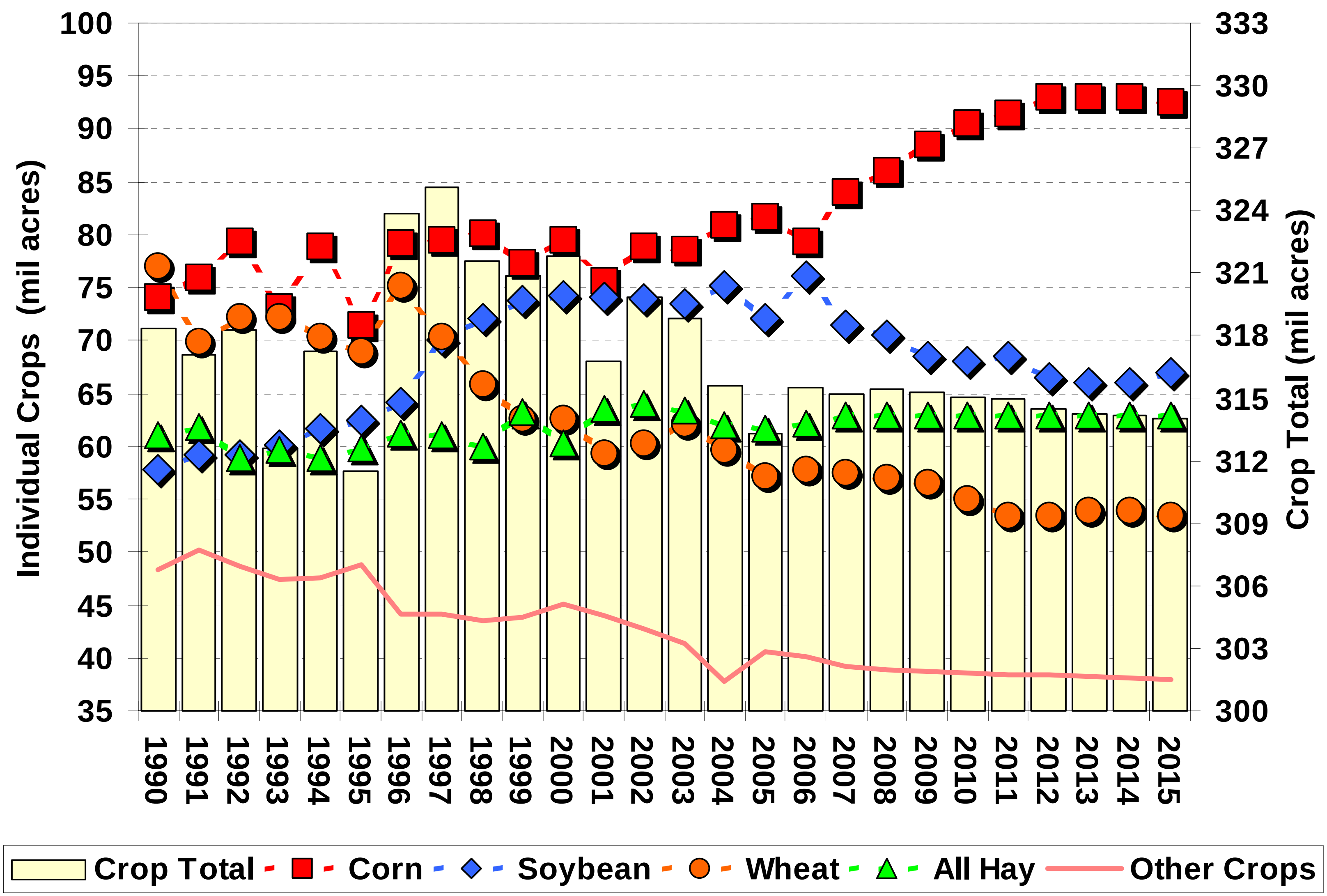


Figure 58: US Crop Area Summary to 2015



Source: Informa

Table 61: US Corn Fundamentals to 2015

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Planted Area (mil. acres)	75.7	78.9	78.6	80.9	81.8	79.4	84.0	86.0	88.5	90.5	91.5	93.0	93.0	93.0	92.5
Harvested Area	68.8	69.3	70.9	73.6	75.1	72.4	77.0	79.0	81.5	83.5	84.5	86.0	86.0	86.0	85.5
Harvested Yield (bu/acre)	138.2	129.3	142.2	160.4	147.9	150.8	153.0	155.3	157.6	160.0	162.4	164.8	167.3	169.8	172.4
Beginning Stocks (mil. bu)	1,899	1,596	1,087	958	2,114	2,296	1,635	1,510	1,435	1,485	1,605	1,630	1,665	1,720	1,760
Production	9,503	8,967	10,089	11,807	11,112	10,919	11,780	12,270	12,850	13,360	13,720	14,170	14,390	14,600	14,740
Imports	10	14	14	11	10	10	10	10	10	10	10	10	10	10	10
Total Supply	11,412	10,578	11,189	12,776	13,236	13,225	13,425	13,790	14,295	14,855	15,335	15,810	16,065	16,330	16,510
Feed Use/Residual	5,864	5,563	5,795	6,160	6,075	6,100	6,040	5,960	5,880	5,800	5,720	5,640	5,670	5,700	5,730
Food/Seed/Ind	2,046	2,340	2,537	2,688	2,980	3,490	3,950	4,460	4,970	5,480	5,990	6,500	6,660	6,830	7,000
(of which Fuel Alcohol)	706	995	1,167	1,323	1,600	2,100	2,550	3,050	3,550	4,050	4,550	5,050	5,200	5,360	5,520
Total Domestic Disappearance	7,911	7,903	8,332	8,848	9,055	9,590	9,990	10,420	10,850	11,280	11,710	12,140	12,330	12,530	12,730
Exports	1,905	1,588	1,900	1,814	1,885	2,000	1,925	1,935	1,960	1,970	1,995	2,005	2,015	2,040	2,060
Total Disappearance	9,816	9,491	10,232	10,662	10,940	11,590	11,915	12,355	12,810	13,250	13,705	14,145	14,345	14,570	14,790
Ending Stocks	1,596	1,087	958	2,114	2,296	1,635	1,510	1,435	1,485	1,605	1,630	1,665	1,720	1,760	1,720
ES: Use Ratio	16%	11%	9%	20%	21%	14%	13%	12%	12%	12%	12%	12%	12%	12%	12%
Farm Price (per bu)	$1.97	$2.32	$2.42	$2.06	$1.95	$2.20	$2.31	$2.40	$2.40	$2.36	$2.38	$2.39	$2.37	$2.36	$2.40
Loan Level	$1.89	$1.98	$1.98	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95	$1.95
VC for Production ($/ac)	162.06	143.77	159.67	172.67	191.08	200.50	203.53	205.90	208.24	210.59	212.91	215.09	217.23	219.31	221.41
Market Revenue (bil $)	18.68	20.85	24.42	24.35	21.72	24.03	27.23	29.45	30.86	31.50	32.61	33.82	34.08	34.47	35.36
Transition/Direct & Cyclical Pmts.	4.05	1.99	1.99	4.48	5.41	3.28	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
Other: LDP/MLG	1.18	0.02	0.08	2.93	2.44	0.02	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Govt Program Payments	5.23	2.01	2.07	7.41	7.85	3.30	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
Production Exp. (bil $)	12.27	11.34	12.55	13.97	15.62	15.92	17.10	17.71	18.43	19.06	19.48	20.00	20.20	20.40	20.48
Net Revenue (bil $) 1/	7.60	9.52	11.95	13.31	8.54	8.13	10.13	11.74	12.43	12.45	13.12	13.82	13.88	14.07	14.88
Non Participant Net	110.49	137.30	168.45	180.75	113.72	112.32	131.56	148.60	152.55	149.06	155.32	160.67	161.39	163.65	173.99

Shaded area represents Informa forecast. Feb 20, 2006

1/ Includes only that revenue associated with actual production. Direct, Counter Cyclical and similarly determined revenue is not included.

Table 62: US Soybean Fundamentals to 2015

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
SOYBEANS															
Planted Area (mil. acres)	74.1	74.0	73.4	75.2	72.1	76.1	71.5	70.5	68.5	68.0	68.5	66.5	66.0	66.0	67.0
Harvested Area	73.0	72.5	72.5	74.0	71.4	75.2	70.5	69.5	67.5	67.0	67.5	65.5	65.0	65.0	66.0
Harvested Yield (bu/acre)	39.6	38.0	33.9	42.2	43.3	41.9	42.4	42.9	43.4	43.9	44.4	44.9	45.4	45.9	46.4
Beginning Stocks (mil bu)	248	208	178	112	256	637	814	624	465	348	280	285	238	230	240
Production	2,891	2,756	2,454	3,124	3,086	3,148	2,990	2,980	2,930	2,940	3,000	2,940	2,950	2,980	3,060
Imports	2	4	6	6	3	5	4	4	4	4	4	4	4	4	4
Total Supply	3,141	2,969	2,638	3,242	3,345	3,790	3,808	3,608	3,399	3,292	3,284	3,229	3,192	3,214	3,304
Crush	1,700	1,615	1,530	1,696	1,695	1,725	1,790	1,800	1,810	1,820	1,830	1,850	1,870	1,880	1,900
Food/Seed/Residual	169	132	109	187	163	151	144	143	141	141	144	141	142	143	147
Total Domestic Disappearance	1,869	1,747	1,639	1,883	1,858	1,876	1,934	1,943	1,951	1,961	1,974	1,991	2,012	2,023	2,047
Exports	1,064	1,044	887	1,103	850	1,100	1,250	1,200	1,100	1,050	1,025	1,000	950	950	975
Total Disappearance	2,933	2,791	2,526	2,986	2,708	2,976	3,184	3,143	3,051	3,011	2,999	2,991	2,962	2,973	3,022
Ending Stocks	208	178	112	256	637	814	624	465	348	280	285	238	230	240	282
ES: Use Ratio	7%	6%	4%	9%	24%	27%	20%	15%	11%	9%	10%	8%	8%	8%	9%
Farm Price (per bu)	$4.38	$5.53	$7.34	$5.74	$5.40	$4.30	$4.70	$4.84	$5.15	$5.50	$5.44	$5.67	$5.70	$5.70	$5.51
Loan Level	$5.26	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
HI-PRO Meal, Decatur (per ton)	$168	$182	$256	$183	$168	$151	$162	$164	$174	$182	$180	$186	$188	$188	$182
Crude Oil, Decatur (per lb)	$0.165	$0.221	$0.300	$0.230	$0.194	$0.160	$0.185	$0.195	$0.210	$0.225	$0.220	$0.230	$0.230	$0.230	$0.225
Crush Margin vs Farm (per bu)	$1.12	$0.89	$1.58	$0.82	$0.43	$0.78	$0.90	$0.90	$0.95	$0.95	$0.95	$0.95	$0.95	$0.95	$0.95
SBO Pct of Product Value	32.9%	37.8%	36.9%	38.6%	36.6%	34.6%	36.5%	37.0%	37.5%	38.0%	38.0%	38.0%	38.0%	38.0%	38.0%
VC For Production ($/ac)	82.72	75.34	79.56	83.17	89.75	93.34	94.50	95.20	95.91	96.64	97.37	98.05	98.74	99.39	100.06
Market Revenue (bil $)	12.68	15.25	18.02	17.92	16.67	13.54	14.05	14.42	15.10	16.17	16.31	16.67	16.81	16.98	16.86
Direct & Cyclical Pmts.	0.38	0.82	0.82	0.82	0.82	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
LDP/MLG	3.44	0.02	0.00	0.30	- - -	3.04	1.67	1.26	0.43	- - -	- - -	- - -	- - -	- - -	- - -
Production Exp.	6.13	5.57	5.84	6.26	6.47	7.10	6.76	6.71	6.57	6.57	6.67	6.52	6.52	6.56	6.70
Net Revenue 1/	9.99	9.70	12.18	11.97	10.19	9.47	8.96	8.97	8.96	9.60	9.64	10.15	10.29	10.42	10.16
Net ($/acre)	136.87	133.76	168.11	161.80	142.82	125.97	127.13	129.11	132.74	143.31	142.83	154.93	158.31	160.32	153.95

Shaded area represents Informa forecast. Feb 20, 2006

1/ Includes only that revenue associated with actual production. Government Direct, Counter Cyclical and similarly determined revenue is not included.

Table 63: US Planted Acreage to 2015 (thousand acres)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Corn, All	75,702	78,894	78,603	80,930	81,759	79,416	84,000	86,000	88,500	90,500	91,500	93,000	93,000	93,000	92,500
Sorghum, All	10,248	9,589	9,420	7,486	6,454	6,628	6,800	7,000	7,200	7,350	7,450	7,550	7,550	7,550	7,500
Barley	4,951	5,008	5,348	4,527	3,875	3,877	3,800	3,750	3,750	3,700	3,700	3,650	3,650	3,600	3,600
Oats	4,401	4,995	4,597	4,085	4,246	4,336	4,290	4,240	4,190	4,140	4,090	4,040	3,990	3,940	3,890
All Wheat	59,432	60,318	62,141	59,674	57,229	57,741	57,500	57,000	56,500	55,000	53,500	53,500	54,000	54,000	53,500
Winter Wheat	40,943	41,766	45,384	43,350	40,433	41,367									
Other Spring Wheat	15,579	15,639	13,842	13,763	14,036	13,874									
Durum Wheat	2,910	2,913	2,915	2,561	2,760	2,500									
Rye	1,328	1,355	1,348	1,380	1,433	1,350	1,340	1,330	1,320	1,310	1,300	1,290	1,280	1,270	1,260
Rice	3,334	3,240	3,022	3,347	3,384	3,145	3,250	3,200	3,100	3,100	3,100	3,100	3,150	3,200	3,200
Soybeans	74,075	73,963	73,404	75,208	72,142	76,102	71,500	70,500	68,500	68,000	68,500	66,500	66,000	66,000	67,000
Peanuts	1,541	1,353	1,344	1,430	1,657	1,775	1,760	1,745	1,730	1,715	1,700	1,685	1,670	1,655	1,640
Sunflowers	2,633	2,581	2,344	1,873	2,709	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960
Rapeseed/Canola	1,494	1,460	1,082	865	1,159	1,110	1,130	1,150	1,170	1,190	1,210	1,230	1,250	1,270	1,290
Flaxseed	585	784	595	523	983	935	700	700	700	700	700	700	700	700	700
Cotton, All	15,769	13,958	13,480	13,659	14,195	14,466	13,750	13,450	13,250	13,050	12,950	12,950	12,750	12,750	12,750
Cotton, Upland	15,499	13,714	13,301	13,409	13,925	14,145	13,500	13,200	13,000	12,800	12,700	12,700	12,500	12,500	12,500
Cotton, Am-Pima	270	244	179	250	270	321	250	250	250	250	250	250	250	250	250
Hay, All	63,516	63,942	63,383	61,966	61,649	62,150	63,000	63,000	63,000	63,000	63,000	63,000	63,000	63,000	63,000
Beans, Dry Edible	1,437	1,930	1,406	1,354	1,659	1,561	1,475	1,475	1,475	1,475	1,475	1,475	1,475	1,475	1,475
Tobacco	432	428	411	408	298	276	266	256	246	236	226	216	206	196	186
Sugar Beets	1,365	1,427	1,365	1,346	1,295	1,302	1,287	1,272	1,257	1,242	1,227	1,212	1,197	1,182	1,167
Double-Counted Acres:															
Soybeans Double-Cropped	4,102	4,179	4,138	4,481	2,833	3,629	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600	3,600
Spring Reseeding	1,400	1,200	300	0	0	0	0	0	0	0	0	0	0	0	0
Crop Total	316,742	319,847	318,855	315,580	313,294	315,501	315,209	315,429	315,249	315,069	314,989	314,459	314,229	314,149	314,019
Government Acres:															
Conservation Reserve	33,560	33,890	34,087	34,860	35,561	35,676	33,926	32,176	32,176	32,176	32,176	32,176	32,176	32,176	32,176
Total Government	33,560	33,890	34,087	34,860	35,561	35,676	33,926	32,176	32,176	32,176	32,176	32,176	32,176	32,176	32,176
Grand Total	350,302	353,737	352,942	350,440	348,854	351,177	349,134	347,604	347,424	347,244	347,164	346,634	346,404	346,324	346,194

Shaded area represents Informa forecast.

Feb 20, 2006

IX. Appendix

A. Additional Corporate Case Studies

Starbucks
In 2004, Starbucks set out to understand more about the risks associated with climate change and to evaluate its contribution to global warming. This effort dovetailed with earlier work the Company had done to assess its environmental footprint. Starbucks initial climate inventory was limited to the major areas of retail, coffee roasting, administrative operations and its distribution network. Using the Greenhouse Gas (GHG) Protocol, Starbucks calculated its total GHG emissions in 2003 to be 254,000 metric tons of carbon dioxide (CO_2) equivalents. Starbucks believes it is the Company's environmental responsibility to continue to find new and innovative ways to reduce these emissions. In an effort to achieve this, Starbucks established an emissions reduction target and detailed appropriate metrics to measure ongoing performance in 2005. As a result of the Company's initial inventory, Starbucks also joined the Green Power Partnership and committed to purchase enough green power to cover 5 percent of their retail energy needs in North America, cutting CO_2 emissions by 2 percent. Expanding on the success of its commitment in 2005, Starbucks has increased its green power commitment to 20 percent in 2006. The findings of Starbucks environmental footprint assessment, as well as the measures the Company is taking to address climate change, are outlined in Starbucks fiscal 2004 Corporate Social Responsibility Annual Report.

Safeway Inc.
Safeway Inc. is a Fortune 50 company and one of the largest food and drug retailers in North America. The company operates 1,776 stores in the United States and Canada under the banners of Safeway, Vons, Pavilions, Dominick's, Carrs, Randalls, Tom Thumb, Pak 'n Save, and Genuardi's. In 2005 Safeway committed to purchase enough renewable energy to power 100 percent of its retail gasoline stations in the US, as well as 15 California supermarkets and 3 supermarkets in Colorado. The company's green power purchase is part of its overall goal of using efficient and environmentally friendly methods of business operation. Safeway is also proud to communicate the importance of renewable energy investment and energy independence to customers and communities. "Protecting the environment and conserving our nation's valuable energy resources is something that Safeway and our customers care deeply about," said Executive Vice President Larree Renda. "By powering our fuel stations, stores and corporate offices with wind energy, we are taking a leadership role in using cleaner sources of electricity."

HSBC Bank North America
HSBC Bank North America joined the Green Power Partnership in 2005, committing to purchase enough renewable energy certificates (RECs) to cover 23 percent of its annual electricity consumption. HSBC has pledged to be "carbon neutral" by 2006. HSBC North America's green power purchase will help the bank achieve this unprecedented environmental goal.

Advanced Micro Devices, Inc.
Advanced Micro Devices, Inc. (AMD) recognizes the potential environmental impacts of global climate change and the need to take precautionary action to protect the global environment. AMD set a goal to reduce carbon emissions from its manufacturing operations by 15 percent by 2005. Shortly after its first purchase of renewable energy in 2000, natural gas prices soared and became even more costly than the fixed green power premium. By 2001, AMD saved approximately $100,000 from its green power procurement and, in response, doubled the company's purchase for the following year. AMD is currently purchasing over 24 million of clean, renewable energy each year, 90 percent of which comes from a Texas wind farm.

WhiteWave Foods
In 2005, WhiteWave Foods more than doubled its purchase of renewable energy certificates to offset the energy use of Horizon Organic dairies, a recent addition to the WhiteWave Foods family of brands. For 2005, the purchase is equal to 49,500 MWH, placing WhiteWave Foods on the EPA Green Power Partnership's Top 25 Partners list, and making it one of the largest 100 percent green powered companies in the US. WhiteWave Foods, through its Silk Soymilk and Horizon Organic brands, continues to take an active role in promoting the use of wind energy to its millions of customers, partners and suppliers. In 2005, the company featured Wind Energy in its exhibit at the Smithsonian's Folk Life Festival in Washington DC. The company has promoted green power on over 300 million cartons of Silk Soymilk as well as on 20 million lids of Silk Cultured Soy yogurt urging consumers to "Power your home with wind." The company has executed a full range of communications tactics to promote wind power and its green power purchasing, including unique customer incentives and promotions, wind-powered events, promoting wind power during Silk and Horizon Organic media efforts, and partnering with suppliers and distributors to further distribute information about wind power. With its access to the consumer market through the dairy sections of the nation's grocery stores, WhiteWave Foods brings the message of wind energy into homes across the US.

Staples
Staples' original commitment to purchase 2 percent of their total energy load or 9,494 MWH green power was an ambitious goal. With dedication, Staples exceeded expectations and uses 48,283 MWH, which includes the largest renewable energy certificate deal in the United States. As the company continues to grow, it is committed to make sure that 10 percent of its energy will come from green power sources. With stores all over the United States, Staples buys landfill gas, biomass, solar, and wind power from five providers that supply Staples with green power through delivered energy products as well as renewable energy certificates. Two of Staple's distribution centers in California are in the process of being powered by on site solar photovoltaic installations. These innovative installations will be based on their supplier's solar hosting model, whereby Staples purchases solar services at a fixed price schedule, but they are not required to provide the capital costs up front for the solar system. Staples is a leader in its communication efforts related to their

green power purchasing, including educating customers and the general public through their website, with in-store signage and through press releases.

Mohawk Paper Mills

Mohawk Paper Mills, located near Albany, New York, manufactures fine printing papers. Mohawk has a longstanding tradition of striving for environmental excellence in all aspects of its business. Its use of wind power for 21 percent of its electric energy requirements is a highly visible way to demonstrate this commitment to environmental stewardship. Customers are responding favorably to the commitment and have asked questions about the potential of wind power.

The Tower Companies

Founded in 1947 and headquartered in North Bethesda, Maryland, The Tower Companies is a family-owned real estate firm committed to socially responsible development. In March 2003, The Tower Companies made a commitment to acquire renewable energy resources equivalent to approximately 40 percent of their annual electricity consumption. Part of The Tower Companies' corporate mission is to lead by example in all areas that facilitate sustainable development of the built environment, and purchasing green power is consistent with that mission. The Tower Companies' principles and employees feel that their job has more meaning as a result of the company's environmental commitment. This positive association encourages not only pride in their company, but also inspires them to lead by example in their personal lives, taking the message of sustainability to a much broader audience. Jeffrey S. Abramson, Partner, The Tower Companies, states, "As the largest builder of healthy buildings in the Washington, DC area, we hope to see others promptly participate in programs such as this--programs which will eventually shepherd America in energy self-sufficiency and better health."

FedEx Kinko’s, Inc.

FedEx Kinko’s, Inc., was a 2002 Green Power Partner of the Year and has been a 2001 and 2003 Green Power Leadership Award winner. FedEx Kinko's is reducing its environmental footprint through efforts that include buying renewable energy, reducing energy use, offering recycled and alternative papers, and minimizing waste. FedEx Kinko's, Inc. purchases renewable energy at more than 400 branches in 18 states, for an estimated 40 million per year. FedEx Kinko's, Inc. is procuring its power from a wide variety of sources, including wind, geothermal, landfill gas, solar, and small hydro.

Hyatt Regency / Reunion & DFW Airport Hotels

Hyatt Regency / Reunion & DFW Airport Hotels is a localized effort to cut greenhouse gasses.

H-E-B Grocery Company

With stores and warehouse facilities located in more than 150 communities throughout Texas and Mexico, H-E-B Grocery Company fully embraces opportunities to achieve a healthy environment. In November 2005 H-E-B joined the

Green Power Partnership and agreed to purchase renewable energy to cover approximately 26 percent of the electricity used by its operations in the Austin, TX region. For 100 years, H-E-B has been an innovative retailer. Known for its fresh food, quality products, and convenient services, HEB strives to provide the best customer experience at the lowest prices. The company's commitment to superior environmental awareness continues as further green power opportunities are explored throughout the regions in which H-E-B operates.

Liz Claiborne Inc.

Liz Claiborne Inc. designs and markets fashion apparel and accessories for women, men, teens, children and infants, via a portfolio of more than 40 brands available at more than 30,000 points of sale worldwide. The Company has committed to offset 100 percent, or approximately 25,000 megawatt-hours, of the electrical consumption for its New Jersey headquarters campus through the purchase of equivalent Green-e certified tradable renewable energy certificates (RECs). Liz Claiborne's green power purchase demonstrates the company's commitment to sustainability and is consistent with its socially conscious environmental and business practices. By purchasing these RECs, Liz Claiborne Inc. is investing in the future of wind power, helping construct new wind farms and bolstering existing farms to create a wider base for future wind power production. The Company was introduced to the Green Power Partnership through its acquisition of prAna, a designer, marketer and wholesaler of climbing, yoga and outdoor/active lifestyle apparel and accessories and a leader in the natural power movement. PrAna launched its Natural Power Initiative in the Fall of 2005, offsetting the power of 250 of its retailers, 100 percent of its headquarters and all of the homes of its full-time employees.

Lowe's Home Centers in NC, NM, SC, TN, TX

Founded in 1946, Lowe's is a $36.5 billion FORTUNE® 50 home improvement retailer serving 11 million customers a week at over 1,200 stores in 49 states. Lowe's is committed to the purchase of nearly 8 million annually of green power from electric utilities in seven states and generates approximately 3 million kilowatts of green power annually from solar photovoltaic systems at four stores in California. While more expensive, utilizing energy efficient equipment paired with efficient facilities management in stores to help mitigate the additional renewable energy costs. Green power purchasing dovetails well with the ENERGY STAR awards Lowe's received four years in a row, from 2003-2006. "Lowe's is proud to be an industry leader in the use of renewable energy," said Robin Nickles, Vice President of Retail Facilities Management. "Our commitment to green power reflects Lowe's core value of operating as a responsible corporate citizen."

823 Congress

823 Congress is a 15-story, 181,381 square foot office building in downtown Austin, Texas. Introduced to green power by a valued tenant, Texas Wind Power, 823 Congress now purchases green power from its local utility's green pricing program for 100 percent of its power needs. Going green has substantially reduced the building's utility costs in comparison to the costs of fossil fuel produced electricity.

Don Tait, Senior Vice President of Property Management for 823 Congress, states, "Being on green power has helped us keep expenses down in a very difficult commercial real estate market. Our tenants appreciate our effort on their behalf. The green power advantage keeps us very competitive in our market. We are pleased to have this advantage."

Academy of Oriental Medicine
One of the guiding principles of the Academy of Oriental Medicine at Austin, Texas, is that learning to heal should take place in a healthy environment. The Academy work's towards that goal by purchasing all of its power through Austin Energy's GreenChoice Program. Efficient energy management, energy conservation, and recycling are other steps the school takes to reduce its environmental impact. Stuart Bailey, the Academy's facilities manager, describes the Academy's commitment to green power, "As a school, our mission is to teach practitioners to help, heal, and transform the lives of their patients. Using renewable energy helps us carry out that mission, making us better stewards of the environment and better able to promote health and healing."

Affiliated Engineers, Inc.
Affiliated Engineers, Inc. (AEI) specializes in the design of mechanical, electrical, piping, and information technology systems. AEI purchases 10 percent of its electrical energy from a local wind farm owned and operated by its local utility. As part of building a new corporate headquarters in Madison, Wisconsin, AEI carefully considered many factors of its corporate ecological footprint. During this process, AEI made a decision to pursue Leadership in Environmental Design (LEED) certification for its new construction project, using the renewable energy purchase as a component of LEED qualification. Although the wind power is purchased at a cost premium to standard electricity, AEI views this purchase as a key facet of its efforts in the realm of sustainable design and corporate social responsibility.

Agilent Technologies
Agilent Technologies delivers critical tools and technologies that sense, measure, and interpret the physical and biological world. These innovative solutions enable a wide range of customers in communications, electronics, life sciences, and chemical analysis to make technological advancements that drive productivity and improve the way people live and work. Agilent is committed to conducting its business in an ethical, socially responsible, and environmentally sustainable manner. To that end, Agilent Technologies has chosen to purchase enough green power to cover approximately 8 percent of the annual electricity needs for its Santa Clara location and Palo Alto Headquarters.

Alterra Coffee Roasters
Alterra Coffee Roasters buys 100 percent green power for all of its retail locations in Milwaukee, Wisconsin. Alterra's efforts in expanding awareness for green power are extensive. They include "java jackets" that promote wind power, presentations at a variety of Milwaukee events, press releases, and newsletters. Close collaboration

with its green power supplier includes an in-store display at Alterra's Milwaukee lakefront location, storefront promotions to enroll customers in the "Energy for Tomorrow" program, Alterra gift certificates for new enrollees, storefront banners, and a plan for a 6-foot wind turbine display model.

Ashforth Pacific, Inc.

Ashforth Pacific, Inc., is an owner and manager of commercial real estate focused on office markets along the West Coast. Ashforth Pacific purchases green power from its local utility to cover 5 percent of the power supplied to the company's portfolio of properties in Portland, Oregon.

Aspen Skiing Company

Aspen Skiing Company operates four ski areas, 15 restaurants, a golf course, and the five-star Little Nell Hotel. Today, 2 percent of its energy is provided by wind power. The company, which is already a leading green ski area, plans to expand its purchase of green energy to 10 percent by 2010. Employees of the company report that they are often asked to explain how its ski lifts or restaurants are powered by wind. The lesson for others: educate your staff that your green power purchase is important and invest in signs or brochures that educate visitors about your green power purchase and how it works. "We tripled our wind power purchases last winter for three reasons: it was the right thing to do, it makes a statement about climate change, which is a threat to our industry, and it helps protect the natural resources we depend on for our business," said Pat O'Donnell, President/CEO.

Atlantic Golf at Queenstown Harbor, a division of The Brick Companies

Atlantic Golf at Queenstown Harbor, a division of The Brick Companies, is purchasing renewable energy certificates (RECs) for 100 percent of its power needs. In addition, the golf course is purchasing RECs to offset its diesel and propane fuel usage.

Aurum SustainAbility

Aurum SustainAbility is a consultancy specializing in catalyzing sustainable solutions to environmental, energy, investment, corporate responsibility, and other issues. Its mission is to help transition the economy and society to a more sustainable model that guarantees future generations will have the resources, vibrant economy, wealth, and standards of living that are enjoyed today. Aurum SustainAbility's purchase of 100 percent green power demonstrates its commitment to sustainable solutions.

Austin Studios

Austin Studios is a non-profit film production facility formed through a partnership between the City of Austin and the Austin Film Society. Since the studios began operating in 2000, more than 50 productions have been based at its facilities, including feature films, music videos, television commercials, and still photography shoots. Austin Studios is committed to using 100 percent green power as part of its overall commitment to preserve the environment. In addition to its commitment to green power, the studios have implemented an onsite recycling program, converted the lighting in all three of its office buildings to more energy-efficient fixtures, and donated its movie sets and construction materials to area schools, theaters, and community groups to keep them out of landfills. "As a community-based non-profit we find that our mission of supporting a sustainable film industry in Central Texas goes hand-in-hand with preserving the natural environment through the use of renewable energy sources. And it is a great marketing tool with all of the environmentally conscious film industry decision makers out in Los Angeles", says Suzanne Quinn, Studio Director.

Batdorf & Bronson Coffee Roasters

Batdorf & Bronson Coffee Roasters, a founding Green Power Partner, is a coffee company committed to quality and sustainability in both product and practice. The company keeps 30,000 pounds of refuse out of the landfill each year by giving coffee grounds and chaff to local farmers to compost, has a solar panel on the roof of its roastery that contributes battery power to the company's computers, and contributes an amount equal to its total yearly gas and electric bill (for all retail and roastery locations in Olympia, Washington, and Atlanta, Georgia) to the purchase of renewable energy certificates. Batdorf & Bronson is part of the Western Washington Green Power Campaign, a unique collaboration among diverse parties to raise renewable energy awareness and increase demand for green power throughout the state of Washington. The company was recognized for its work with the Western Washington Green Power Campaign at the 2004 Green Power Leadership Awards.

Bentley Prince Street, a subsidiary of Interface, Inc.

Bentley Prince Street, a subsidiary of Interface, Inc., has committed to purchase 30,500 MWh of renewable energy certificates over a 6-year period. By combining this purchase with its onsite generation, a rooftop photovoltaic project, Bentley Prince Street uses 100 percent renewable electricity. Interface, Inc. received the 2004 Green Power Leadership Award, recognizing outstanding green power purchases by three of its subsidiaries: Bentley Prince Street, Interface Fabrics, and Interface Flooring Systems.

BMW Manufacturing

BMW Manufacturing used landfill gas to generate 25 percent of the power needed to operate its Spartanburg, South Carolina manufacturing facility. Landfill gas is piped from a landfill to the manufacturing facility to power its four gas turbines, which generate approximately 4.3 MW of electricity for the factory, and also supply hot water for cooling, heating, and hot water needs. BMW credits EPA's Landfill Methane Outreach Program for educating the company on the advantages of landfill gas in terms of environmental impact and lower energy costs.

Boise Consumer Co-op

Boise Consumer Co-op is a health specialty foods cooperative founded in 1973. The Boise Co-op purchases green power to cover a significant portion of its operations. Boise Consumer Co-op purchases green power through its utility's green pricing program.

Boulder Associates
Boulder Associates joined the Green Power Partnership in 2005 with a purchase of 100-percent wind power. Boulder Associates provides comprehensive planning, programming, architecture, interior design, and construction administration services to clients in the healthcare and senior living industries. The firm's commitment to green power is one example of how it sets an example of good environmental stewardship to its clients and community.

Cayuse Vineyards, LLC
Cayuse Vineyards, LLC, located in Washington's Walla Walla Valley, owns and manages five vineyards. The company shows its environmental commitment through the purchase of green power from the local utility.

CH2M Hill
CH2M Hill, an employee-owned consulting firm founded in Oregon, now has 12,000 employees and 120 offices worldwide. Its Pacific Northwest regional office now purchases 10 percent of its electricity from green sources and is involved in the design and development of wind power projects that provide the energy for the renewable energy certificates that the company purchases.

Choice Organic Teas
Choice Organic Teas has demonstrated its commitment to the environment by purchasing 100 percent wind energy for its Seattle, Washington facility. From its inception, Choice Organic Teas has focused on being socially and environmentally responsible by offering only organic tea and being the first tea crafter to bring Fair Trade Certified tea to the United States. Utilizing a renewable energy source was one more way that Choice Organic Teas could show its dedication to minimizing its environmental footprint.

Clif Bar Inc.
Clif Bar Inc., a 2003 Green Power Leadership Award winner, is a Berkeley, California-based producer of all-natural energy and nutrition foods. Clif Bar is purchasing renewable energy certificates to cover the energy used to power its offices, manufacturing operations, and business travel. As part of its commitment to sustainability from the field to the final product, Clif Bar reduces its ecological footprint by purchasing 2.2 million kWh of wind energy to offset its CO_2 emissions.

Climate Solutions
Climate Solutions is a nonprofit organization whose mission is to stop global warming at the earliest point possible by helping the Pacific Northwest and British Columbia become world leaders in practical and profitable solutions. Recognizing that solutions to global warming are energy solutions, the staff at Climate Solutions' Olympia and Seattle, Washington, offices strive to be as climate-neutral as possible. For several years, they have purchased renewable energy certificates to offset 100 percent of the carbon dioxide generated from both their Olympia and Seattle offices'

energy consumption. Climate Solutions also purchases renewable energy certificates to offset the carbon dioxide emissions generated as a result of their employees' air travel and work-related driving. The Olympia office also benefits from green power generated by a 750-watt solar photovoltaic system on its roof. Climate Solution's Co-Executive Director Paul Horton described the enormous rewards of Climate Solution's and other companies' and nonprofits' commitments to green power: "The transition from the wasteful use of fossil fuels to the super-efficient use of renewable resources presents extraordinary economic opportunities for agriculture, entrepreneurs, and communities that pioneer solutions. It also holds the promise of cleaner air, healthier ecosystems, more livable communities, and other quality-of-life benefits."

Columbia Vista Corporation
Columbia Vista Corporation, a lumber company based near Vancouver, Washington, is currently buying enough green power from its local utility to cover 15 percent of its annual electricity needs. The purchase is for the company's three Vancouver facilities.

Counter Production
Counter Production manufactures solid surfaces from recycled glass. These can be used for the same applications as granite or marble. Counter Productions joined the Green Power Partnership in 2003. The company's purchase of 100 percent green power is consistent with its objectives and demonstrates its dedication to sustainable business practices. "Our ability to use green power to fuel our operations makes the recycled glass products we make even more sustainable", says Chuck Teller, President. "The reused post consumer glass and the use of renewable resources are essential elements of our business. Our sustainable business practices are a benefit to our company, our customers and our community."

Debra Lynn Dadd Communications
Debra Lynn Dadd Communications joined the Green Power Partnership in 2004, committing to purchase renewable energy to fulfill 100 percent of its annual power needs. The company provides information to consumers through books, newsletters, websites and other communications to help them make better choices. "Green power is better for health and the environment in so many ways," says owner Debra Lynn Dadd. "Green energy certificates make it practical and affordable for small and home-based businesses to fulfill environmental objectives and encourage growth in renewable energy markets."

Domaine Carneros
Domaine Carneros built a new Pinot Noir winery in Napa, California that houses the largest rooftop photovoltaic system on any winery in the world with a peak capacity of 120 kW. It is expected to produce 381,500 kW annually, which is 40 percent of the facility's total electric load. The solar roof panels cover 9,400 square feet, reduce heating and air-conditioning costs due to their insulation and thermal reflection value, and protect the roof from thermal cycling and UV degradation for

their 25-year lifespan. Domaine Carneros officially marked the completion of the solar installation on June 21, 2003, "summer solstice," in conjunction with the opening of the new Domaine Carneros Pinot Noir facility and a combination tasting, tour, and celebration. A solar information kiosk to educate staff and visitors has been installed in the Domaine Carneros tasting room, which showcases the energy and environmental benefits of the solar electric system. The system is an integral part of Domaine Carneros' efforts to help meet the winery's growing electrical energy needs by using clean, renewable energy resources.

Earthlight Books
Earthlight Books is a family-owned and operated bookstore in Walla Walla, Washington, that has been in business for more than 30 years and features more than 100,000 new, used, and antique books. The store shows its commitment to the environment through the purchase of green power from its local utility.

EcoFish
EcoFish promotes ecologically responsible and sustainable consumption of seafood. EcoFish purchased green power to cover 100 percent of its total electricity use in its New Hampshire facilities. This purchase of renewable energy demonstrates EcoFish's commitment to the environment from sea to sky.

Ecoprint
Ecoprint provides nonprofit and other organizations with integrated graphic communications printing, design, data, and mailing services using environmentally responsible materials and processes. To simultaneously achieve its environmental and business goals, Ecoprint decided to invest in 100 percent wind-generated electricity. Ecoprint understands its impact on the environment and the power of making environmentally sound purchasing decisions. "Though it costs us a bit more, we're completely committed to wind power because it helps advance our mission of creating a sustainable business," says Roger Telschow, Ecoprint's President and Founder.

Elfon
Elfon is a Website-hosting and design company located in Salt Lake City, Utah. Elfon joined the Green Power Partnership in 2003 and has committed to purchasing 100 percent wind power from its utility green pricing program. "We think of wind power as another way to look out for our customers," says John Rusho, General Manager. "Pollution-free wind power is good for us, our customers, and the environment."

Encore Ceramics
Encore Ceramics is a leading designer and manufacturer of handcrafted ceramic tile. The company, located in Grants Pass, Oregon, joined the Green Power Partnership in 2005 after purchasing enough renewable energy credits (RECs) to offset all energy consumed by business activities, including electricity, natural gas, automobile miles, and air travel. Encore was driven to make this commitment to

achieving "climate neutral" status by their core belief in sustainable business practices.

Epson Portland Incorporated
Epson Portland Incorporated, the maker of products such as ink cartridges, was one of the first corporations to purchase clean wind power in the Portland, Oregon area. The company is buying 10 percent clean wind power for its Hillsboro-based manufacturing plant. “We really strive to be a good corporate citizen,” says Randal McEvers, Epson’s Assistant Corporate Secretary and Director of General Affairs. “Epson is involved in the community, and we are continually seeking new ways to recycle materials and reduce our impact on the environment. Supporting renewable power is an ideal way for us to extend that commitment. ” The company is also involved in environmental outreach activities, which include Earth Day events, electronics collection and recycling, and Adopt-A-Highway programs.

ERG
ERG is a multidisciplinary consulting firm offering a broad range of professional services in the fields of environmental science and engineering, communications, economic research and analysis, occupational health and safety, facility planning and engineering, energy, and information technology. ERG purchases renewable energy certificates to offset over 60 percent of its electricity consumption at its 14 offices nationwide. ERG is committed to improving the local and global community--not only in its work, but also in its actions, including its commitment to using electricity from renewable energy sources. "This purchase is a very tangible way for ERG to demonstrate to our employees, our customers, and our communities that we support the development of clean, renewable energy resources and the reduction of greenhouse gas emissions," said ERG's President, David Meyers.

The Fairmont Hotel / Washington, D.C.
The Fairmont Hotel / Washington, D.C., committed to purchase 6 percent of its annual electric load from wind-generated power. Waste management, energy conservation, water conservation, and environmentally preferred purchasing are other green practices the hotel is undertaking. Although the hotel is just getting started with many of its green practices, it has already achieved cost-savings in many areas. The Fairmont has found that the good will created with its hotel guests as it implements and promotes environmentally friendly practices goes a long way toward building customer loyalty. The Fairmont surveyed its staff and found the 97 percent believe that protecting the environment is important. Additionally, the survey found that staff wholeheartedly supports the introduction of environmentally friendly practices in the workplace. Hotel employees from all levels are excited to participate in the hotel's Environmental Committee and share their ideas on how to protect our environment.

Fetzer Vineyards
Fetzer Vineyards is a founding member of the Green Power Partnership. In May 1999, Fetzer became the first US winery to purchase 100 percent green power to

meet its electrical demand. Fetzer also installed a 40 kW photovoltaic (solar) array on site at one of its facilities. Although Fetzer initially used investments in energy efficiency to offset a green power price premium, under its current energy contract, buying green power is less expensive than buying traditional power from the local utility.

Frog's Leap Winery
Frog's Leap Winery is surrounded by 40 acres of organically farmed estate vineyard. In addition, the winery owns 88 acres and farms 100 additional acres in the Rutherford, California appellation. Using the best of Napa Valley's organic and sustainably grown grapes and the most traditional winemaking techniques, John Williams and his winemaking team strive to produce wines that deeply reflect the soils and climate from which they emanate. Through its commitment to provide on-site solar power, the winery has reinforced its belief that thoughtful ecological decisions are also good business decisions. The winery's solar array produces 100 percent of its facility's electrical power needs. Green power joins a growing list of ecological practices in place at Frog's Leap, all of which the winery believes have energized its work environment, solidified and enhanced its mission, served as positive community role models, and provided positive public relations.

Ginny's Printing
Ginny's Printing is committed to making the environmental impact of its business as gentle as possible. Ginny's is proud to be members of the Green Power Leadership Club, and that 100% of its electricity is purchased through the Austin Energy Green Choice program. In addition, Ginny's uses vegetable based inks; is one of largest paper recyclers in Austin; uses direct to plate technology that uses non-silver based chemicals; and is knowledgeable about recycled papers and recommend their use.

Green Mountain Coffee Roasters
Green Mountain Coffee Roasters is purchasing renewable energy certificates from the Rosebud Sioux Tribe Wind Farm and the Schrack Family Dairy Farm Methane projects. These renewable energy certificates offset all of Green Mountain Coffee Roasters' physical operations-based activities and direct transportation impacts, allowing the company to become greenhouse gas emissions neutral. Green Mountain Coffee Roasters is committed to a triple bottom line and taking actions consistent with an environmental conscience in all aspects of its business operations.

GTI Coatings, Inc.
GTI Coatings, Inc., located in Austin, Texas, provides metal cleaning and precision Mil-spec plating services to the telecommunications, electronic, aerospace, and semiconductor industries in Texas and across the United States. The company has committed to use 100 percent green power for all its power requirements. Because GTI Coatings continually strives to reduce pollution in all phases of its operations, the company considers the purchase of green power to be the next logical step toward its commitment to improve overall environmental quality.

Harbec Plastics, Inc.
Harbec Plastics, Inc. was formed in 1977 by toolmaker Bob Bechtold and has grown to become a full-service supplier of plastic injection molded parts to many Fortune 500 customers. The company purchases wind renewable energy certificates in the amount of 51.6 MWh and also operates an on site wind turbine with a capacity of 250 kW. The wind turbine generates about 350 MWh annually or about one-third of the power used by the facility. In addition to using renewable energy, Harbec recently established an employee benefit that offers its employees a subsidy for buying utility-supplied green power at their residences. One-third of all employees are participating.

Hayward Lumber Company
Hayward Lumber Company was the first lumber supplier in the nation to stock Forest Stewardship Council-certified framing materials and phase out arsenic and chromium pressure-treated lumber. Hayward Lumber's green power commitment is reflected in its flagship building, the Hayward Building Systems manufacturing facility in Santa Maria, California. The facility features a 118 kW photovoltaic system that satisfies 45 percent of the facility's electricity load. Hayward Lumber has marketed and showcased its new manufacturing facility as a successful, profitable example of a green building. The company has received a wide array of press coverage and provided tours for more than 800 people. The facility was a stop on the Sustainability Project's 2002 Parade of Green Buildings. Hayward Lumber's on-site solar generation is now leveraged in a brand name, "SolarTruss," for the components that are produced at the plant. By branding their trusses, Hayward Lumber is educating contractors and architects that their trusses are built using renewable energy sources.

Hewlett Packard
Hewlett Packard is purchasing green power equal to almost 3 percent of its total electricity load. In addition to it purchase of green power, HP facilities have implemented rigorous environmental, health, and safety systems for identifying, measuring, managing, and reducing potential adverse environmental impacts. Purchasing green power, along with developing environmentally sustainable products and services, are some of the means by which HP delivers on its commitment to global citizenship.

Interface Fabrics
Interface Fabrics has purchased 100 percent renewable electricity to cover the energy associated with manufacturing select patterns of its Terratex® product. The company is also contributing a certain amount per megawatt-hour of electricity that it purchases toward a green energy reinvestment fund to create new green power alternatives in Maine. Interface, Inc. received the 2004 Green Power Leadership Award, which recognized outstanding green power purchases by three of its subsidiaries: Bentley Prince Street, Interface Fabrics, and Interface Flooring Systems.

Interface Flooring Systems
Interface Flooring Systems is a leading manufacturer of modular carpet that has committed to purchase enough Green-e certified renewable energy certificates to offset 100 percent of the manufacturing electricity needs of its Troup County, Georgia facility for 5 years. Additionally, the LaGrange, Georgia facility operates a 17 kilowatt onsite photovoltaic array. Parent company Interface, Inc. received the 2004 Green Power Leadership Award, which recognized outstanding green power purchases by three of its subsidiaries: Bentley Prince Street, Interface Fabrics, and Interface Flooring Systems.

Lockheed Martin Corporation
Lockheed Martin Corporation, one of the nation’s leading defense and aerospace contractors, is purchasing green power to meet 10 percent of its Palo Alto facilities’ power requirements, or 100 percent of the output of one large-scale wind turbine, on an annual basis. This is the first renewable power purchase nationally by a leading US defense and aerospace contractor. Derived from clean wind and solar generation sources, Lockheed Martin’s renewable power commitment (1,800 MWh annually) was the largest clean power commitment to its local utility's green power program at the time of the purchase. “The company’s commitment to renewable power is an extension of a broad set of initiatives we’ve implemented nationally to conserve energy and minimize our impact on the environment,” stated Dr. James T. Ryder, Ph.D., Lockheed Martin Director of Technology Development.

Lundberg Family Farms
Lundberg Family Farms is a family-owned and operated farm committed to growing and producing organic rice and rice products in the Sacramento Valley of Northern California. Lundberg’s eco-positive farming ethic has guided its soil enrichment, water management, and wetlands preservation initiatives, and made renewable energy a natural fit for the company. Lundberg Family Farms’ purchase of approximately 4,800 MWh per year of California wind-derived renewable energy certificates is enough to supply 100 percent of the operation’s total load. Lundberg puts the Green-e logo on product packaging, including its new Rice Chips, and plans to have all packaging brandish the Green-e logo in the years ahead. In addition, Lundberg has spread the word about green power through coupons its power provider’s renewable energy customer welcome kit, displays and posters at industry trade shows, and media coverage. Lundberg’s purchase represents the largest US renewable energy commitment by an agribusiness and stands out as the first mass-market consumer product to place the Green-e logo on its packaging, making Lundberg an important market trendsetter.

My Organic Market's
My Organic Market's (MOM's)’ mission is to provide the opportunity for people to help the environment and improve their lives by purchasing healthy, high quality, eco-friendly products. MOM's strives to accomplish this by focusing on discount prices, organic produce, customer services, and a large selection of products. In

addition to their support of locally grown and organic foods, MOM's has committed to purchasing enough green power to cover 100 percent of its electricity needs. The company has also created an internal initiative called Environmental Restoration (ER) in its ongoing effort to preserve, protect, and restore natural systems. With ER, MOM’s has committed to the "greening" of its day-to-day operations by developing and implementing environmentally responsible best business practices. Purchasing green power is a major component of this overall mission. "Being an environmentally friendly company not only helps the world to be a better place, it also helps our business' bottom line by increasing employee morale and customer loyalty," said Scott Nash, President of MOM's.

New Belgium Brewing Company
New Belgium Brewing Company was the first brewery in the United States to use 100 percent wind power to meet its electricity needs. New Belgium's interest in green power stems from its desire to reduce carbon dioxide emissions, a byproduct of its beer-making fermentation process. New Belgium decided to buy wind power as part of its environmental strategy and is also generating electricity on-site with co-generation.

New Leaf Paper
New Leaf Paper develops and distributes environmentally responsible, economically sound paper. The company began purchasing green power for its San Francisco headquarters facility in 2003 to meet its own environmental goals and fulfill the expectations of customers and partners. For the past 15 years, New Leaf Paper has consistently worked to produce leading paper grades by evaluating the environmental impact of every aspect of paper making, including energy sourcing. Most recently, New Leaf has increased its green power usage through the production of certain papers using electricity generated from biogas. New Leaf Paper believes that buying green power compliments its mission of producing the most environmentally responsible papers on the market.

Nike World Headquarters
Nike World Headquarters purchases renewable energy credits to cover 53 percent of its electricity consumption. This purchase helps Nike meet its goal to reduce carbon dioxide emissions 13 percent below 1998 levels by the end of 2005 from Nike-owned facilities and business travel activities. "Nike is making great strides in doing its part to clear the air and promote sustainable, low-impact energy sources,” said Jim Petsche, Director of Corporate Facilities. “We are continuing our commitment to improve energy efficiency and reduce greenhouse gas emissions. It's simply good, smart corporate citizenship."

Norm Thompson Outfitters
Norm Thompson Outfitters, based in Portland, Oregon, manages three online and catalog brands: Norm Thompson, Solutions, and Sahalie. The company believes that global climate change is among the most pressing global challenges and that businesses should step forward to take an active role in minimizing its impact. By

purchasing green power through renewable energy certificates, Norm Thompson hopes to help convert fossil fuel-based power grids to clean energy sources.

Outpost Natural Foods Cooperative
Outpost Natural Foods is dedicated to implementing sustainable green building practices and green design in updating and building retail spaces.

The Port of Portland
The Port of Portland (OR) is a regional transportation public agency that owns and operates four airports, three maritime cargo terminals, a river dredge, and engages in property development. The Port's green power commitment, purchased from wind power sources, is approximately 7 percent of all power consumed at its facilities. The primary driver behind the Port's commitment was to meet its corporate environmental goals and objectives by purchasing energy from sustainable sources. This action is consistent with the Port's corporate environmental philosophy to reduce its environmental footprint while supporting regional development of renewable energy resources. Bill Wyatt, Executive Director, notes that the Port's use of green power is "a way to purchase our electric energy from a sustainable source and support a vital and emerging industry. " The Port of Portland was the first port authority to participate in the Green Power Partnership.

ReCellular
ReCellular collects, resells, and recycles used wireless phones and accessories. The company has committed to purchase green power to cover 50 percent of its annual electricity needs. Eric Forster, Senior Vice President, says that ReCellular's green power commitment "is another important way we demonstrate to our customers and partners that we are the environmental leader in our field."

Recycline
Recycline is a consumer products company with a strong commitment to the environment. The company's mission is to help consumers conserve natural resources. The company also seeks to support the US recycling industry in its business practices and through volunteer, professional, and community actions. To reduce its environmental impact, Recycline buys wind power to cover 100 percent of its total electricity consumption.

RenewAire
RenewAire manufactures energy recovery ventilators that improve indoor air quality and conserve energy year round for homes and large buildings. Under a prime directive from the company's mission statement as a renewable energy and efficiency products company, RenewAire currently purchases 20 percent of its electrical power from green power sources. The company feels that one of the biggest benefits from its green power purchase is that it has attracted employees and added to a positive working environment.

Rivanna Natural Designs
Rivanna Natural Designs offsets 100 percent of its annual CO_2 emissions from office heating, electricity use, and business travel, in keeping with the organization's environmental commitment. Rivanna's clients also appreciate its commitment to green power and sustainable business operations.

Rockwell Collins
Rockwell Collins is a leader in the design, production, and support of communications and aviation electronics solutions for commercial and government customers worldwide. The company's commitment to reduce greenhouse gas emissions associated with its operations led it to purchase 10,000 MWh of Green-e certified tradable renewable certificates from new wind projects in Iowa and biomass facilities across the nation. Rockwell Collins' renewable energy commitment prevents the emission of 13,800,000 pounds of carbon dioxide, a key greenhouse gas, annually. "Rockwell Collins is committed to environmental sustainability and recognizes that this renewable energy purchase is an innovative and effective way to reduce the company's greenhouse gas emissions," said Clay Jones, Rockwell Collins Chairman, President, and CEO.

Sandy Alexander
Sandy Alexander serves the high-end web and sheet-fed printing needs of Fortune 500 clients. Sandy Alexander purchases 100 percent of its electrical power from renewable wind power sources. The company's annual purchase of 9,000 megawatt-hours of wind energy is the largest such commitment in the US printing and publishing industry. In addition, Sandy Alexander's commitment to wind-generated electricity enables the company to help its clients achieve their own environmental and sustainability objectives while leading by example in its business sector.

Shell Solar
Shell Solar is dedicated to making the promise of environmentally friendly energy a practical reality today. The company has a commitment to alternative energy solutions that is unique to the industry.

Spire Solar Chicago
Spire Solar Chicago is a manufacturer, designer, and integrator of solar electric panels and systems. The company joined the Green Power Partnership in 2004 with a commitment to use 40 MWh of onsite generation annually. Spire Solar Chicago generates renewable electricity using onsite solar power, or photovoltaics. Spire is located in a building that is Platinum-certified by the US Green Building Council's Leadership in Energy and Environmental Design (LEED) and is heated and cooled by a ground source heat pump. Spire Solar Chicago is part of the Chicago Solar Partnership of the US Department of Energy's Million Solar Roofs Initiative.

St. Francis Winery

St. Francis Winery, located in California's Sonoma Valley, has been crafting fine wines since 1978. In June of 2004, the Winery installed a 457kilowatt solar electrical system, covering 80,000 square feet. The solar array, one of the largest in California's wine country, provides electricity for more than 40 percent of the winery's power needs.

Sun & Earth

Sun & Earth, a natural cleaning products company, purchases wind power to cover 100 percent of its total energy consumption. Sun & Earth sees the connection between a clean home and clean energy: neither should involve toxic substances nor harm your health. The company's commitment to wind power is an extension of its corporate philosophy that environmental protection and quality can go hand in hand.

Sundance Resort

Sundance Resort is a community preserve dedicated to maintaining the balance of art, nature, and community. In accordance with its well-known and longstanding commitment to environmental sustainability, Sundance is committed to the effort to find cleaner, more sustainable energy alternatives. Sundance has purchased wind power for its own operations and has launched a community campaign to challenge homeowners to match this purchase by buying wind power for their homes. "For decades I have supported the development of alternative renewable energy systems and have always hoped Sundance would become an example of a community motivated to support new alternatives", says Robert Redford, owner. "This initial purchase is our commitment and first step in a more comprehensive energy efficiency program."

The Coca-Cola Company

The Coca-Cola Company is the world's largest beverage company, marketing four of the world's top five soft drink brands. The Coca Cola Company is purchasing 6,000 megawatt-hours (MWh) of renewable energy certificates from wind energy sources. This commitment will offset 2 percent of the electricity load for the 25 operations The Coca-Cola Company owns and operates in North America. The Coca Cola Company believes that a sustainable business plan and a sustainable environment go hand in hand. By participating in the Green Power Partnership, The Coca-Cola Company wishes to support and promote cost-effective renewable power generation. "We recognize the interrelationship between energy and the environment. Our purchase of green power is consistent with our overall commitment to conduct our business in ways that protect and preserve the environment. Green power is a clean, natural way for us to demonstrate to our stakeholders that we are a global steward for the environment," said Bryan Jacob, Environmental Technologies Manager.

The Joinery
The Joinery specializes in handcrafted hardwood furniture. It is the largest producer of furniture in the Pacific Northwest using woods, which are certified according to the strict guidelines of the Forest Stewardship Council. The Joinery purchases renewable energy certificates from wind power to cover 100 percent of its electricity use for its 15,000 square foot workshop and 7,000 square foot showroom in Portland, Oregon. Marc Gaudin, the company's founder, says, "We like to be on the forefront of new ideas and ways to be kind to mother earth."

Xantrex Technology
Xantrex Technology is a leader in the development, manufacturing and marketing of advanced power electronic products and systems for the distributed, mobile and programmable power markets. As a founding Green Power Partner, the company's facilities in Arlington, Washington and Livermore, California operate on 100 per cent green electricity.

Zackin Publications
Zackin Publications joined the Green Power Partnership in 2005 and is 100-percent green powered. For more than 35 years the company has provided business-to-business information to key decision-makers, enabling them and their staffs to achieve business success. Two of Zackin's publications, North American Windpower and Alternative Energy Retailer, provide information on the renewable energy industry. Zackin decided to purchase green power as an example of its environmental leadership and to help support the industries they cover.