

The Biodiesel Industry: Feedstocks, Capacity, and Subsidies

Chelsea Ruth Conover

April 25, 2008
Master of Environmental Management
Lincoln Pratson, Advisor

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment and Earth Sciences of Duke University

2008

Acknowledgments

Many thanks are due to my family, friends and mentors who have helped me develop my passion for the environment and who have made the completion of my education possible. Special thanks to my advisor Lincoln Pratson for all of his support, patience and ideas through the process of this study. Additional thanks goes to the Climate Change Policy Partnership for providing financial support, and especially to Christopher Galik for helping me to focus my ideas and remain mentally stable. Lastly, thanks to Bill Somerlot for teaching me the most important lesson of all: how to survive in the absence of the bliss of ignorance by maintaining a sense of humor and a focus on what matters most.

Abstract

Concerns over global climate change, national security and limited petroleum resources have heightened US interest in renewable fuels in recent years. Biodiesel made from plant oils and animal fats is one such alternative. In 2007, the United States passed the Energy Independence and Security Act, setting new goals for the production of biofuels. In order to analyze the ability of the biodiesel infrastructure to meet the Renewable Fuel Standards outlined in the recently-passed Energy legislation and to determine the importance of current government subsidies in meeting these standards, I examined current and potential demand for biodiesel, possible feedstocks, and capital costs. Current US biodiesel refinery capacity exceeds the amount of production mandated, but production has only reached approximately one fourth of this capacity. With future capacity expected to double by 2009, biodiesel refineries will be able to produce the required biodiesel by 2012 at prices that are competitive with conventional diesel assuming subsidies remain above \$0.72. The importance of the subsidy and the potential of the biodiesel industry are both based on assumptions about two volatile prices: the price of vegetable oils and the price of diesel. These prices are the key factors in determining the success of the industry and the public and private costs of meeting the Renewable Fuel Standard.

Table of Contents

Acknowledgements	ii
Abstract.....	iii
List of Tables.....	v
List of Figures.....	v
Introduction.....	1
Biodiesel Background.....	1
Current Biodiesel Market.....	2
Current Diesel Market.....	5
Diesel Production.....	5
Diesel Consumption.....	9
Diesel Uses.....	13
Prices.....	15
Feedstock Analysis.....	17
Soybeans.....	18
Canola.....	25
Palm.....	27
Sunflower Seed.....	27
Cottonseed.....	29
Coconut.....	30
Corn.....	31
Peanut.....	31
Animal Fats.....	33
Prices.....	36
Supply Curve Factors.....	37
Capacity Supply Models.....	43
Conclusions.....	49
References.....	51
Appendix.....	53

List of Tables

Table 1: Biodiesel feedstocks, production and targets for selected countries.....	5
Table 2: Amount of biodiesel produced from different feedstock in 2007.....	39

List of Figures

Figure 1: European biodiesel consumption.....	4
Figure 2: Biodiesel production in the United States.....	4
Figure 3: Diesel production by top country/region 2005.....	6
Figure 4: Average percent change in diesel production since 2000.....	7
Figure 5: Diesel as a percent motor fuel produced.....	8
Figure 6: Diesel demand by top country region 2005.....	9
Figure 7: Average percent change in diesel demand since 2000.....	11
Figure 8: Diesel as percentage of motor oil used.....	12
Figure 9: US diesel end uses.....	14
Figure 10: Nominal price of diesel fuels.....	16
Figure 11: Real prices of diesel fuels.....	16
Figure 12: Breakdown of the cost of one gallon of biodiesel.....	18
Figure 13: World soybean production and contribution by nation.....	19

Figure 14: Top soybean import/export nations.....	20
Figure 15: World production of the soybean oil.....	21
Figure 16: World imports and exports of soybean oil.....	22
Figure 17: Domestic uses of soybean oil.....	23
Figure 18: US Bioenergy Program: Reported gallons produced (log scale).....	24
Figure 19: US Bioenergy Program: Reported biodiesel production from top feedstocks.....	25
Figure 20: World canola production.....	26
Figure 21: Top sunflower seed importing nations.....	29
Figure 22: Top world producer of cottonseed.....	30
Figure 23: US supply and disappearance of peanuts.....	33
Figure 24: World production of lard (excluding China).....	35
Figure 25: US consumption of lard (edible and inedible).....	35
Figure 26: Production and distribution of lard in the US.....	36
Figure 27: Price of feedstocks.....	37
Figure 28: 2007 production stack.....	40
Figure 29: Biodiesel refinery cost by plant capacity.....	41
Figure 30: Capital cost of biodiesel per gallon of capacity.....	42

Figure 31: Current biodiesel capacity.....	44
Figure 32: Minimum and maximum production costs for multi-feed plants.....	45
Figure 33: Current and future capacity, 2007 prices.....	46
Figure 34: Current and future capacity, 2008 prices.....	47
Figure 35: Forecasted subsidy requirements.....	48
Appendix Figure 1: 2005 biodiesel production by country.....	53
Appendix Figure 2: Top biodiesel producing countries in 2005.....	53
Appendix Figure 3: Largest diesel suppliers by country/region.....	54
Appendix Figure 4: Diesel demand by highest demanding countries/regions.....	55
Appendix Figure 5: Diesel percent share of passenger vehicle market.....	56
Appendix Figure 6: Diesel passenger vehicle registration by type.....	56
Appendix Figure 7: US diesel consumption by end use.....	57
Appendix Figure 8: United States domestic consumption and crush.....	57
Appendix Figure 9: Destinations of US exports of soybean oil.....	58
Appendix Figure 10: World production and crush of canola.....	59
Appendix Figure 11: US Acquisition and disappearance of canola.....	59
Appendix Figure 12: World production of palm oil.....	60

Appendix Figure 13: Major palm oil exporting nations.....	61
Appendix Figure 14: World production of sunflower oil.....	62
Appendix Figure 15: Top world producers of sunflower seed.....	63
Appendix Figure 16: US Sunflower seed oil.....	64
Appendix Figure 17: United States crush of sunflower seed.....	64
Appendix Figure 18: Top coconut oil producers.....	65
Appendix Figure 19: Top coconut oil consumers.....	65
Appendix Figure 20: Supply and disappearance of coconut oil in the US.....	66
Appendix Figure 21: US corn oil supply and disappearance.....	67
Appendix Figure 22: Top producers of peanuts (in the shell).....	68
Appendix Figure 23: World production of tallow and grease.....	68
Appendix Figure 24: 2005 top producers of lard.....	69

Introduction

Biodiesel is an increasingly popular fuel associated with environmental and international security benefits. The objectives of this project were to determine the current and potential demand for biodiesel in the United States and to examine the factors that impact price and supply. These objectives required an in-depth analysis of potential feedstocks. Using this data, a supply curve was created in order for two additional objectives. The supply curve was used to analyze the ability of the biodiesel infrastructure to meet Renewable Fuel Standards set by the United States government and to determine the importance of current government subsidies in meeting these standards. The capacity of the biodiesel industry is large enough to supply the mandated amounts of biodiesel; however, under most price scenarios, government subsidies must remain in order to create a competitive market for biodiesel.

Biodiesel Background

Petroleum is the largest energy source in the United States, accounting for 39.8% of primary energy consumption, 69% of which goes to transportation. The transportation sector is completely dependent on petroleum products, at 98% of transportation fuels directly produced from petroleum (EIA 2006). Recent growing concern over global climate change, national security and limited petroleum resources has made the need for alternative transportation fuels obvious, drawing public attention to biofuels. The most recent energy bill in the United States, The Energy Independence and Security Act, has mandated certain quantities of various biofuels to be produced within the United States. Biodiesel is arguably the most attractive biofuel option, because it can be used directly in diesel engines and other existing diesel infrastructure such as

pipelines and distribution trucks. Diesel engines use 20-40% less fuel per mile traveled than similar gasoline engines (EERE 2007), and using biodiesel does not compromise this efficiency since B100 (or 100% biodiesel) has only 8.65% less energy content than conventional diesel. B20 (20% biodiesel) or B2 is often used instead of B100, and these fuels have even higher energy contents, at only 1.73% and 0.17% less than conventional diesel, respectively (NBB 2005).

Though biodiesel can be used in existing infrastructure, like any fuel, it must meet certain standards in order to avoid damage to equipment. ASTM International, a technical standards development organization (ASTM 2008), has set fuel quality specifications for biodiesel and all biodiesel blends. Biodiesel blends of less than 5% are incorporated into regular diesel standards under ASTM D975 specifications, and all other blends must meet ASTM D6751 specifications (NBB Aggressive 2007). In addition to these standards, BQ-9000 is a quality assurance program for biodiesel that began accrediting producers in 2004. BQ-9000 is a combination of International Organization for Standardization documentation requirements and testing protocols that are required under ASTM D6751 (Jessen 2006). Initial accreditation costs over \$3000, and as of April 2008 there were nine accredited biodiesel marketers and twenty accredited biodiesel refiners (BQ-9000 2008). Fuel standards are important because biodiesel is in direct competition with conventional diesel, and if low quality fuel is causing maintenance problems with vehicles, then biodiesel is less cost competitive with diesel.

Current Biodiesel Market

The European Union has been leading the world in biodiesel production, reaching over 1.5 billion gallons in 2006 (Fig. 1), whereas in the United States, biodiesel has only very recently made an appearance in the market. In 2005, US production jumped to 75 million gallons of production, up from 25 million in the previous year. This quantity has continued to rise, with biodiesel estimated at 450 million gallons of production in the United States alone in 2007 (Fig. 2). Despite the fast growth the industry has been experiencing, biodiesel is still concentrated in only a few regions of the world. EU nations produce and consume the largest portion in the world at about 85% in 2005. Of this production, Germany refines the most at approximately 53% (Appendix Fig. 1). The industry is much more concentrated than the diesel industry, with four nations producing 75% of the biodiesel in 2005. The top producing countries in order are Germany, France, Italy, and the United States (Appendix Fig. 2), though Brazil is expected to reach these levels of production in the next few years (Thurmond 2007). Each country uses different feedstocks depending on what is available and cost efficient in that region. EU nations use mostly canola oil, along with small amounts of sunflower seed oil and soybean oil. The United States uses soybean oil as its main feedstock but also uses waste vegetable oil, animal fats, canola oil, and small amounts of other vegetable oils. Table 1 below shows the primary feedstocks and production goals of major biodiesel producing countries.

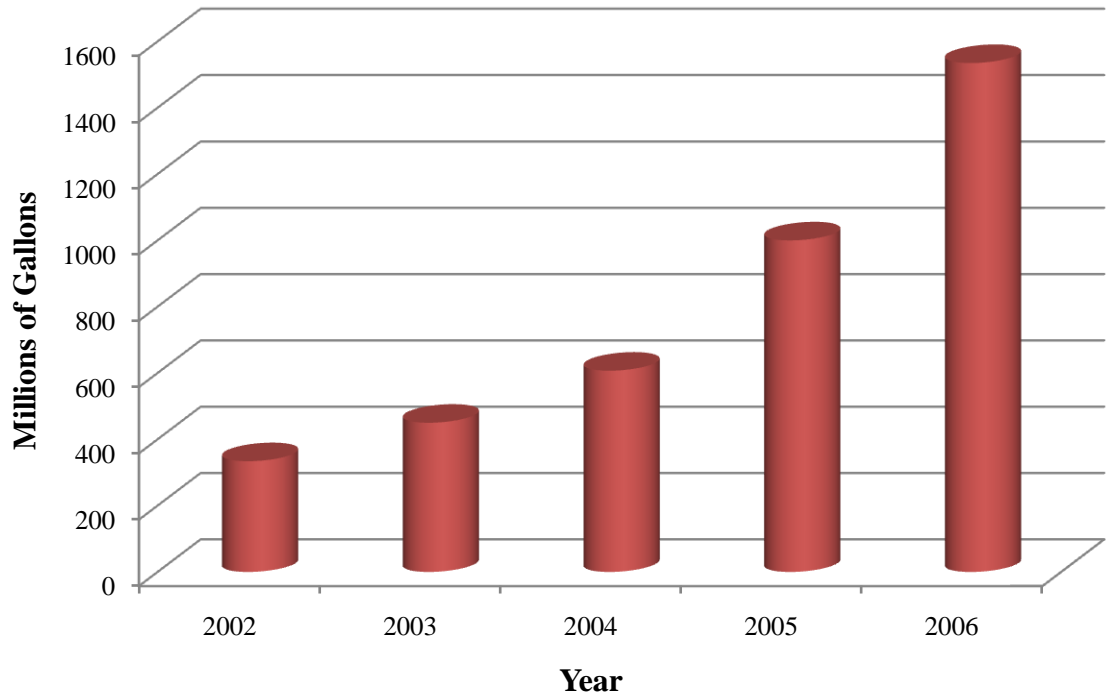


Figure 1: European biodiesel consumption, 2002-2006 (EBB 2008).

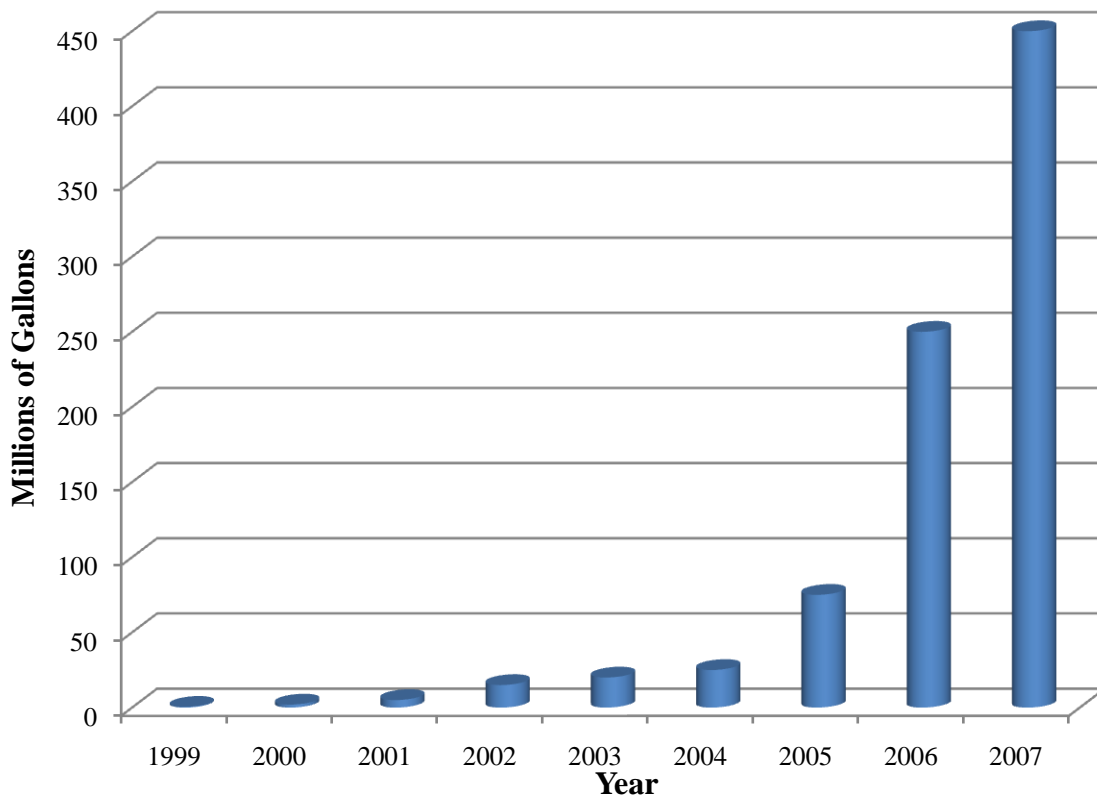


Figure 2: Biodiesel production in the United States, 1999-2007 (NBB 2007).

Table 1: Biodiesel feedstocks, production, and targets for selected countries (Coyle 2007)

Country/Region	Feedstock(s)	2007 Estimated Production (MMg)	Blending Targets
Brazil	Castor Seed	64.1	2% blend of biodiesel in early 2008; 5 % by 2013
EU	Rapeseed (Canola, Sunflower, Soybean)	1,731.9	5.75% biofuel share of transportation fuel by 2010; 10% by 2020
Indonesia	Palm Oil, Jatropha	107.7	10% biofuel by 2010
Malaysia	Palm Oil	86.8	5% biodiesel blend used in public vehicles
Thailand	Palm Oil, Recycled Vegetable Oil	68.8	Palm biodiesel to replace 10% of diesel demand by 2012
United States	Soybeans, Other Oilseeds, Animal Fats, Recycled Fats and Oils	444.5	1 billion gallons of biodiesel by 2012

Current Diesel Market

Diesel Production

Because biodiesel is a replacement fuel for fossil fuel diesel, the most appropriate way to analyze the market potential for biodiesel is to examine the diesel market. Diesel is produced from crude oil at refineries around the world, reaching over 1 billion tonnes or 364 billion gallons in 2005. Seventy-five percent of this diesel is produced in only 10 countries/regions. OECD European nations lead the world in production, representing almost 24% of the world

total (OECD 2007). Other top diesel refining countries in order include China, Russia, Japan, India, Brazil, Saudi Arabia, Korea, and Canada (Fig. 3).

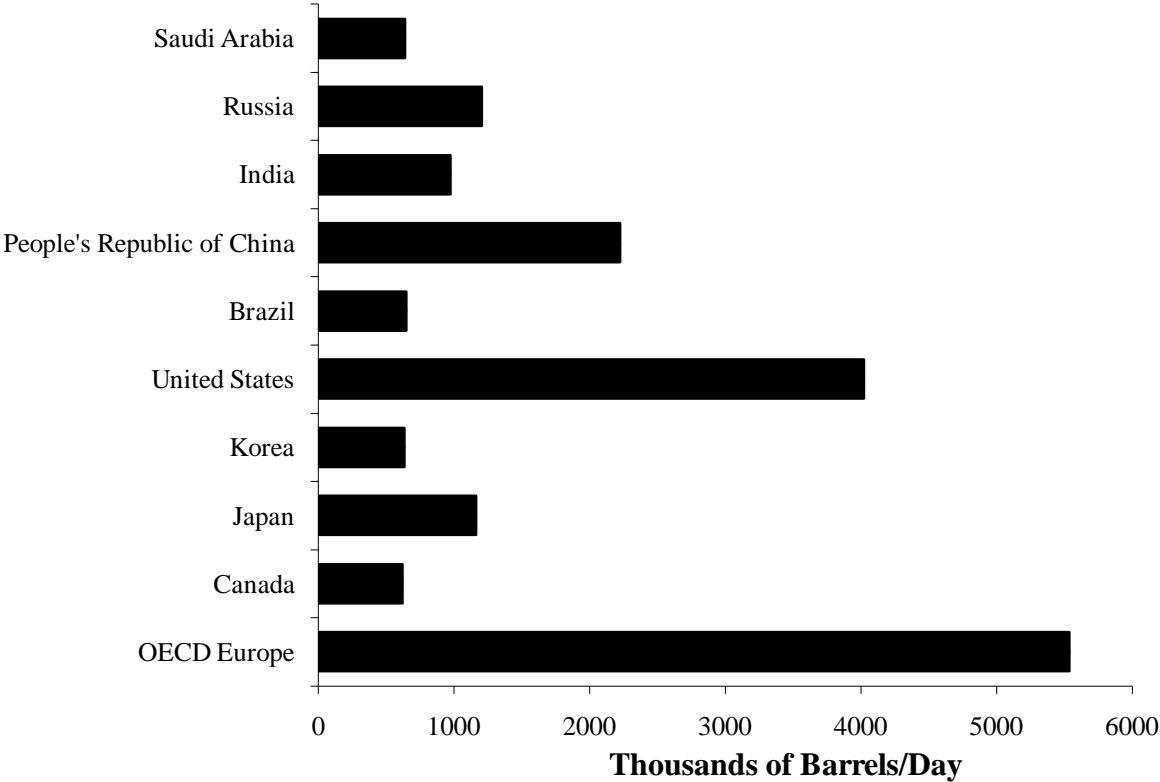


Figure 3: Diesel production by top country/region, 2005 (OECD 2007).

On average, world production of diesel has been increasing in recent years, and this is also true for most of the top diesel refining nations. Korea, Japan, and Canada have all stayed at about the same production levels (Appendix Fig. 3). The 5-year running average of all nations shows that the world has been increasing production at about 2.6% each year (Fig. 4). While most countries have been increasing their diesel production at a relatively steady rate, China's production has increased noticeably starting in 2003. They have been well above the 2.6% level,

increasing at an average of 9.4% each year since 2000. Brazil, Russia, Saudi Arabia and India have also been increasing production at rates higher than the world average. Japan is the only nation out of the top producers that has actually decreased their production, though this has only been a 0.7% decrease.

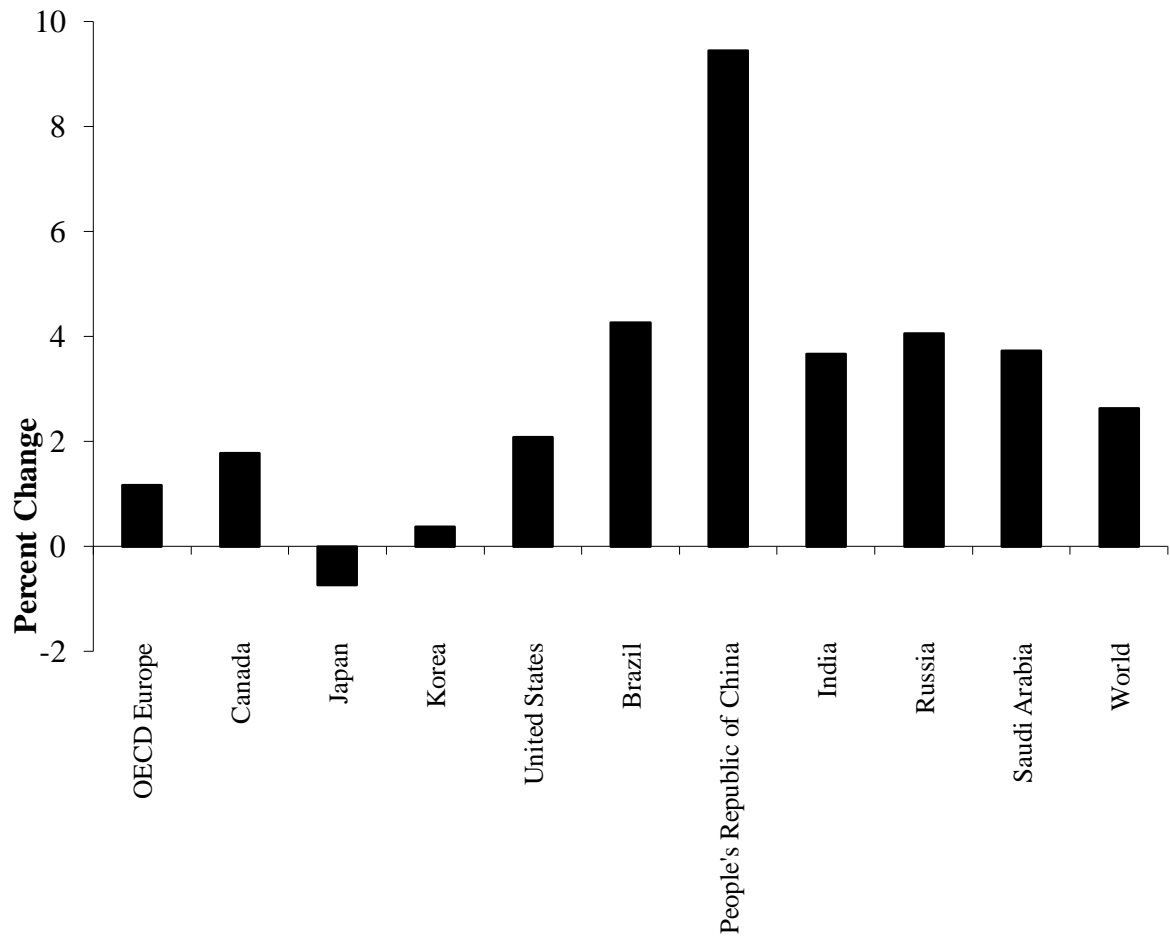


Figure 4: Average percent change in diesel production since 2000 (OECD 2007).

Diesel and gasoline are the two main petroleum products that can be used for transportation in common personal and road vehicles. In the US, gasoline is overwhelmingly the most important of these transportation fuels, account for over 60% of fuel consumption (EIA

2001). Conversely, in most other major diesel-producing areas, diesel dominates the motor fuel production. India produces the highest percentage of diesel fuel for transportation, producing just above 80%. The world percentage production has been at about 55% diesel for transportation fuels, with only the United States and Canada producing at a lower percentage; however Canada has been increasing their percentage of diesel production since 2000, as has China, OECD Europe, Korea and Brazil (Fig. 5). This signifies an increased use of diesel engines as compared to use of gasoline engines in these regions.

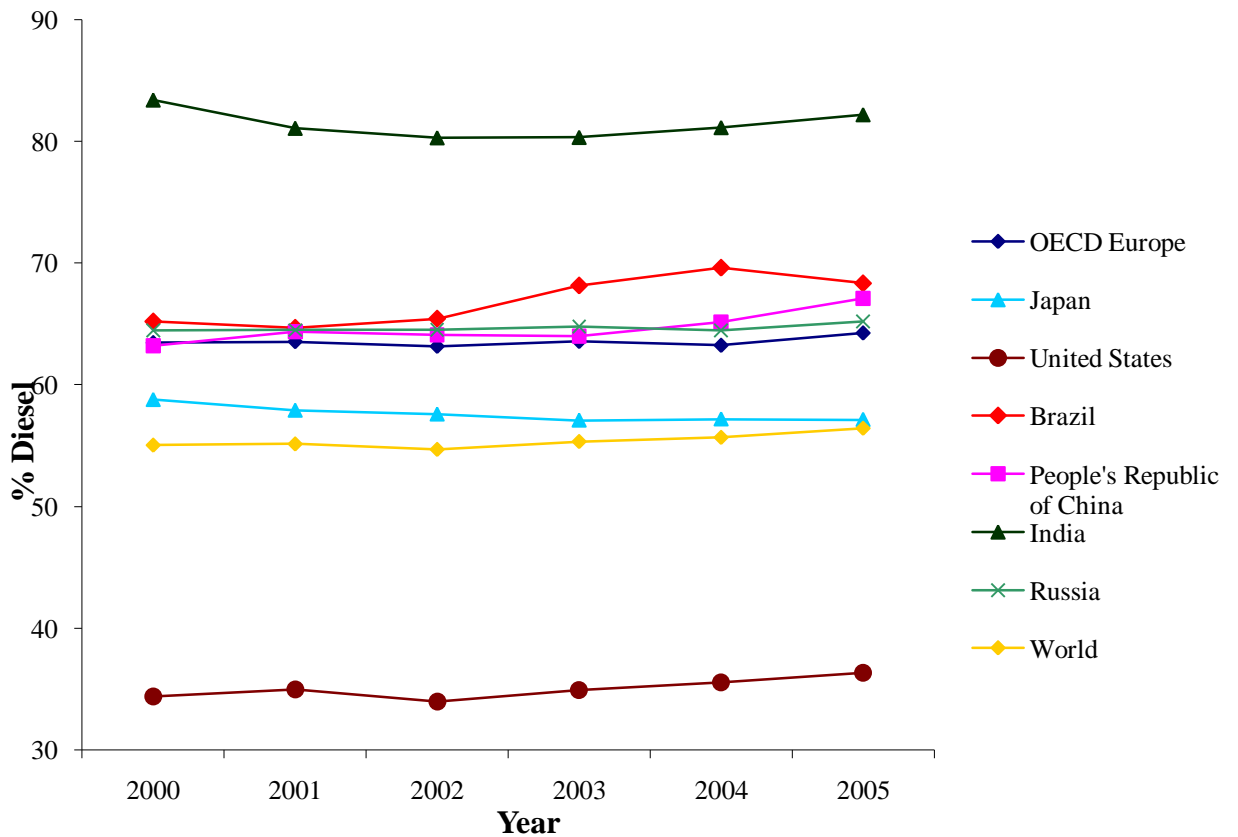


Figure 5: Diesel as percent motor fuel produced (OECD 2007).

Diesel Consumption

The top producing regions of fossil fuel diesel are, in large part, the same regions that consume the diesel fuel. In 2005, the world consumed over 94 billion gallons of diesel per day, with 75% of this consumption coming from 12 nations. Leading these in demand are OECD European countries with 6.1 million barrels of consumption per day. Other top diesel consuming countries in order include the United States, China, Japan, India, Brazil, Indonesia, Canada, Russia, Saudi Arabia and Korea (Fig. 6). The similarity between the top refining and top demanding areas demonstrates the fact that most countries import their oil as crude oil and refine it domestically. For example, in 2006 the United States imported 66% of its crude oil but only 5.7% of its diesel (Durbin 2006).

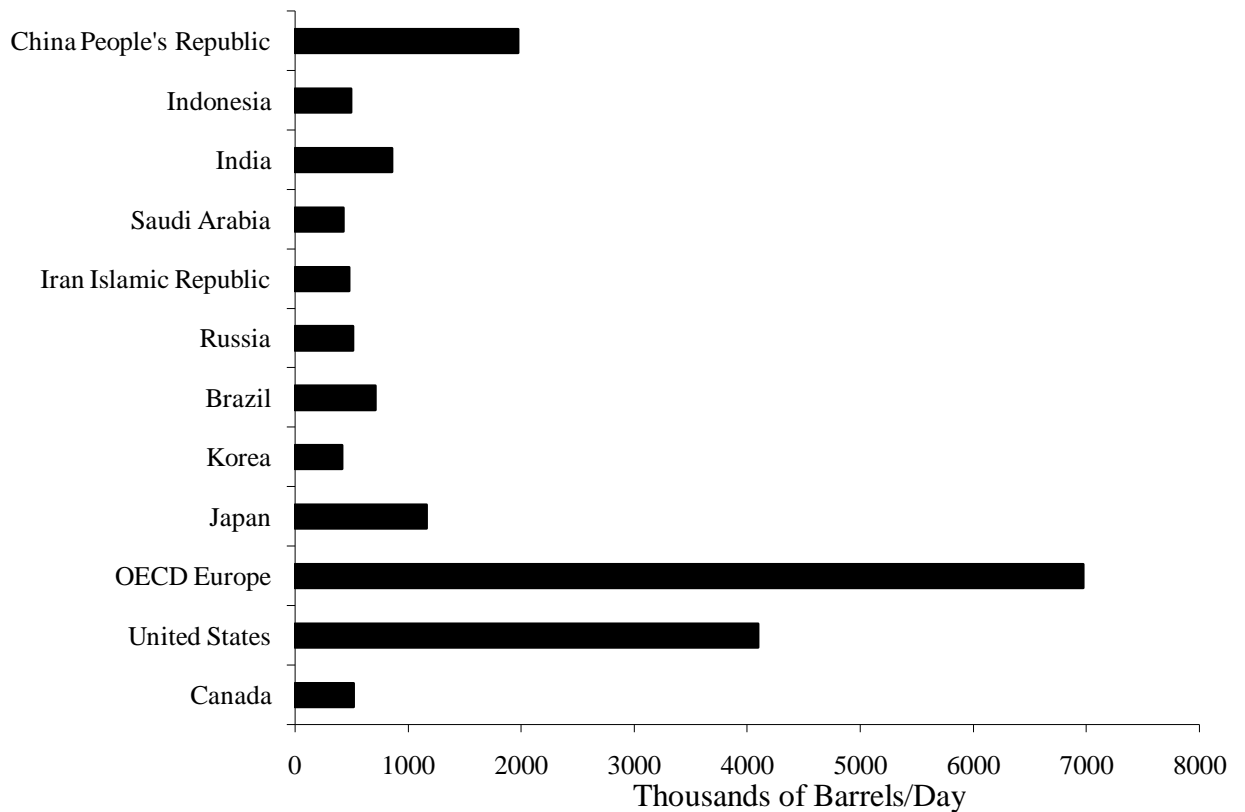


Figure 6: Diesel demand by top country/region, 2005 (OECD 2007).

Total world demand for diesel has been increasing steadily since 2001, which has also been the case for most of the top demanding countries (Appendix Fig. 4). The exception to this is Japan and India, both of which have begun to decrease their demand. OECD European countries experienced a sharp increase in demand in 2004, and then demand decreased again in 2005. On average, international diesel demand has been increasing at 2.8% for the past 5 years. China's demand is increasing at an alarmingly faster rate of 10.25% per year since 2000, while Indonesia, Saudi Arabia, and Iran have also been increasing their demand at rates higher than the international average (Fig. 7). Alastair Bedwall, senior manager for J.D. Power Automotive Forecasting, states that the reason for the overall increase in demand for diesel fuel and engines revolves around rising energy prices and new environmental regulations. Daily notes "As a proven, cost-effective and off-the-shelf solution, diesel has a head start over other emerging fuel-efficient technologies... With energy prices at elevated levels and new regulatory pressure to improve light-truck fuel efficiency, a range of fuel-efficient alternatives to the conventional gasoline engine will be required (Daily 2006)."

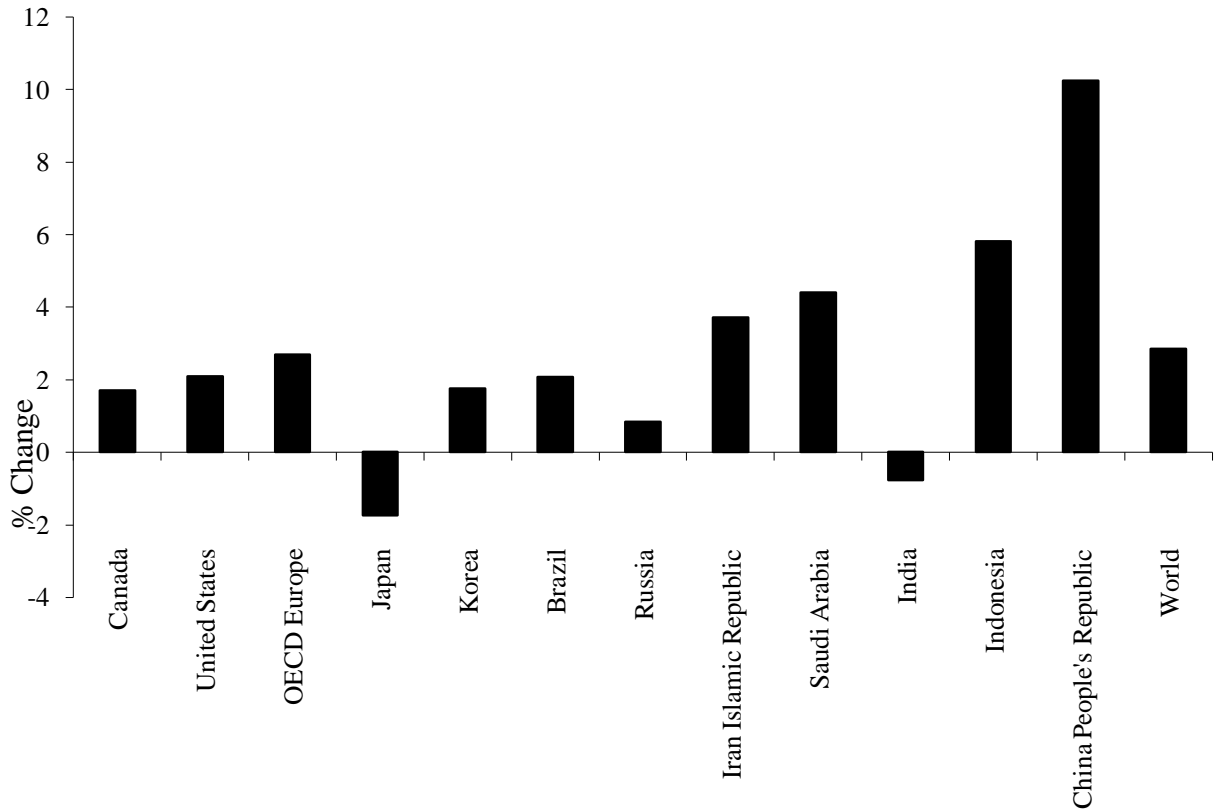


Figure 7: Average percent change in diesel demand since 2000 (OECD 2007).

Demand for specific fuels is directly related to the demand for related types of vehicles. Virtually all semi-trucks and other delivery vehicles, buses, trains, boats, ships, and farm, construction, and military equipment have diesel engines, but the personal vehicle market is still dominated by gasoline-powered engines (EIA Diesel 2007). In 2005, there were about 44,000 diesel light-duty vehicles, 478,000 medium-duty trucks, and 22,000 other diesel vehicles registered in the United States. In total, these vehicles accounted for only 3.6% of the passenger vehicle market (Polk 2005). Volkswagen is the largest global supplier of diesel-fueled passenger vehicles, followed by Ford Motor Company. Toyota is expected to begin penetrating a significant share of the market as well. Western European countries have been driving the recent increase in diesel demand, and are predicted to continue doing so. The market is expected to

reach 29 million vehicles by 2015 (Daily 2006). The top diesel demanding regions tend to use higher percentages of diesel fuel than gasoline, and use higher percentages than the world average of about 50% diesel, 50% gasoline (Fig. 8). India uses the highest percentage of diesel as transportation fuel, though this percentage has been decreasing as gasoline vehicles have become more common. Korea also uses a high percentage of diesel fuel, and the percentage for OECD Europe has been rising near Korea's levels.

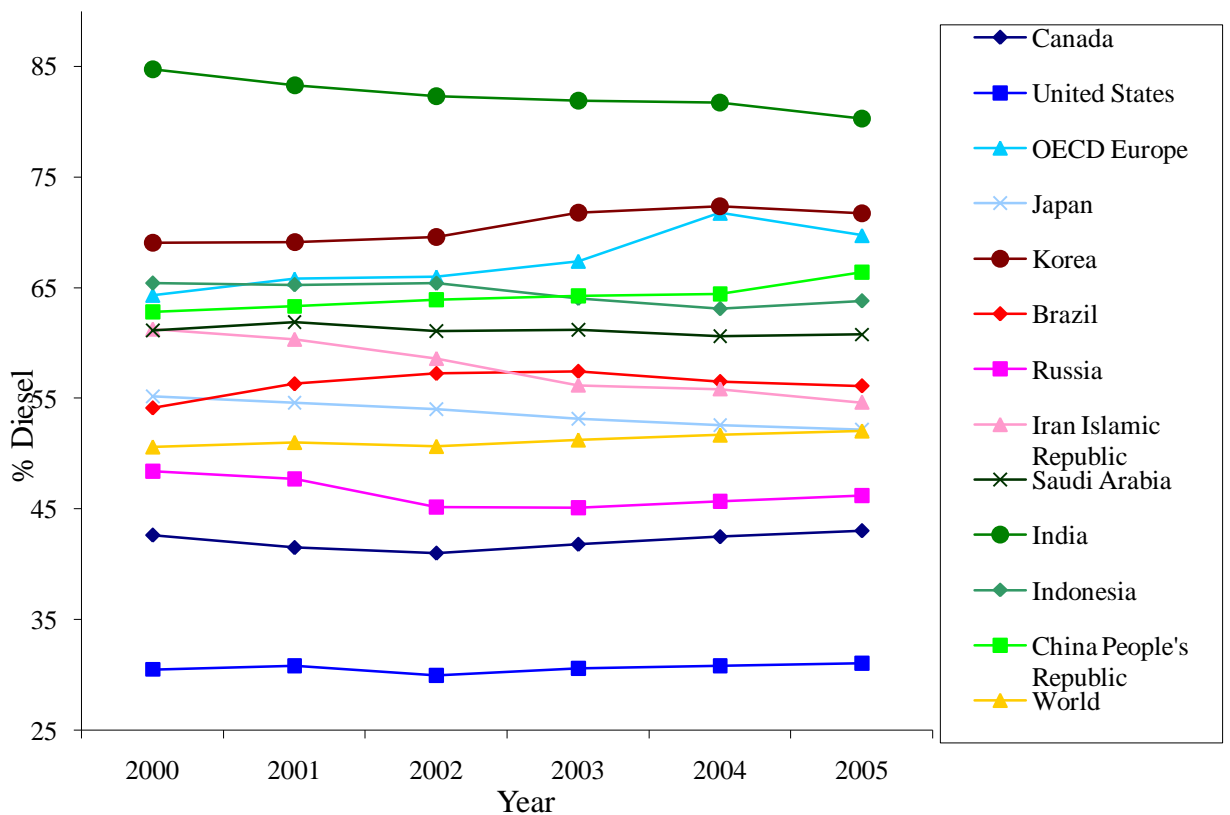


Figure 8: Diesel as a percentage of motor oil used (OECD 2007).

Of the top consuming countries, the United States uses the lowest percentage of diesel fuel for transportation, which is a result of even higher gasoline demand. Demand for gasoline vehicles in the US has been rising at much faster rates than for diesel vehicles. This is largely

due to hesitation by consumers to buy diesel vehicles; the public still considers diesel engines to be major polluters. However, recent EPA standards have required No. 2 distillate fuel (diesel) to meet lower sulfur standards. By June of 2006, 80% of all highway diesel fuel had to be less than 15 ppm sulfur fuel, or Ultra-Low Sulfur Diesel. By December of 2010, all highway diesel fuel must meet this standard (EIA Diesel 2007). As a result of these standards and also increasing fuel prices, consumers are beginning to look towards diesel cars, which are about 30% more efficient than gasoline cars (Durbin 2006). According to J.D. Power Automotive Forecasting, the United States, as well as Canada, has an “enormous potential” for diesel passenger vehicle sales (Daily 2006). By their estimations, the U.S. was at about 3.2% of the light-vehicle sales in 2005. Polk Automotive Intelligence estimates a slightly higher percentage (Appendix Fig. 5). Medium-duty trucks account for the majority of the diesel passenger vehicles sales (Appendix Fig. 6). J.D. Power predicts an increase in the diesel market share to about 10% by 2015 (Daily 2006). Automakers have a reason to expand their diesel production, because certain low NO_x-emitting vehicles now qualify for up to \$3400 in tax credits through 2010. The market is still somewhat limited, however, due to regulations in California, Massachusetts, Maine, New York, and Vermont that prevent the sale of diesel vehicles. Diesel is also only sold at about 42% of fuel stations throughout the United States (Durbin 2006).

Diesel Uses

The main use of diesel fuel in the United States is on-highway transportation, accounting for approximately 60% of diesel consumption (Fig. 9). On-highway transportation includes automobiles, trucks and buses, as well as the vehicles that are used to transport petroleum products. Other uses include off-highway, military, vessel bunkering, railroads, electric utilities, farms, oil companies, industrial, commercial, and residential consumption. Off-highway

consumption consists of construction facilities and equipment, logging, junkyards and refrigeration units on trucks. Vessel bunkering is defined as any commercial or private boat, including those operated by oil companies but excluding those operated by the U.S. Armed Forces. All purchases made by the U.S. Armed Forces, Defense Energy Support Center and Department of Defense are accounted for under military uses. In terms of diesel used for non-transportation uses, farms use diesel for tractors, irrigation pumps, crop dryers, smudge pots and milking machines. Oil companies themselves consume a portion of diesel during operations for drilling equipment, refining operations and space heating. In the industrial sector, diesel fuel is used mostly for powering machinery, but is also used for heating, air conditioning and lighting. Some diesel fuel is also used as an input for various manufactured products. Commercial and residential uses of diesel mainly include space and water heating, cooking, air conditioning, refrigeration and lighting.

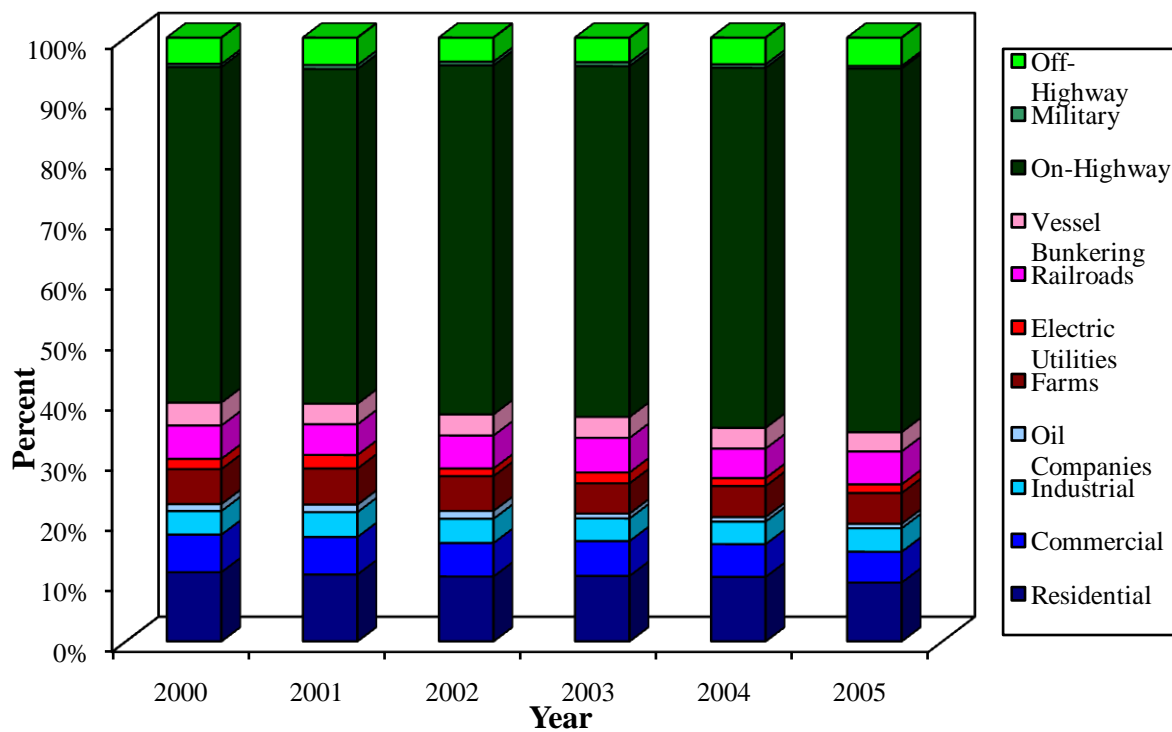


Figure 9: US Diesel end uses (EIA 2005).

The amount of diesel used for on- and off-highway transportation has been increasing steadily since 2000, while many other end uses of diesel have actually decreased (Appendix Fig. 7). Residential and commercial uses have both decreased, while industrial use decreased slightly in 2002 but has since risen. Oil companies, farms, military and electric utilities have also been decreasing their consumption of diesel while vessel bunkering and railroads have stayed relatively stable. Railroad use of diesel fuel tends to fluctuate year to year.

Prices

The cost of biodiesel as compared to fossil fuel diesel is a key factor in its future market penetration. Historically, B99 or B100 has been significantly more expensive than regular diesel. As the percentage of biodiesel in the diesel mix decreases, the price decreases as well (Fig. 10). Nominal prices are shown below and taken from the EIA as available; biodiesel costs vary greatly by region and feedstock and therefore data is only available twice a year and is based on limited sampling. The graphs below represent retail fuel costs at private and public costs and therefore include taxes and subsidies. Prices of B99-B100 have stayed around \$3.30 with the exception of June 2006, when prices spiked to \$3.76. The price of B2-B5 stays very close to the price of diesel, while the price of B20 is always slightly higher than diesel, with the exception of May of 2007. When comparing prices, it is important to take into account the slightly lower energy content of biodiesel compared to fossil fuel diesel. In order to compare prices over time and between types of fuel, Figure 11 shows the price in real dollars per gallon of diesel equivalent. This depiction does not significantly change the shape of the curves; however, it demonstrates the higher cost of B100 due to its lower energy content.

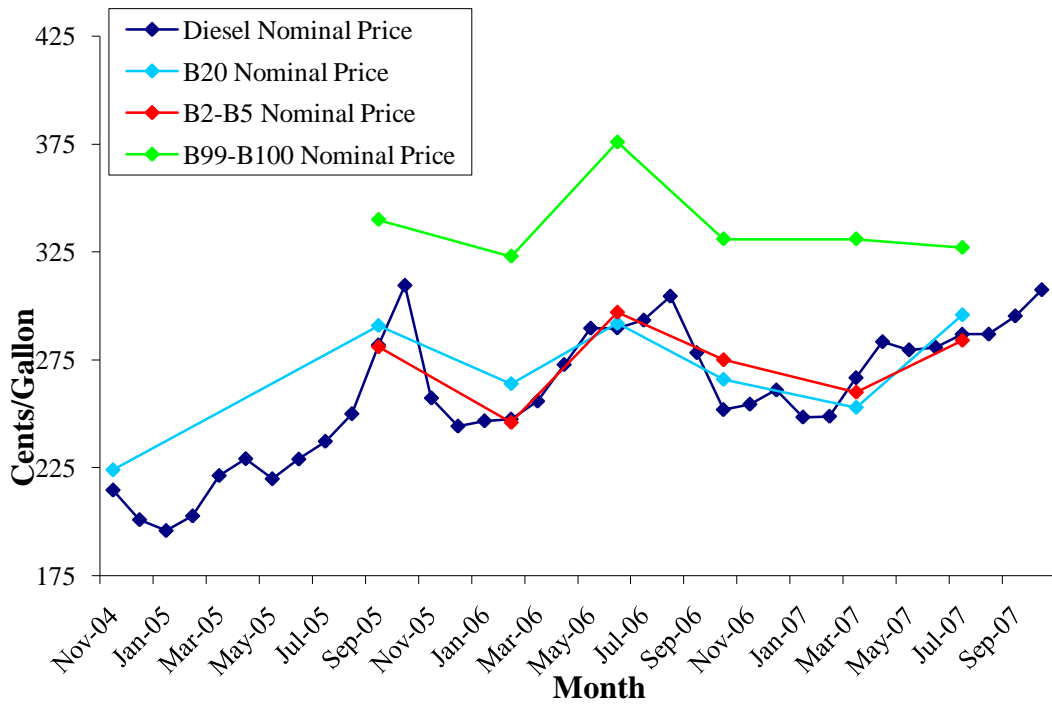


Figure 10: Nominal price of diesel fuels (EIA 2007, EERE 2005-2007).

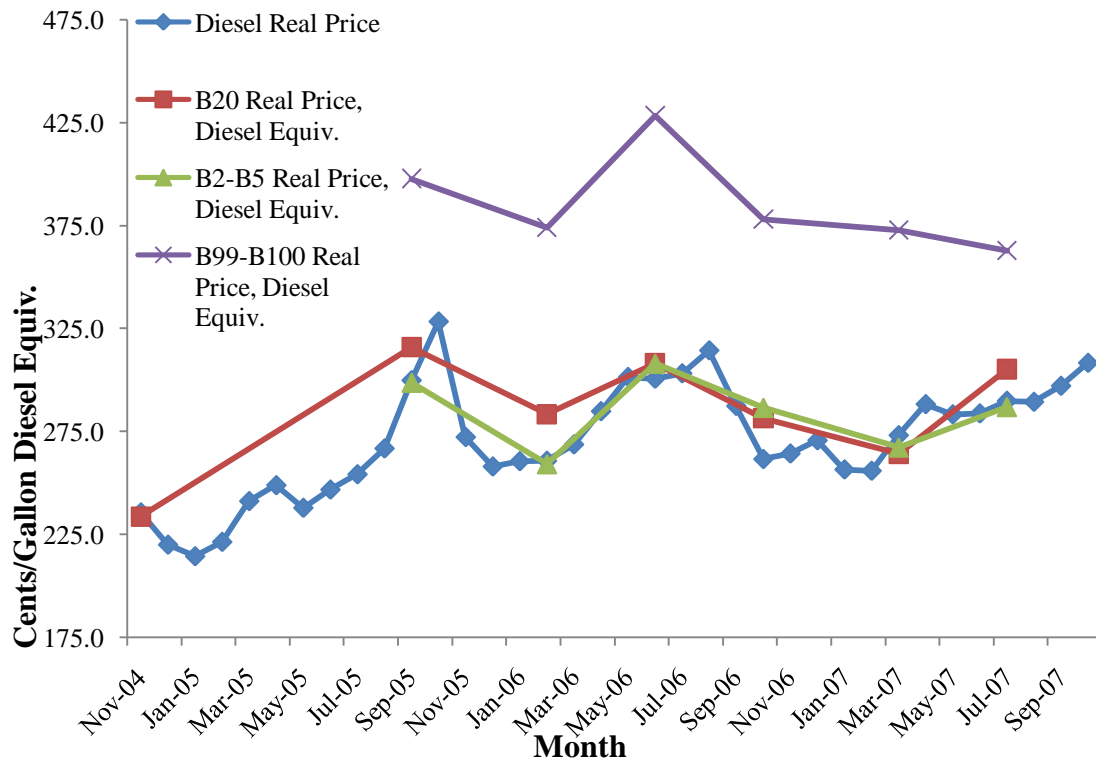


Figure 11: Real prices of diesel fuels (EIA 2007; EERE 2005-2007).

Feedstock Analysis

The major determinant of the cost of biodiesel is the feedstock from which it is produced. In order to determine the market potential of biodiesel, it is necessary to analyze the costs of each feedstock, as well as their different characteristics and availability. According to the EIA, for fuel produced from virgin vegetable oils, feedstocks can account for 70-78% of the production cost. For non-virgin oils, this percentage can be anywhere from 0-70% (Howell 2005). Soybeans were used as an example feedstock to further breakdown of the cost of a gallon of biodiesel. Analysis of a 2005 gallon of biodiesel produced from soybeans (Fig. 12) shows that the soybeans account about 30% or \$1.01 of a \$3.40 gallon of biodiesel, and the transport of the soybeans to the soybean crushing facilities costs only 1% or \$0.03. Crushing the soybeans is the most expensive part of the process, accounting for 35% (\$1.21) of the cost of production. Transporting the oil to the biodiesel refinery costs approximately \$0.13, and the refining of the soybean oil to produce biodiesel costs only slightly more than the soybeans themselves, at about \$1.02.

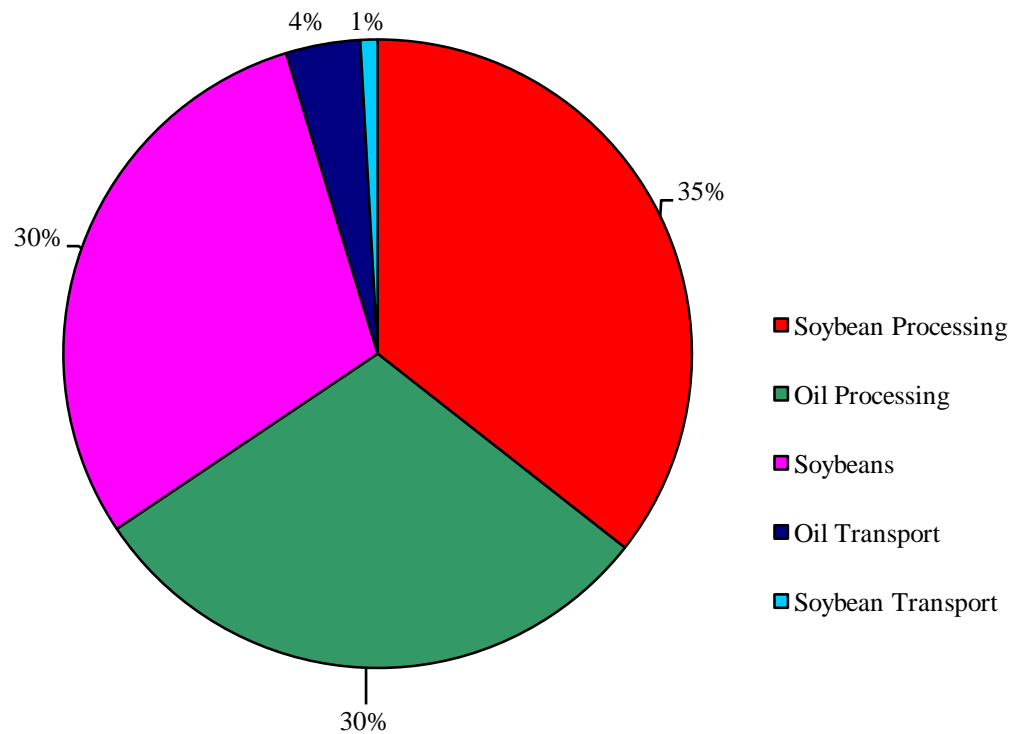


Figure 12: Breakdown of cost of one gallon of biodiesel (EERE 2005; CRB 2006).

Soybeans

As previously mentioned, the United States uses soybean oil as its primary feedstock source for biodiesel. The United States is the highest producing nation of soybeans (Fig. 13), dedicating an average of 72 million acres of land to the crop. This area represents 17% of all the cropland in the lower 48 states. Each acre of land yields 43 bushels of soybeans, which has risen from 28.9 bushels per acre in 1975. Yield is expected to increase by approximately 0.5 bushels per year (EIA 2007). South America also grows significant amounts of soybeans, with Brazil and Argentina as the second and third largest producers in the world. The US produces a relatively consistent amount of soybeans each year, though there was a noticeable decline in the 2003-04 season. Brazil, Argentina, Bolivia, and Russia are all increasing their production. The

EU was the major importer of soybeans until the 2002-03 agricultural year, when China surpassed the EU (Fig. 14). China has remained the top importer of soybeans since that time, despite also being the fifth largest producer in the world. Other nations that import significant amounts of soybeans include Japan, Mexico, Taiwan and Korea. The three top producers, the US, Brazil and Argentina, are also the top exporting countries, followed by Paraguay and Canada.

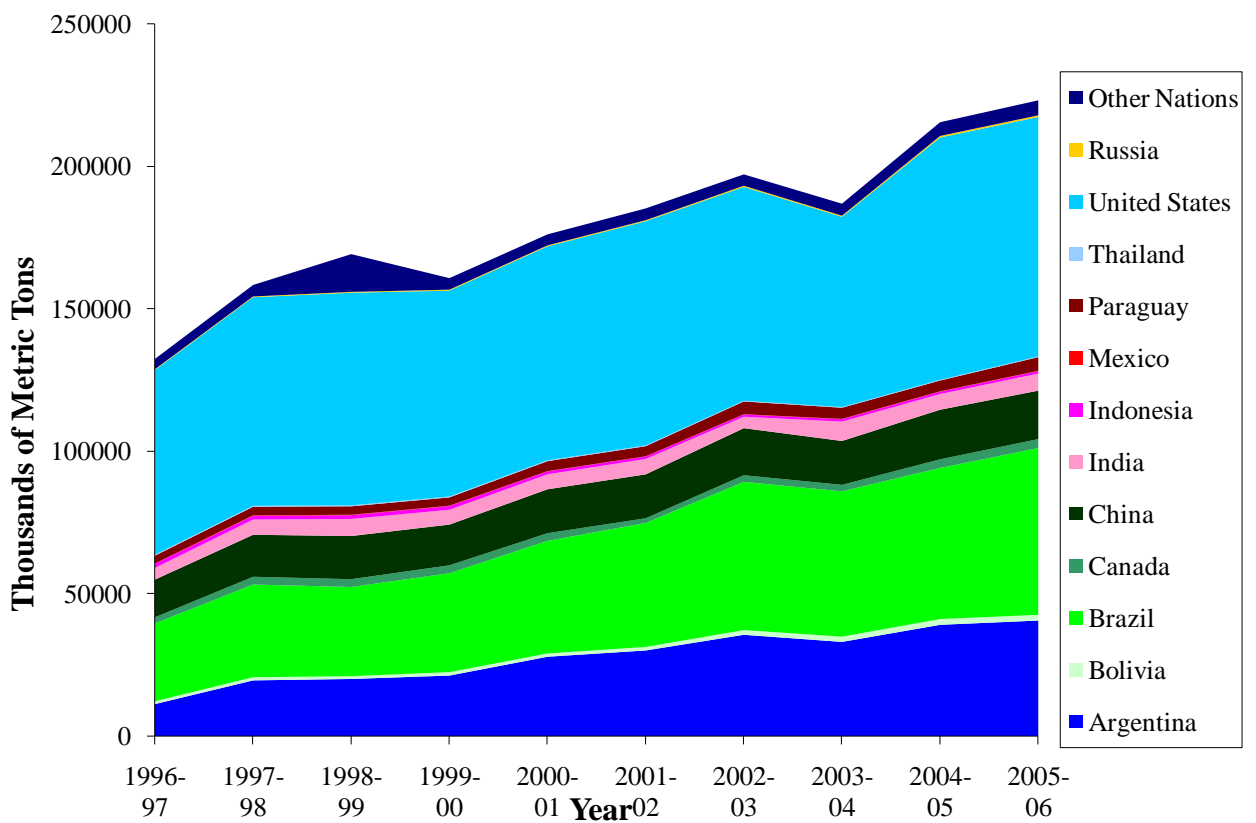


Figure 13: World soybean production and contribution by nation (CRB 2006).

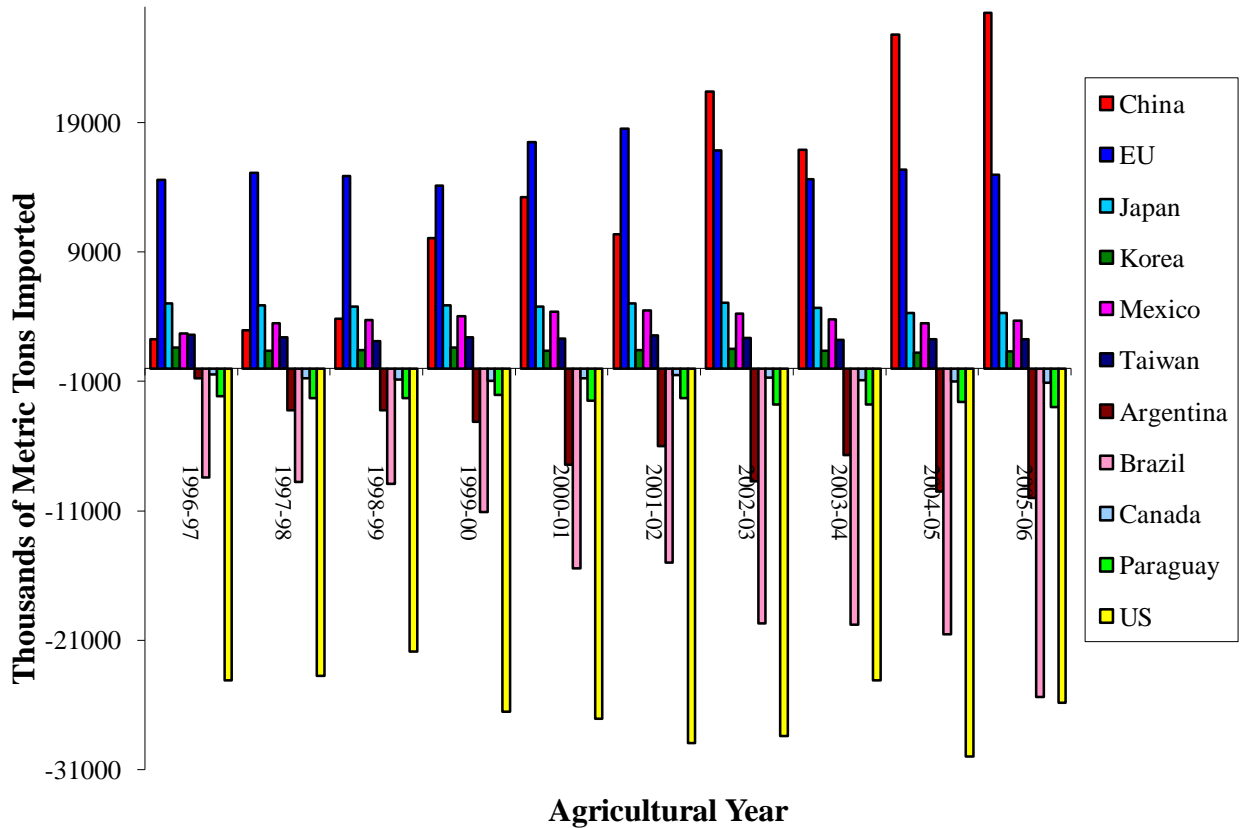


Figure 14: Top soybean import/export nations (CRB 2006).

The vast majority of soybeans is crushed and used for meal and oil, and the remainder is used in whole bean form for food (Appendix Fig. 8). About 19% of the weight of a soybean is extracted as oil, though this amount varies with the temperature and amount of sun during the growth period. Similar to soybeans, the United States is the top producer of soybean oil in the international market. Along with Brazil and the EU, the US accounted for the majority of the soybean oil production until the most recent decade, at which point other countries began significantly increasing their production (Fig. 15). While the US and Brazil are the two top exporters of soybean oil, US exports have decreased slightly and Brazil's have increased significantly since the turn of the century (Fig. 16). These trends demonstrate the interaction of the US's constraints on soybean oil exports with growing world demand. India is the major

importer of soybean oil; however, it is not receiving significant amounts from the United States. The US exports primarily to Canada and Mexico, and has decreased export amounts to further countries such as Pakistan, Morocco, India, and Peru (Appendix Fig. 9). Oil that is not exported is used mostly for shortening and cooking and salad oils (Fig. 17). This has not always been the case as soybean oil was used mostly for resins and plastics until the last decade before it began to replace lard in shortening because of rising health concerns in the United States. Another recent change in use has been an increase use for biodiesel, which absorbed approximately 15% of available soybean oil in 2007.

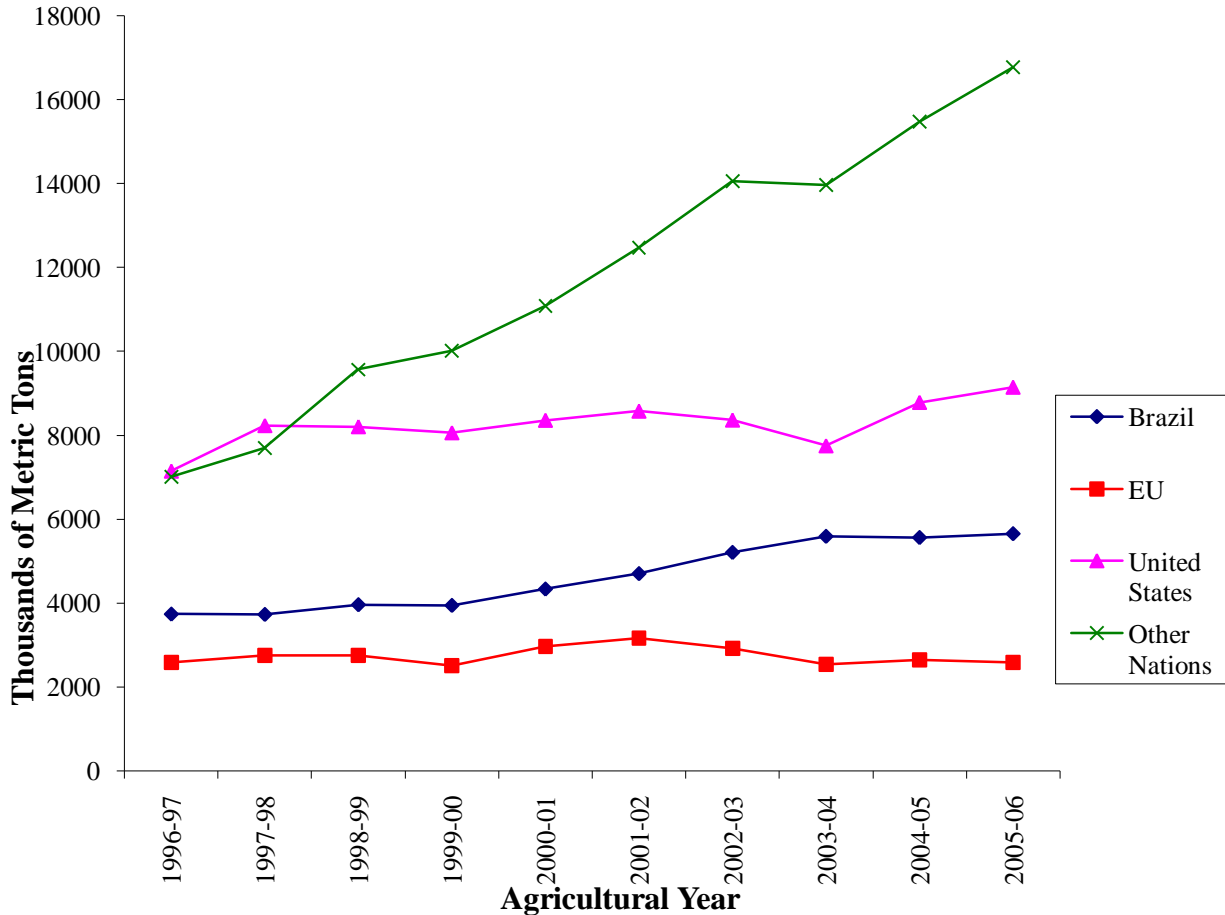


Figure 15: World production of soybean oil (CRB 2006).

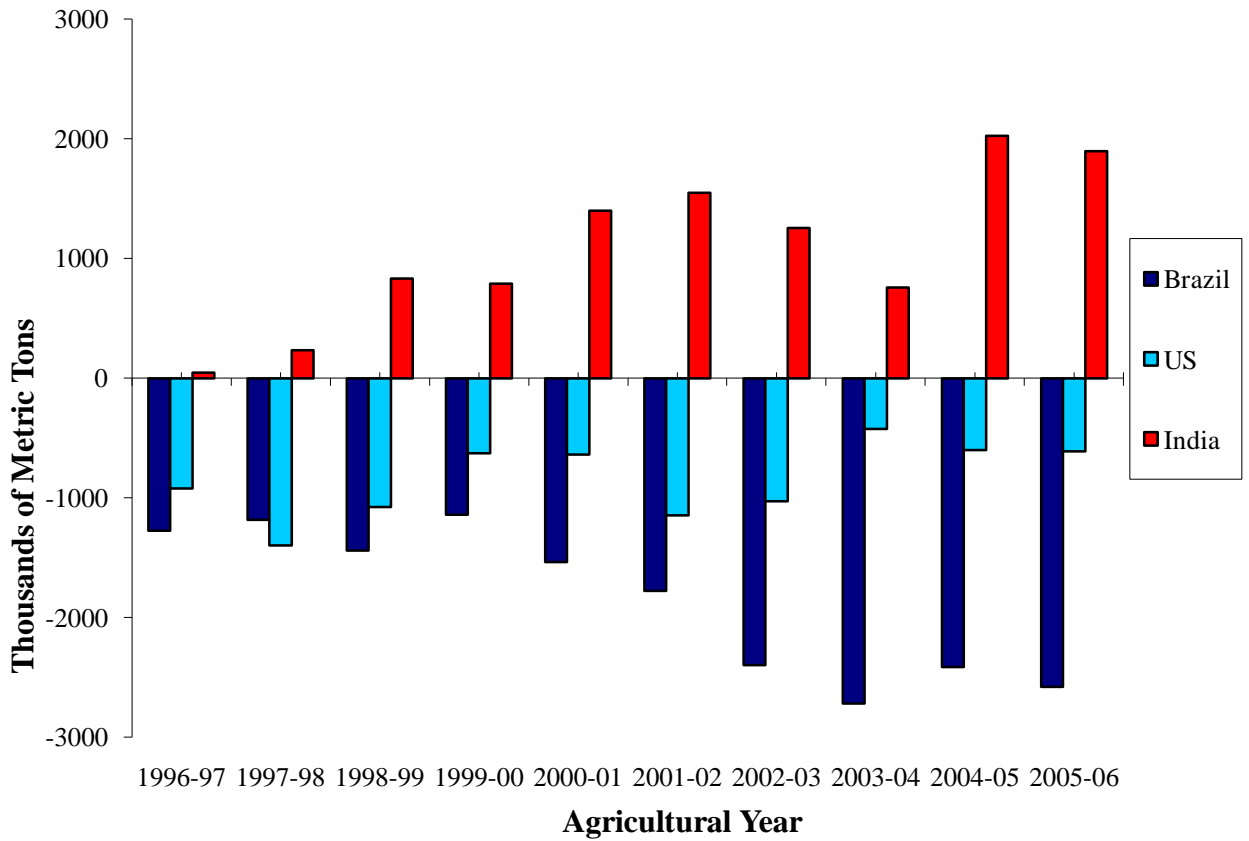


Figure 16: World imports and exports of soybean oil (CRB 2006).

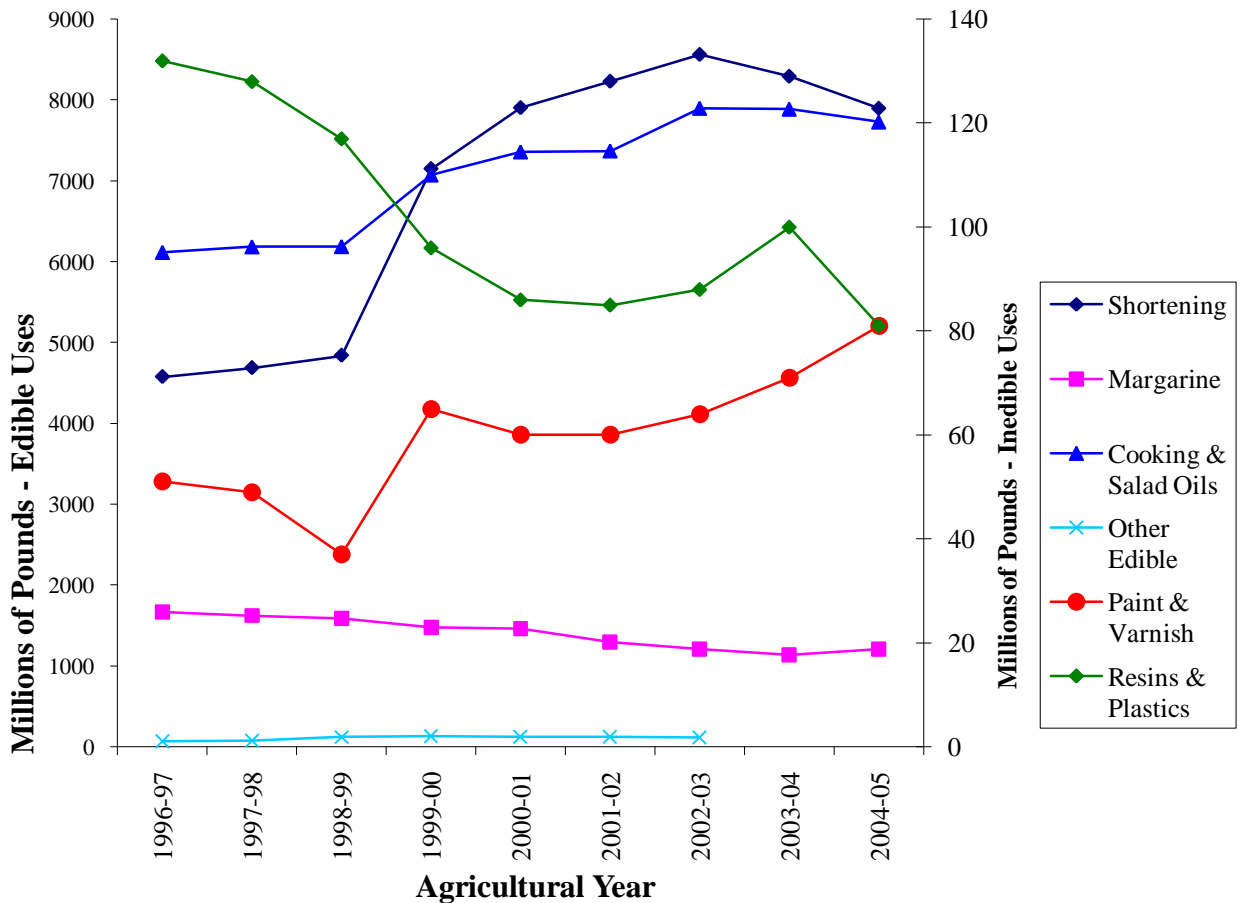


Figure 17: Domestic uses of soybean oil (CRB 2006).

The widespread use of soybean oil as a feedstock for biodiesel in the United States has resulted from a number of different factors. First, because the US is the largest producer of soybeans and soybean oil in the world, soybeans are commonly available in almost all regions of the country. Soybean oil is the most common vegetable oil produced in the US, accounting for 60% of the total fats and oils produced domestically. These factors contribute to a relatively low price of soybeans compared to most other plant oils. The national soybean associations have effectively promoted the product as a biodiesel feedstock, and biodiesel producers have been loyal customers because of its reasonably constant chemical composition (Stroup 2004). The USDA voluntary Bioenergy Reporting program provided information on the amount of different

feedstocks used to produce biodiesel through 2006, when the program lost funding. The results of the reports are important in demonstrating the dominance of soybean oil as a feedstock (Fig. 18). Various animal fats and oils were reported as a distant second most commonly used feedstock (Fig. 19). Though the findings from the Bioenergy Reporting program are not a complete picture of the entire biodiesel industry, the results are consistent with the refinery capacity in the United States.

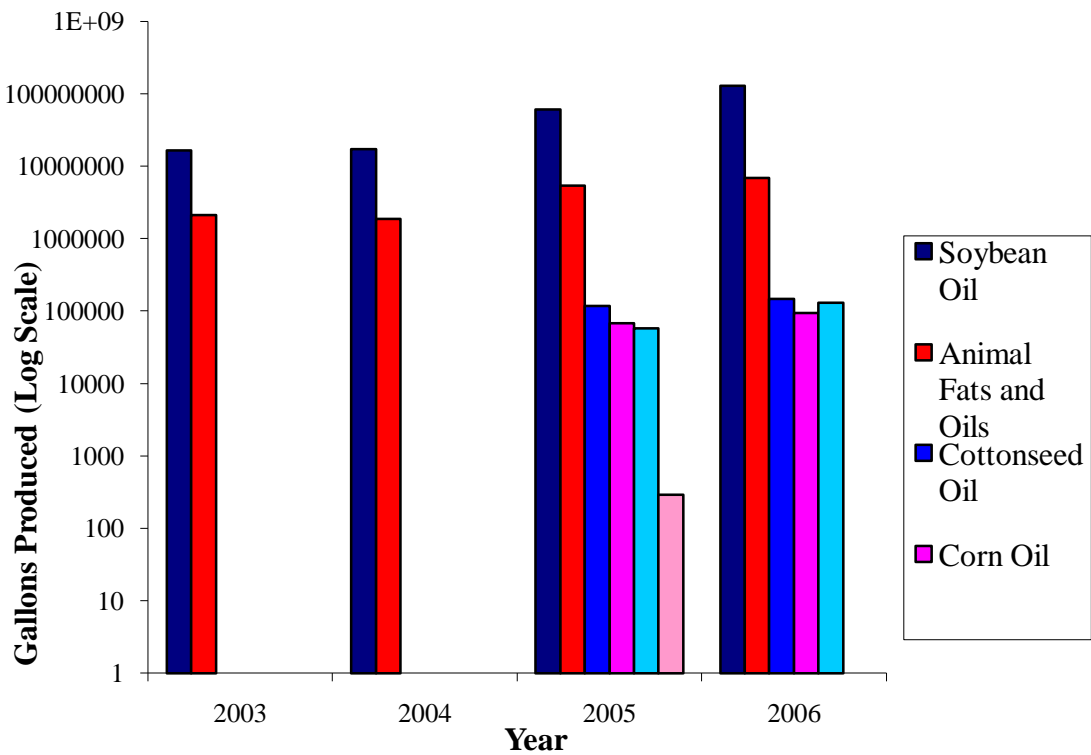


Figure 18: US Bioenergy Program: Reported gallons produced (log scale) (USDA Bioenergy 2006).

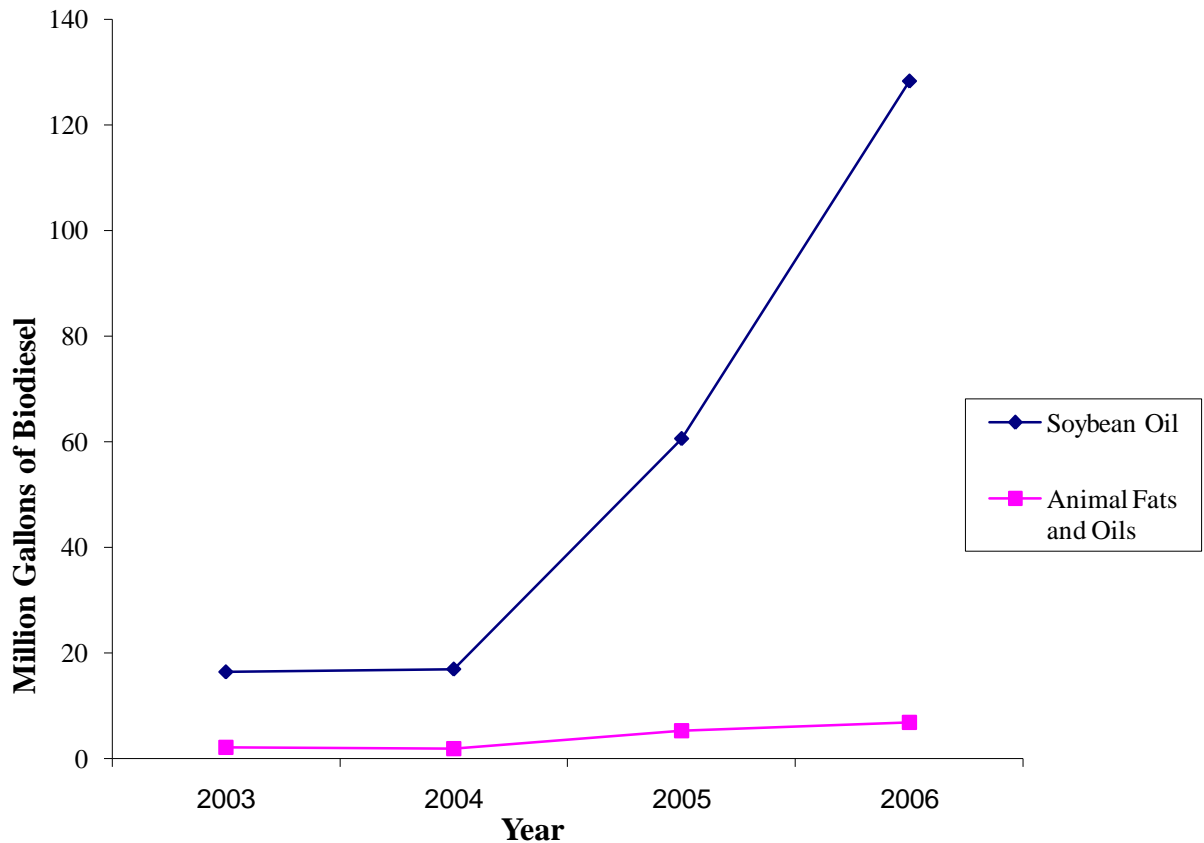


Figure 19: US Bioenergy Program: Reported biodiesel production from top feedstocks (USDA Bioenergy 2006).

Canola

Canola oil is the most common biodiesel feedstock in the EU, and therefore internationally. Canola plants originated in Canada and are a modified version of the rapeseed plant. The pods of the plants contain small seeds that are then crushed. Approximately 40% of the weight of the seed is extracted for oil, which is over double the content of soybeans. Consequently, canola is primarily grown for its oil (Appendix Fig. 10) and is generally considered a better crop for biodiesel production. It accounts for approximately 13% of vegetable oil in the world, and is the third most common after soy and palm oil. The oil is also often used

for salad and cooking oils, margarine, ink manufacturing, greases, cosmetics, medicines and soap. Seeds that are not crushed are sometimes used in birdfeed, and the meal from the crush is used in high-protein livestock feed. Though Canada originated the crop, China was the highest producing country until 2000-01. During the 2000-01 growing season Germany took over most of the EU's canola production and surpassed China's production levels (CRB 2006) (Fig. 20). China and the EU consume their domestically produced canola, leaving Canada as the top exporter of canola oil worldwide. Canada dedicates 13 million acres of land to canola production and produces only 15% of the total world crop, but export 75% of the world's imports (Canola 2007). Seventy-five percent of those exports go directly to the United States (CRB 2006). The United States acquires most of its canola already crushed as opposed to importing the seed and crushing it domestically (Appendix Fig. 11).

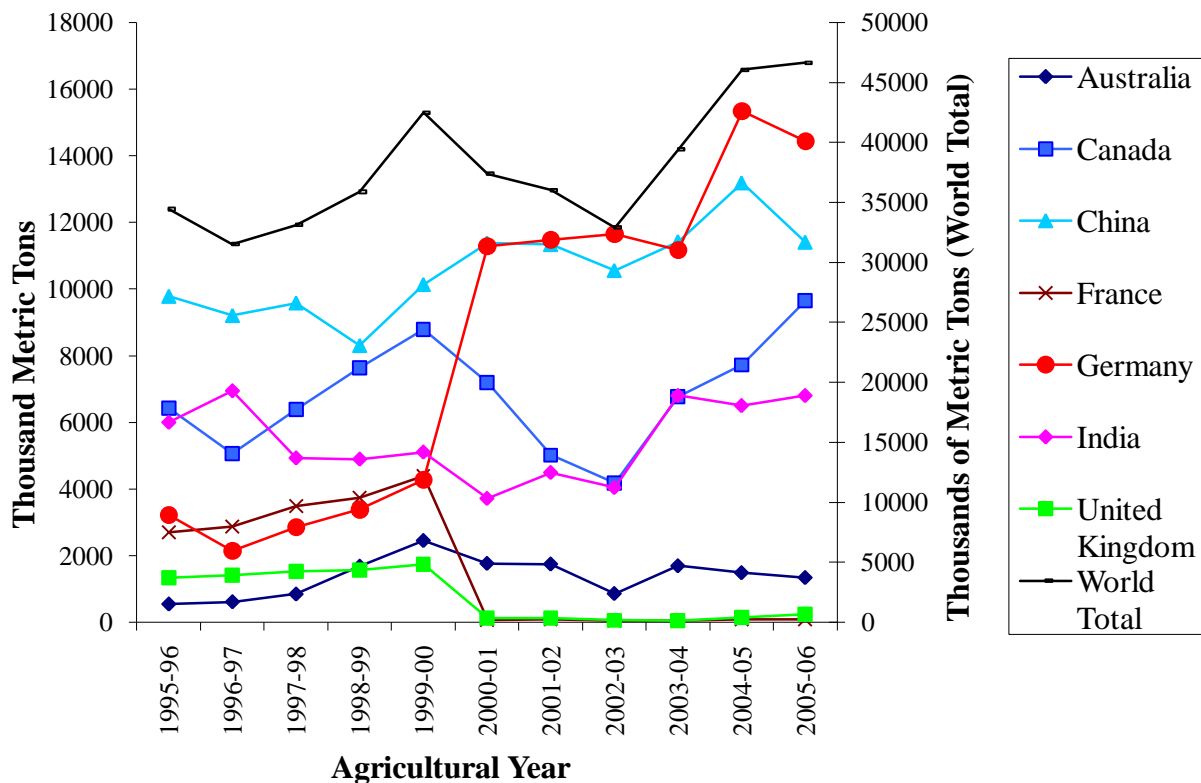


Figure 20: World canola production (CRB 2006).

Palm

Unlike most other vegetable oils, palm oil is actually produced from the flesh of the fruit of the palm tree. Oil can be extracted from the seed similarly to other plants, but this process produces a much lighter oil. Oil from the seed is called palm kernel oil and is generally used for food, while palm oil is used more often for soap, ointments, cosmetics, detergents, and machinery lubricants. Ten times the amount of oil is extracted from the fruit than from the seed. Malaysia is the top producer of palm oil, followed closely by Indonesia. Nations near the equator produce more palm oil, with Nigeria, Thailand and Colombia as major producers as well (Appendix Fig. 12). Malaysia and Indonesia are also the top palm oil exporting nations, with exports increasing significantly every year. Nigeria, Thailand, and Colombia consume their palm oil domestically and therefore do not export, leaving Hong Kong, Papua New Guinea and Singapore as other leading palm exporters (Appendix Fig. 13). India and China are the world's largest importers of palm oil. India experienced a major increase in demand in the mid 1990's, and China began to experience a similar increase starting in 2000. China has now surpassed India in palm oil demand. The United States' growth in demand for palm oil imports has been increasing similarly to China and India, with imports reaching 315,000 metric tonnes in 2005. Other major importing countries, including Germany, the Netherlands, Pakistan, and the UK, have maintained a relatively constant demand for palm oil imports.

Sunflower Seed

Sunflower seeds are commonly grown and used for oil worldwide. The weight of the seed is 39-49% oil, which accounts for about 80% of the value of the seed. One acre of sunflower seed crop yields approximately 50 bushels of seed per acre which can be made into 50

gallons of oil. This high oil content and the high energy content of the oil (93% of the energy content of fossil fuel diesel) makes sunflower seed oil a good candidate for biodiesel production. However, high prices and variable acreage and crush of the seeds have been major barriers to its use. Sunflower seeds are used often for food for people, livestock, and birds, and the oil is used mainly for soaps, candles, varnish and detergents. Argentina and the Former USSR are the two top producers of sunflower seeds. Argentina, however, began to decrease its production at the beginning of the 21st century and fluctuate sunflower seed exports on a yearly basis. The Former USSR began to increase, now dominating world production (Appendix Fig. 14). This is also the case for sunflower seed oil, because most seeds are crushed in the country in which they were grown (Appendix Fig. 15). China, France, India, Romania, Hungary and the United States also grow large amounts of sunflowers seeds. The Former USSR and even Uruguay have thus recently been major players in the international market. Turkey, the Netherlands, Spain, Germany and France are the highest importing countries in the world, though overall imports have been decreasing in recent years (Fig. 21). Turkey, France and Spain import their seeds and produce the oil domestically, making them the top sunflower seed oil producing nations after Argentina and the Former USSR. In the past decade, the United States has been decreasing its production of sunflower oil. Domestic consumption has remained steady thus the US has decreased its exports in response to decreased production (Appendix Fig. 16). The decreased production in the United States is partially due to a decrease in sunflower seed supply but is also a result of decreased crush. The US crushed approximately half of its sunflower seed until 2002, at which point sunflower seed crush decreased (Appendix Fig. 17).

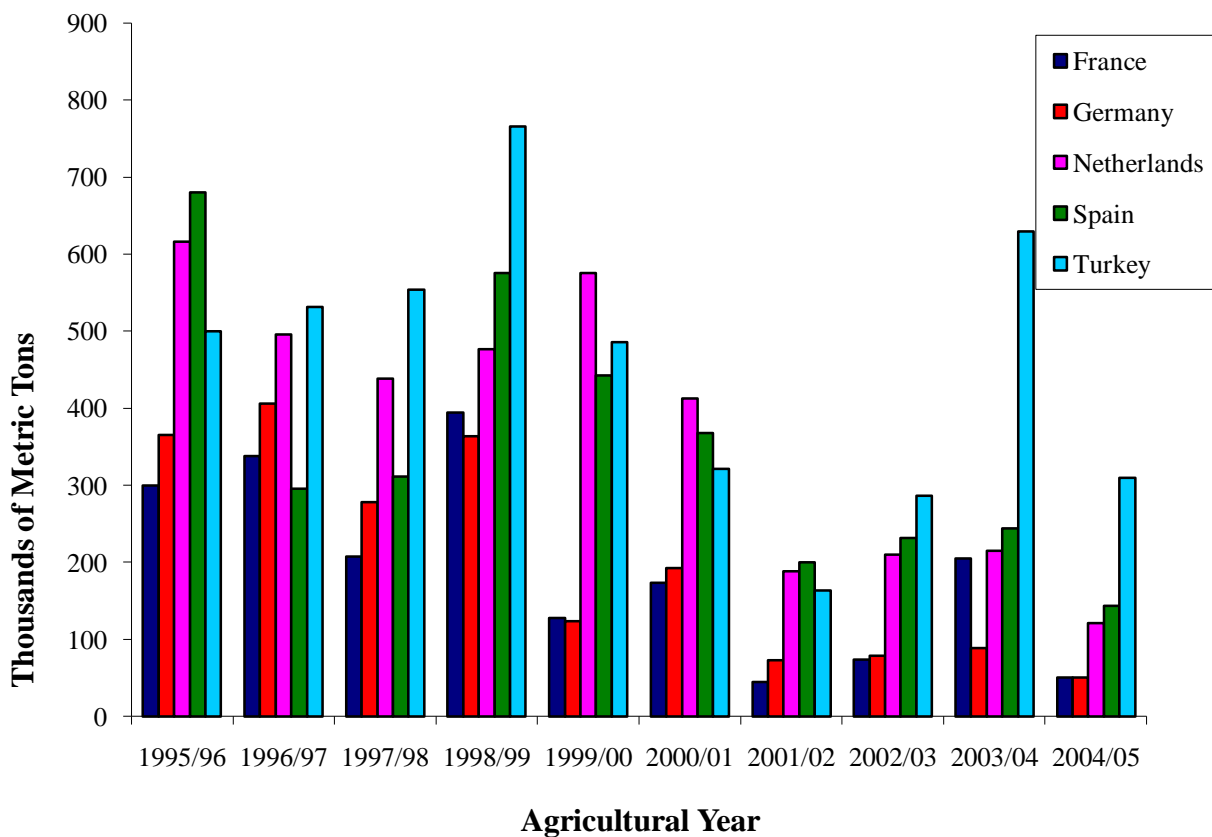


Figure 21: Top sunflower seed importing nations (CRB 2006).

Cottonseed

Cottonseed is a less common feedstock for biodiesel, though it is a common crop in all regions of the world. Approximately 16% of the weight of the seed is extracted as oil (NCPA 2002), and is used most often for cooking oil. The seeds of the cotton plant provide 18% of a cotton producer's income. China is the world's most prevalent producer of cottonseed, with 24% of the world's total production. The US, India, and Pakistan are also major producers at 17%, 16% and 10% respectively. These countries have all been increasing their production in recent years (Fig. 22).

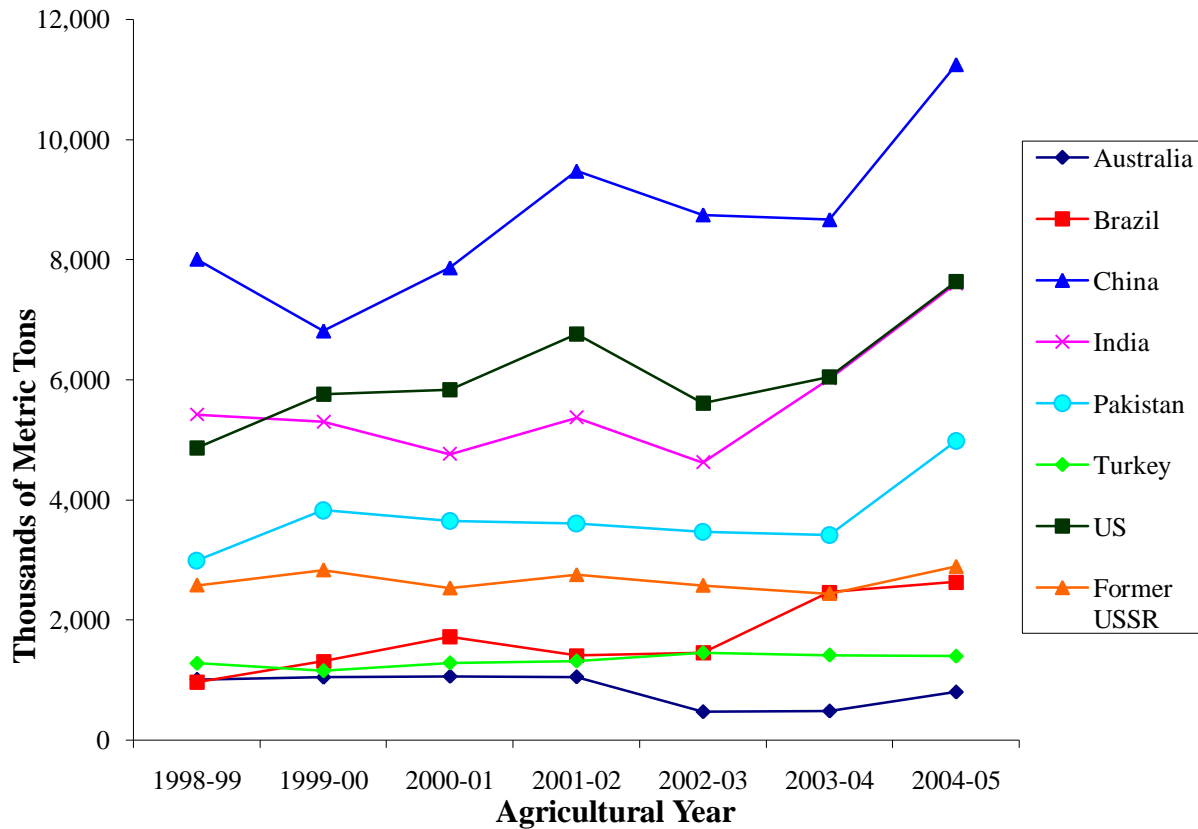


Figure 22: Top world producers of cottonseed (CRB 2006).

Coconut

Another less common feedstock for biodiesel is coconut oil, though coconut oil itself has been a common cooking oil for thousands of years. It is mainly produced in tropical areas and is a staple of most diets in those areas. The US imported and used coconut oil as a major cooking oil until WWII when there were shortages of imported oil. Coconut oil that is fit for human consumption must go through an extended refining process. Expeller press and solvent extraction methods are used to remove the oil from the copra, and then the oil must be neutralized, bleached, and deodorized at high heat and with a vacuum. The byproduct of this refined oil is

used for livestock feed, and the refined oil is used mostly for margarine, shortening, salad oils, confections, and energy or sports drinks, as well as soaps, detergents, shampoos, cosmetics, candles, glycerin and synthetic rubber. Coconut oil is produced in the nations that grow coconut palms. The Philippines produce 41% of the world's palm oil, and other top producers include Indonesia, India, and Mexico (Appendix Fig. 18). Europe is the top consumer of coconut oil, consuming nearly as much as Indonesia produces on a yearly basis. India and the United States are also large consumers of coconut oil that must import their supplies (Appendix Fig.19). In the past decade, the US has been gradually decreasing its use of coconut oil for inedible consumption and increasing its edible consumption (Appendix Fig. 20).

Corn

The United States dominates the world market for corn, at 41% of production, and corn dominates US agricultural acreage. It is grown primarily for its use as livestock feed, and is not traditionally grown as an oilseed crop because it contains only 4% oil content. Oil from “high-oil” corn can account for up to 7% of the corn weight (CRB 2006). Though corn is not grown as a biodiesel feedstocks, some refiners have begun using the oil byproduct from ethanol production to produce small amounts of biodiesel (GSCT 2007). Alternatively, corn oil is also used for cooking oil, margarine, mayonnaise, soaps, paints, inks, varnishes, and cosmetics (CRB 2006) (Appendix Fig. 21).

Peanuts

Peanut oil can also be used for biodiesel production, but like many other possible feedstocks, it is not widely available and is even more expensive than sunflower seed oil. When

peanuts were originally brought to the United States, they were used primarily for pig feed, but now there are over 300 uses for peanuts including shaving cream, leather dye, coffee, ink, cheese and shampoo. There are four basic types of peanuts in the US: Runner, Spanish, Valencia and Virginia. Peanut oils are produced primarily from Spanish peanuts. It is extracted from shelled and crushed peanuts through hydraulic pressing, solvent extraction or expelled pressing. The refined oils, which must be bleached and deodorized, are used for cooking, margarine and shortening. Press cake, the byproduct from crushing, and the tops of peanut plants are used as cattle feed. In addition to refining the oil for biodiesel, energy can also be produced from peanuts by burning the dry shells for electricity. China is the leading producer of peanuts in the world, followed by India, the US, Nigeria and Indonesia (Appendix Fig. 22). China's production increased significantly at the end of the 20th century, while India's decreased. Other top producing countries have stayed relatively steady in their production. The United States uses the vast majority of its peanut stocks directly for food, only crushing a small percentage for oil (Fig. 23).

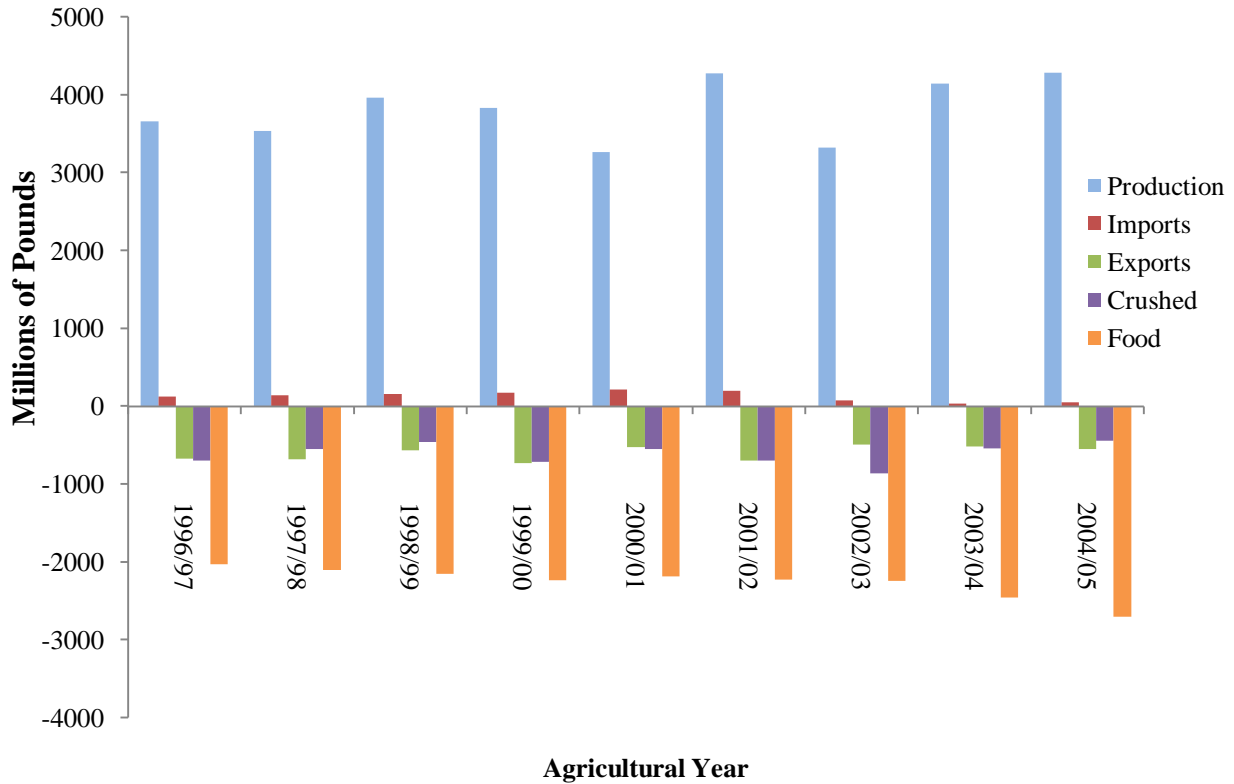


Figure 23: US Supply and disappearance of peanuts (CRB 2006).

Animal Fats

Animal fat products are, like plant oils, composed of triglycerides. They have been proven to emit less NO_x than plant oils when burned as fuel and are generally less expensive despite requiring more pretreatment. Biodiesel produced from animal fats is generally considered a more environmentally-friendly product than biodiesel from other feedstocks because it is made from a waste product and solves the problem of grease and fat disposal (Stroup 2004). The American Fats and Oils Association provides specifications such as color, melting point, density, moisture content and insoluble impurities to characterize different types of fats, including edible tallow, edible lard, top white tallow, all beef packer tallow, extra fancy tallow, fancy tallow, and yellow grease. Lard and tallow are the two animal fat commodities traded in the United States.

Lard is the fat layer removed from pigs, and thus its supply is directly related to the supply of pigs raised for livestock. It is a preferred cooking oil because it produces very little smoke when heated. Lard is also used for medicinal purposes such as in ointments, plasters, liniments and laxatives. China is by far the largest producer of lard in the world due to the common consumption of pork (Appendix Fig. 23), and only continues to grow. The United States is the next highest producer of lard, followed by Germany, Brazil, the Former USSR, Spain, Poland, Italy, France and Canada. Brazil experienced a drastic increase in lard production in 2000 (Fig. 24), related to an increase in all Brazilian agricultural production but especially hog production. Lard production in the US has been increasing steadily, but consumption has been decreasing significantly due to health concerns (Fig. 25). This has led to a large increase in lard exports (Fig. 26).

Tallow and grease, similar to lard, are the fat collected from the production of cattle for food. It is used for margarine, cooking oil, baking products, soap, candles and lubricants. Because the production of tallow and grease is directly related to the production of cattle, those countries that raise large numbers of cattle are large producers of tallow and grease. The US dominates the world market for tallow and grease, followed by Australia, Argentina and Canada (Appendix Fig. 24).

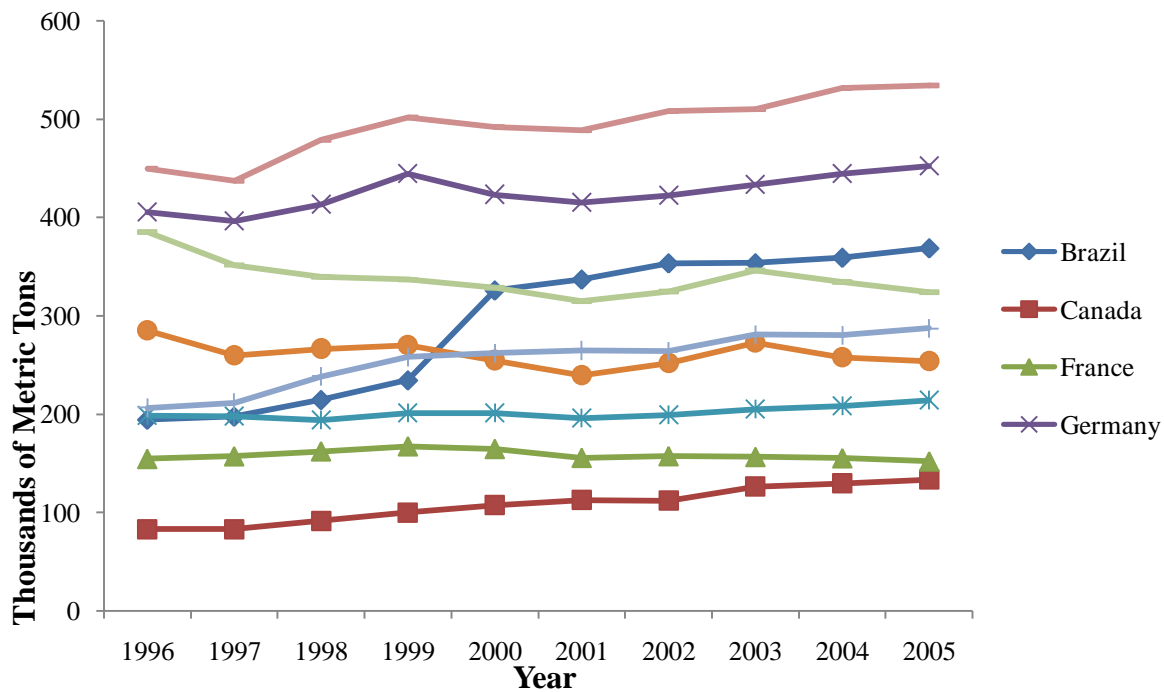


Figure 24: World production of lard (excluding China) (CRB 2006).

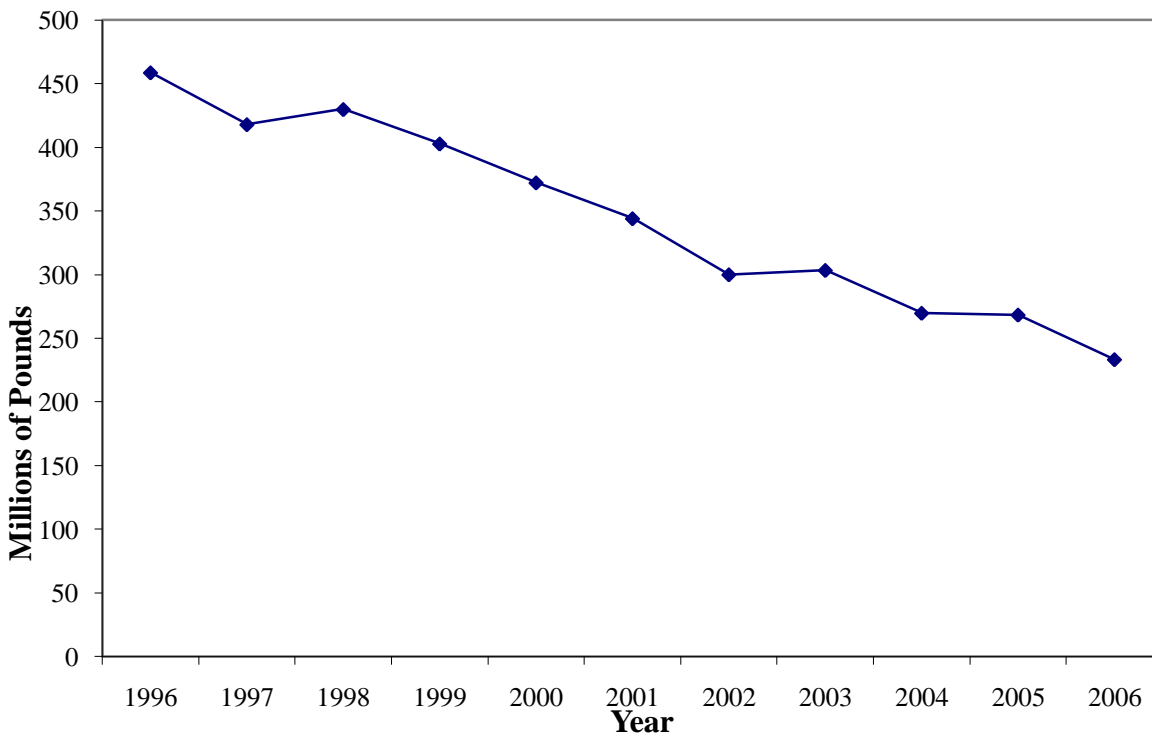


Figure 25: US consumption of lard (edible and inedible) (CRB 2006).

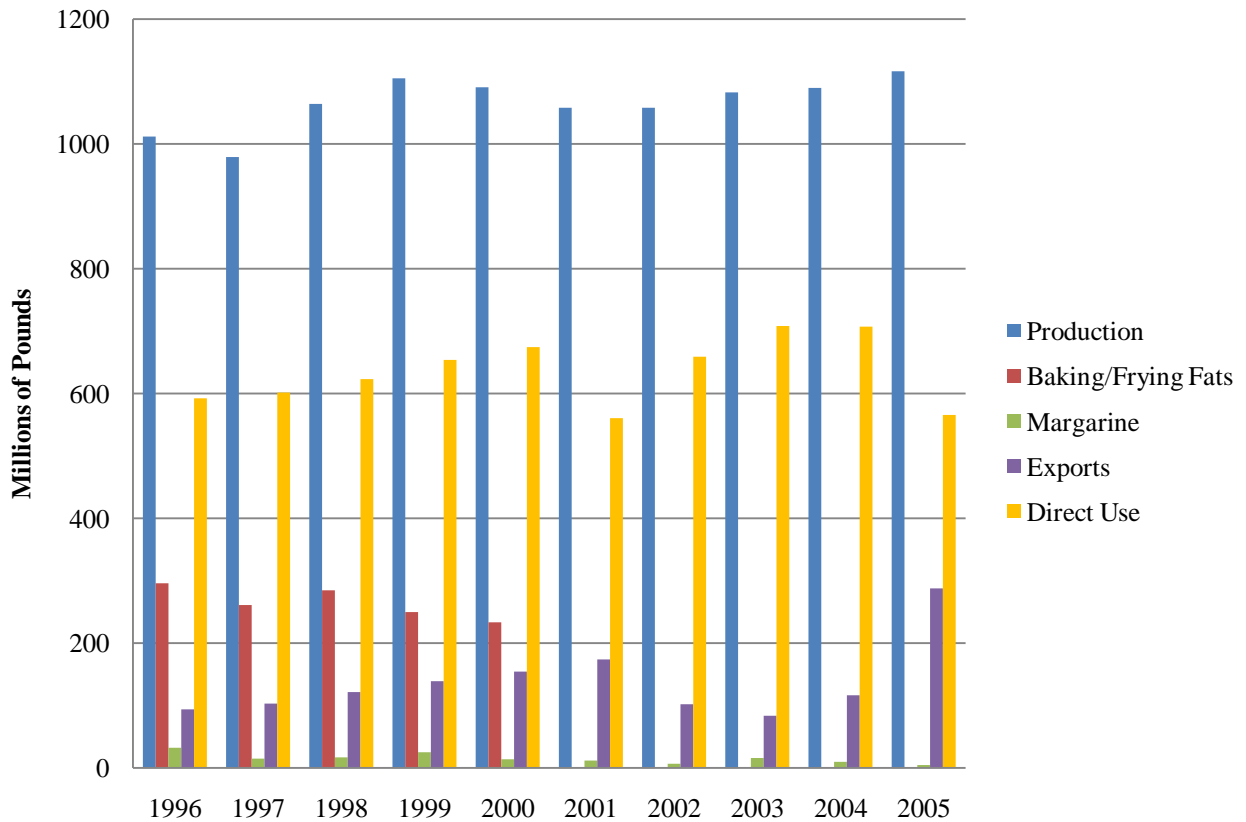


Figure 26: Production and distribution of lard in the US (CRB 2006)

*Baking/frying fats info withheld after 2000

Prices

The main factor in determining which feedstock is used for biodiesel is price. In general, animal fats are less expensive than vegetable oils (Fig. 27). Tallow, grease and lard have been less than \$0.20 per pound, though lard has risen above \$0.20 in the past few years. One gallon of biodiesel can be produced from approximately 7 to 7.6 pounds of fat or oil according to the National Biodiesel Board; 7.5 pounds was assumed for this analysis. Soybean oil and corn oil are the least expensive plant seed oils in the US, usually below \$0.30 a pound. Sunflower seed oil and peanut oil can be up to twice as expensive.

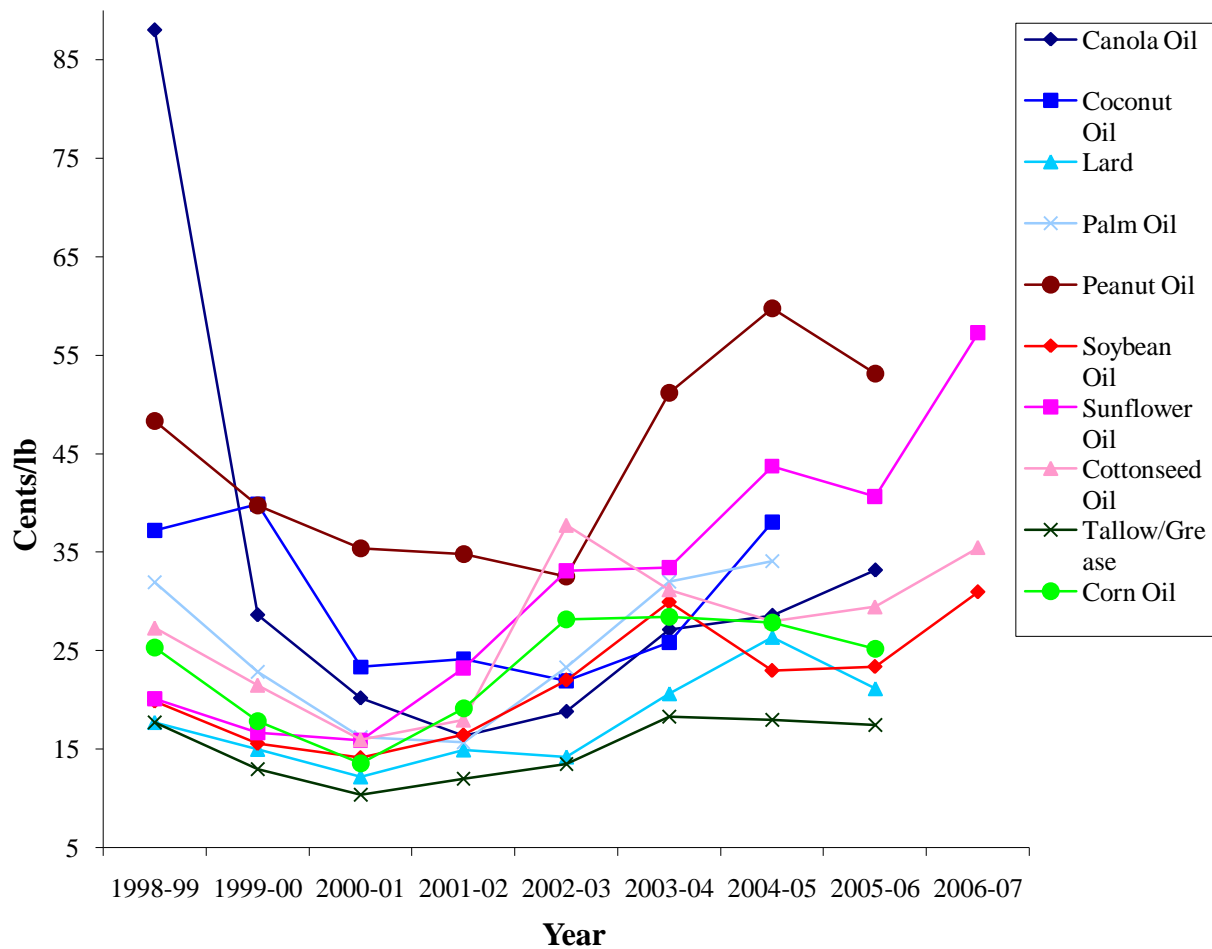


Figure 27: Prices of feedstocks (CRB 2006).

Supply Curve Factors

In order to understand the interaction between the price of feedstocks and the amount of biodiesel produced and supplied to the market, series of supply stacks and supply curves were constructed based on EIA data and commodity prices. The EIA equation was adopted from the NEMS model for the biodiesel supply curve in the Annual Energy Outlook publication for 2007.

The equation for calculating the cost of production for one gallon of biodiesel is

$$CG=FC+CAP+OPER-GLYC-SUBSID$$

Where CG is the cost of production per gallon of biodiesel, FC is the cost of the feedstock used to produce one gallon of biodiesel, CAP is the capital cost per gallon of production capacity per year, OPER is the operation cost per gallon, GLYC is the value of the glycerin byproduct, and SUBSID is the amount of the subsidy received from the United States government per gallon of biodiesel.

For the 2007 production models, the quantities of biodiesel from different feedstocks listed below were estimated using 2007 production estimates as well as estimated assumptions of feedstock percentages. These percentages are based on numbers reported to the USDA Bioenergy Reporting program, which lost funding in 2006, as well as capacity estimates from the Biodiesel Magazine and the National Biodiesel Board (Table 2).

Table 2: Amount of Biodiesel Produced from Different Feedstocks in 2007

Feedstock	Gallons of Biodiesel Produced
Soybean Oil	409,500,000
Waste Vegetable Oil	13,500,000
Animal Fats (Lard, Tallow, Grease)	13,500,000
Canola Oil	9,000,000
Other (Cottonseed Oil, Sunflower Seed Oil, Palm Oil, Corn Oil)	450,000

All prices are adjusted from EIA inputs and use USDA feedstock prices in 2007 dollar values. The operation cost value of \$0.58 per gallon was adopted from the original EIA model. The EIA assumes \$0.21 (\$2007) value of glycerin; however, recent surplus in the glycerin market due to increased supplies from biodiesel producers has caused crude glycerin prices to fall as low as \$0.02 per pound. Most refineries are able to receive between \$0.06 and \$0.10 per pound (Kotrba 2007); \$0.08 was assumed for all scenarios. For all scenarios, the EIA value of \$0.18 per gallon was adopted for capital cost. The figure for 2007 Production Stack shows the quantity of biodiesel produced from each feedstock and the cost of producing one gallon of biodiesel from that particular feedstock (Fig. 28).

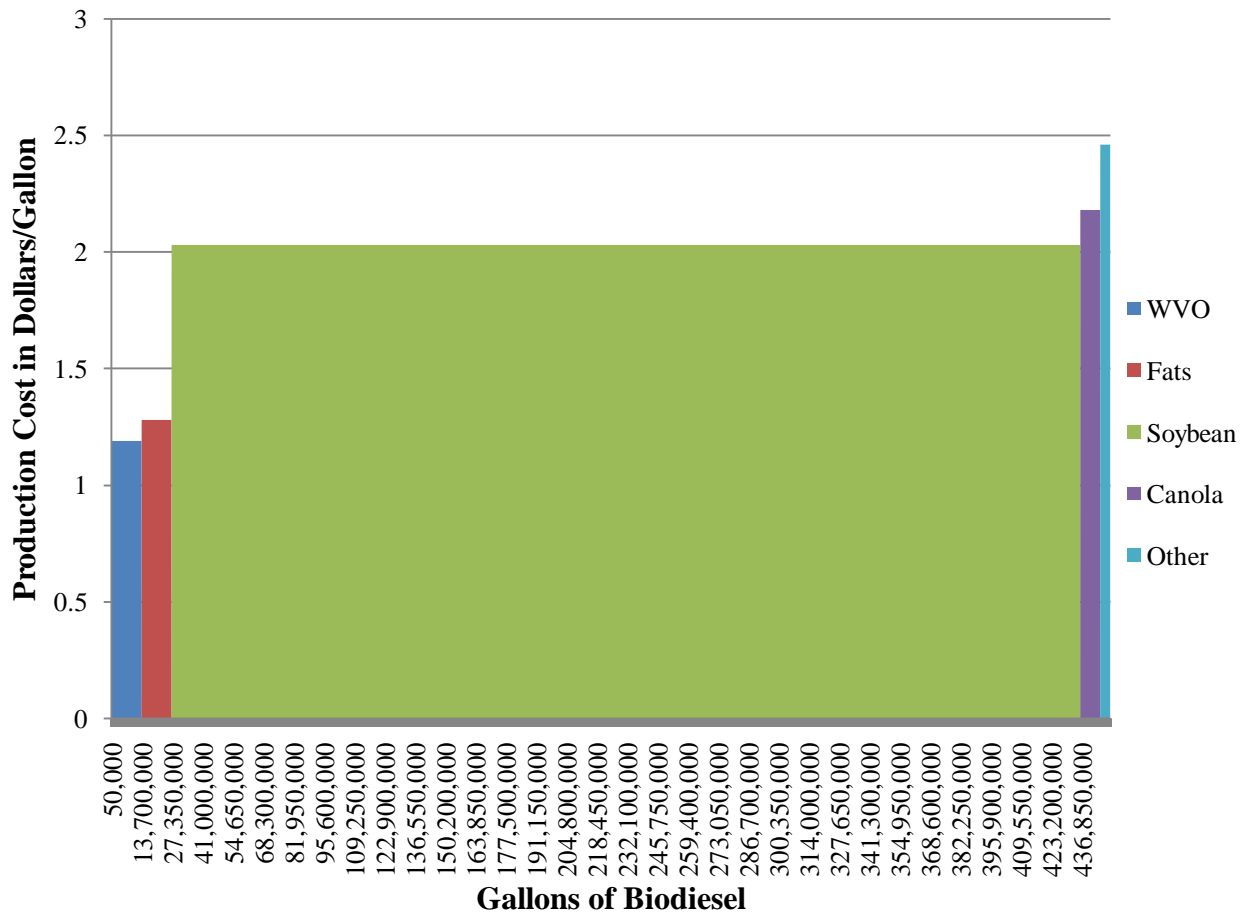


Figure 28: 2007 production stack.

One basic assumption made in the EIA model is that capital cost is linear – each gallon of capacity costs the producer the same amount per year no matter the size of the plant. Accounting for economies of scale in refineries shows that capital costs decrease as the plant size increases. In order to generate an equation for this trend, capital costs were used from a study from the National Renewable Energy Laboratory (Howell 2005).

Using the average cost of the plants, cost of a biodiesel plant can be calculated as (Fig. 29)

$$C = 2.4904g^{0.6021}$$

where C is the total capital cost of the refinery and g is the capacity of the refinery. For example, a 10 million gallon plant would cost $2.4904 \times 10,000,000^{0.6021}$, or \$40,829.03. A simple correlation gives an R^2 value of 0.99 when compared to actual average cost per plant.

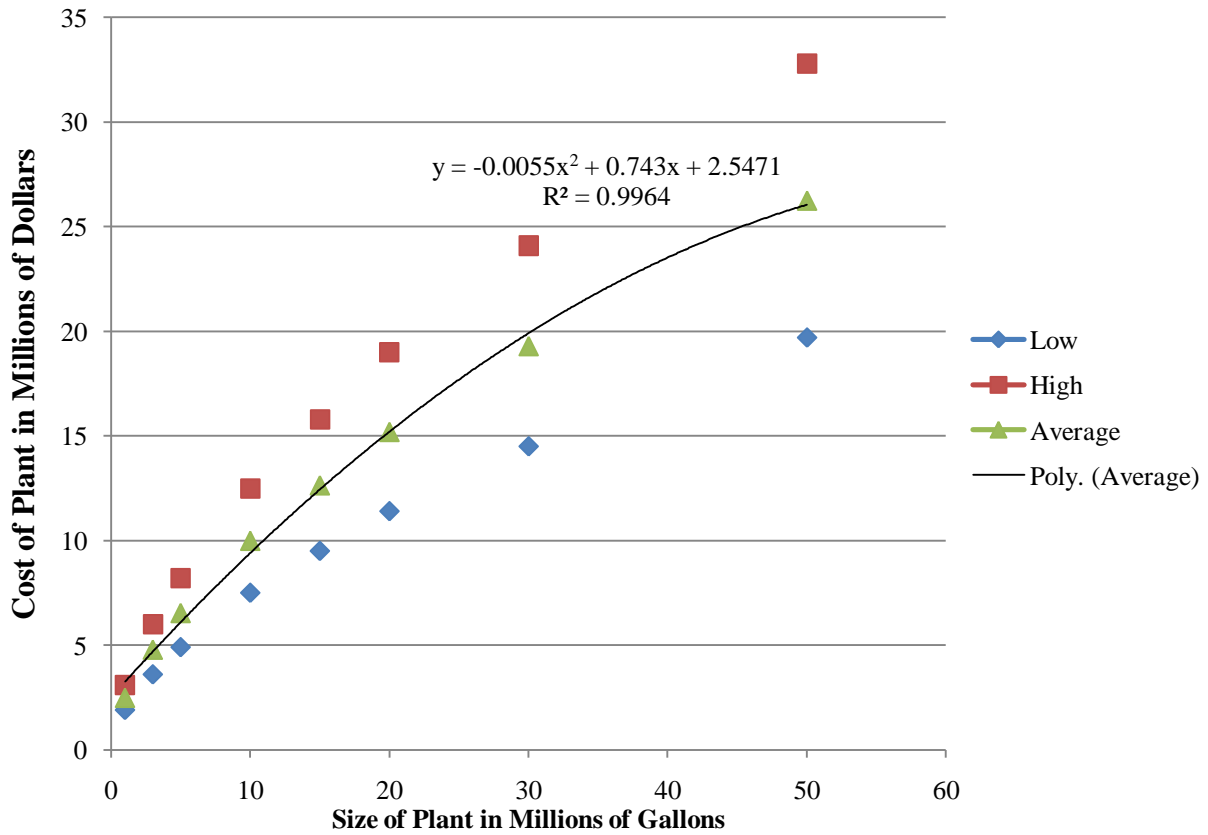


Figure 29: Biodiesel refinery cost by plant capacity (Howell 2005).

In order to determine capital cost per gallon, the equation needs to be rearranged. When calculating this equation per gallon of biodiesel, the result is the equation (Fig. 30)

$$C_g = 2.4904g^{-.398}$$

where C_g is the capital cost per gallon. The simple correlation for this equation gives an R^2 value of 0.9999.

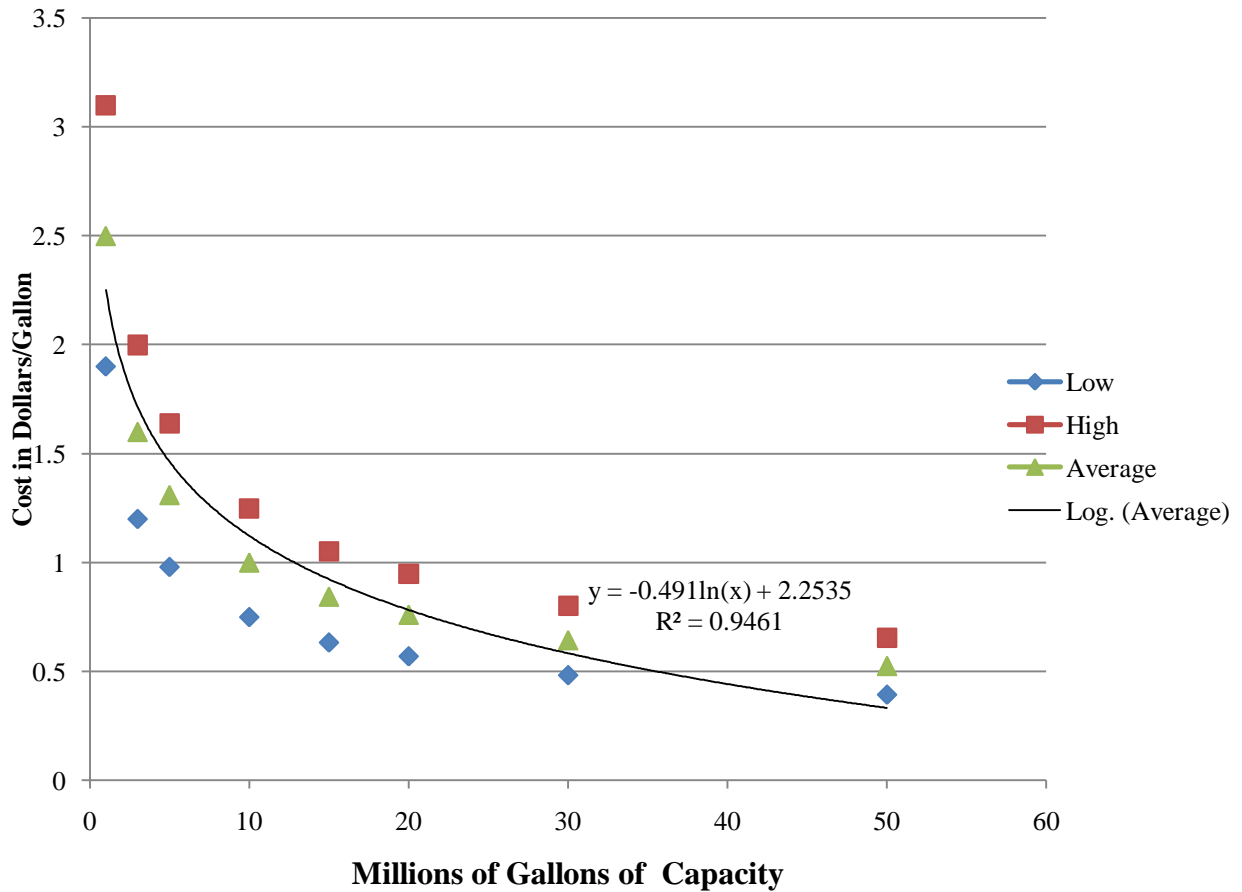


Figure 30: Capital cost of biodiesel per gallon of capacity (Howell 2005).

Capacity Supply Models

The potential of the biodiesel industry was examined by creating capacity supply curves from data about size and feedstock choice compiled from the Biodiesel Magazine refinery database and the National Biodiesel Board. The supply curves show how much biodiesel could be produced at what cost per gallon, and the curves were reconstructed based on varying assumptions and compared to biodiesel mandates set by the Renewable Fuel Standard.

The first model (Fig. 31) shows the cost of production based on the refinery capacity in August of 2007 and 2007 feedstock prices. This basic model also assumes that all multi-feedstock plants are using soybean oil, because this is the most common feedstock. This assumption is consistent with the results of the USDA Bioenergy Reporting program. The supply curve shows that the refinery infrastructure has the capacity to produce over 1.4 billion gallons of biodiesel at a price of less than \$2.00. Small amounts of biodiesel can be produced at prices not much higher than a dollar, but production costs level off after \$1.83, and the majority of the capacity can produce biodiesel between \$1.83 and \$2.00.

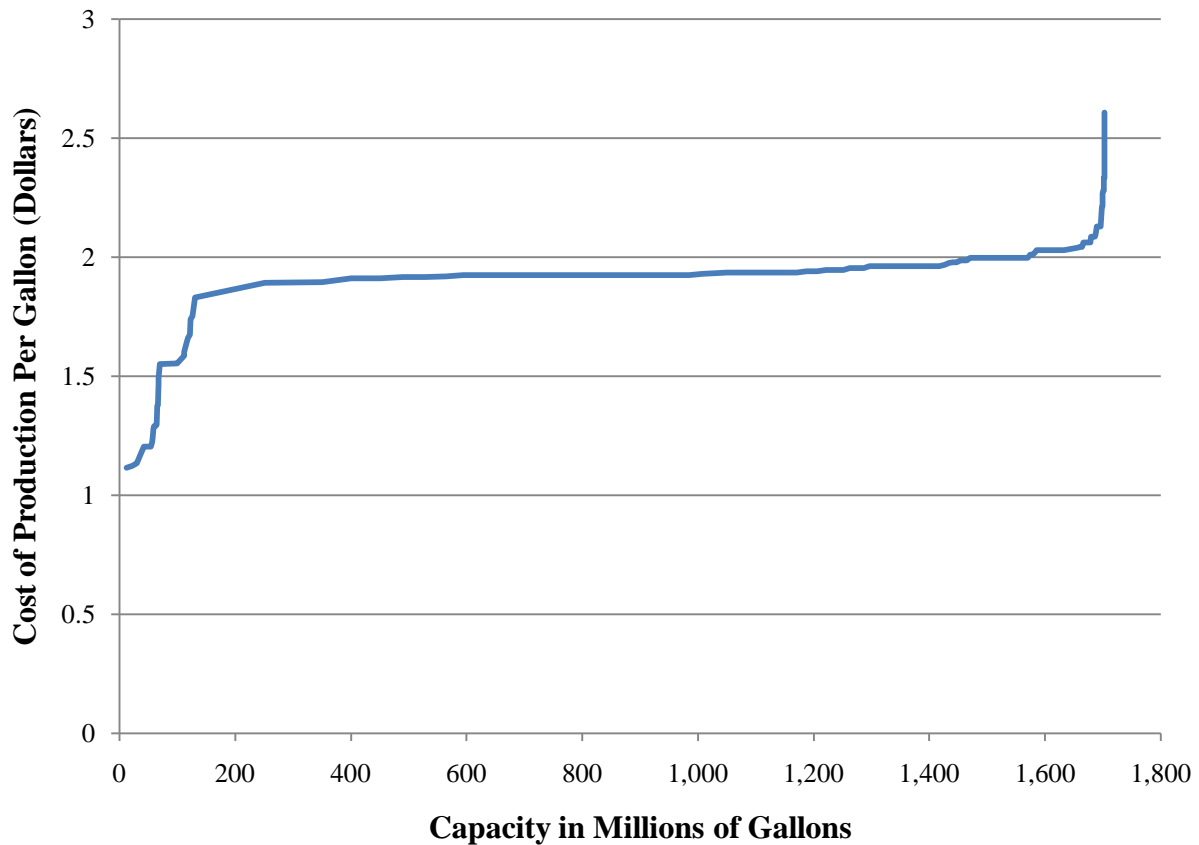


Figure 31: Current biodiesel capacity

In the next model (Fig. 32), the multi-feedstock plant assumption was tested and production costs were recalculated with low- and high-priced feedstocks. This is an important assumption to examine because 1 billion of biodiesel made entirely from soybean oil would require 40% of 2007 soybean oil production. Such unprecedented strain would likely alter the price conditions. Canola oil was used as the high-price feedstock and waste vegetable oil as the low-cost feedstock. Subsidies were adjusted for the multi-feedstock plants in the low-price scenario to account for the lower subsidy amount received when using recycled feedstocks. Under the high-price scenario, only about 900 million gallons of biodiesel can be produced at a price less than \$2.00. However, with the low-cost scenario, nearly the entire capacity potential

could produce biodiesel at a price less than \$2.00, and over 600 million gallons could actually be produced at a cost of less than \$1.00. These assumptions are not realistic in either case, because these quantities of waste vegetable oil and canola oil are not available in the United States; however, this result demonstrates the range of possible production costs.

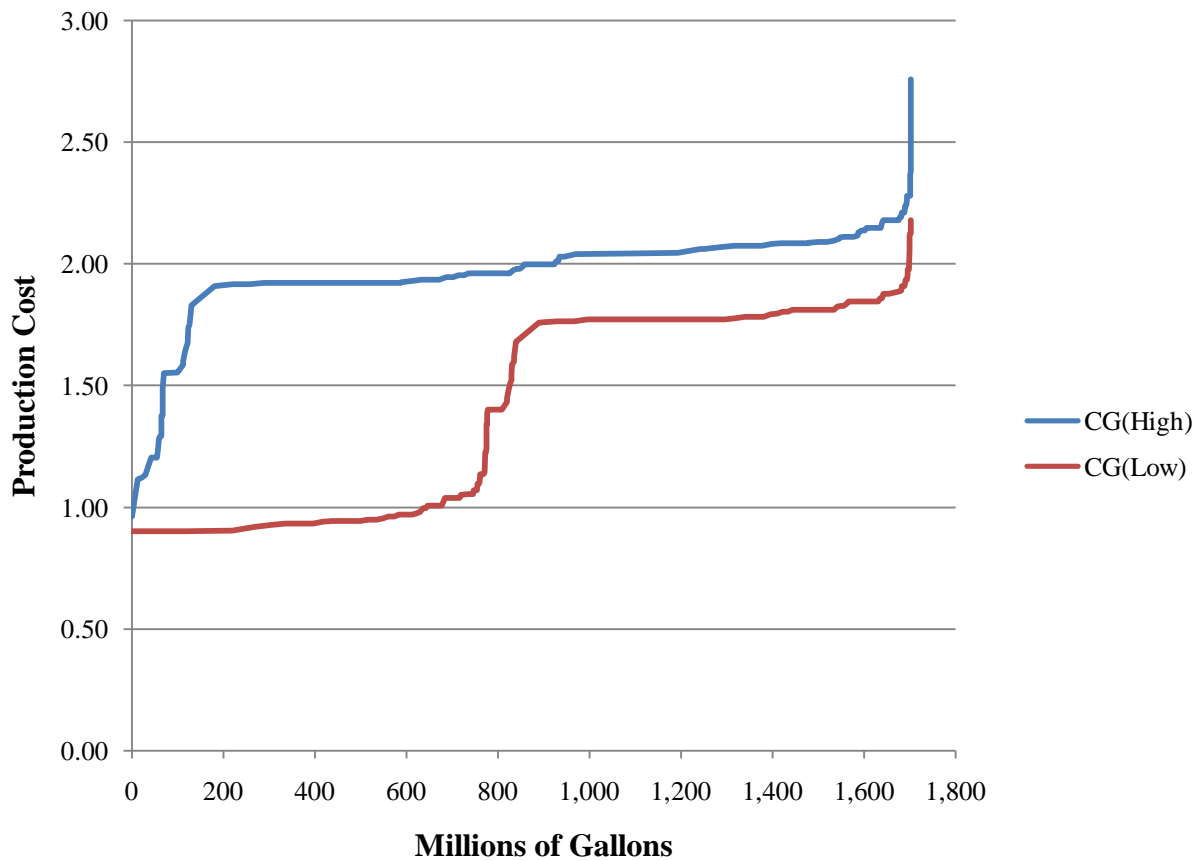


Figure 32: Minimum and maximum production costs for multi-feed plants.

This next scenario (Fig. 33) shows a comparison of the amount of biodiesel produced in 2007, the refinery capacity in 2007, and what the refinery capacity will be by the end of 2008. US production of 450 million gallons was about 26% of the total available refinery capacity in 2007, and this production will double by the end of 2008. Comparing the capacity to the goals

set by the renewable fuel standards, more than enough capacity to produce the 1 billion gallons mandated already exists. Biodiesel refiners can produce more than 1 billion gallons at a price that is competitive with the 2007 price of conventional diesel (\$2.88, or \$2.63 biodiesel equivalent).

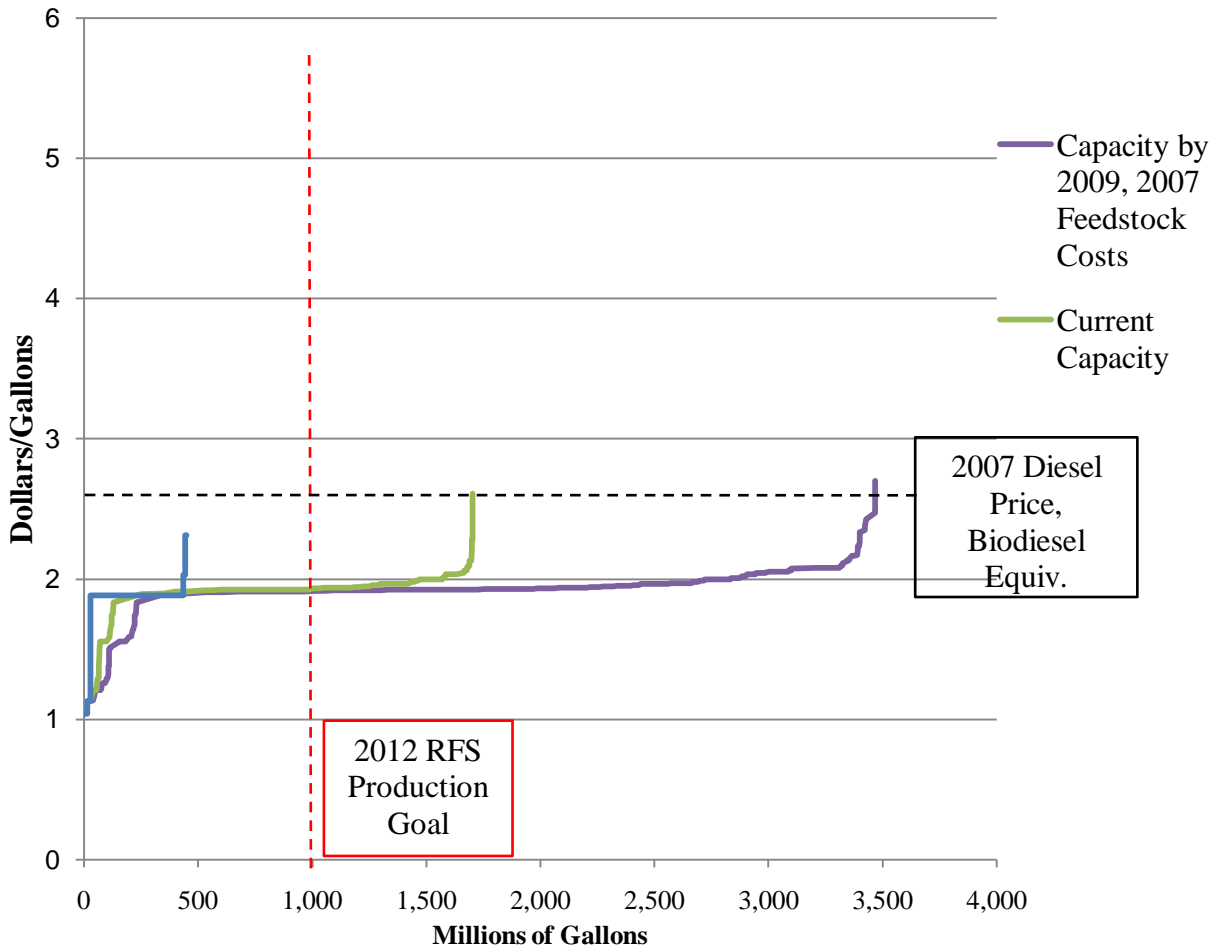


Figure 33: Current and future capacity, 2007 prices.

Because of recent jumps in feedstock and diesel prices, the conclusions of the above scenario are not highly likely. For the next model, average feedstock and diesel prices for January-April 2008 were used in order to determine the supply curve of the additional capacity by the end of 2008 (Fig. 34). This result shows that biodiesel is not nearly as competitive with conventional diesel as in recent years. The least expensive billion gallons of biodiesel that can

be produced can still be sold at a price that is slightly less than that of conventional oil, but the market competition is much tighter.

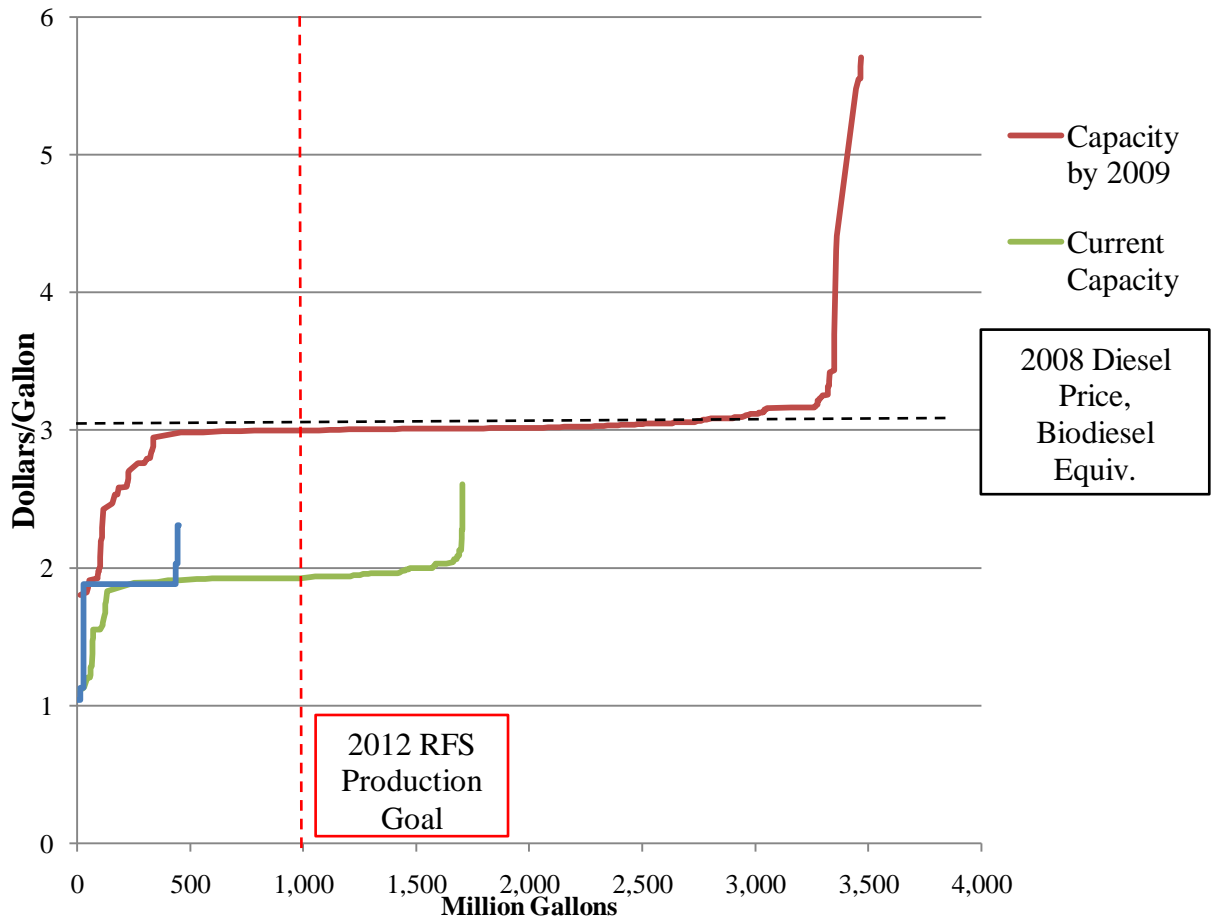


Figure 34: Current and future capacity, 2008 prices.

Because the Renewable Fuel Standard mandates that the US must be producing 1 billion gallons of biodiesel per year by 2012, price predictions were examined out to this point (Fig. 35). If current subsidies are maintained, the industry will be able to produce 1 billion gallons at a price well below the predicted 2012 price of diesel. But without the subsidy, conventional diesel is much less expensive than biodiesel. In order for biodiesel to break even with diesel at the 1

billion gallon mark, biodiesel requires at least a \$0.72 subsidy. However, considering the high diesel prices in recent years, biodiesel may not need a subsidy at all. The US can produce over 3 billion gallons of biodiesel at a price that is less than the 2008 price of diesel without any subsidy at all. However, because vegetable oil prices tend to rise and fall with crude oil prices, it is likely that if 2012 diesel prices are relatively high, feedstock prices will also be high. Biodiesel production will most likely always require government subsidies unless there are drastic advancements made in feedstock oil contents, acreage yield, or production efficiency.

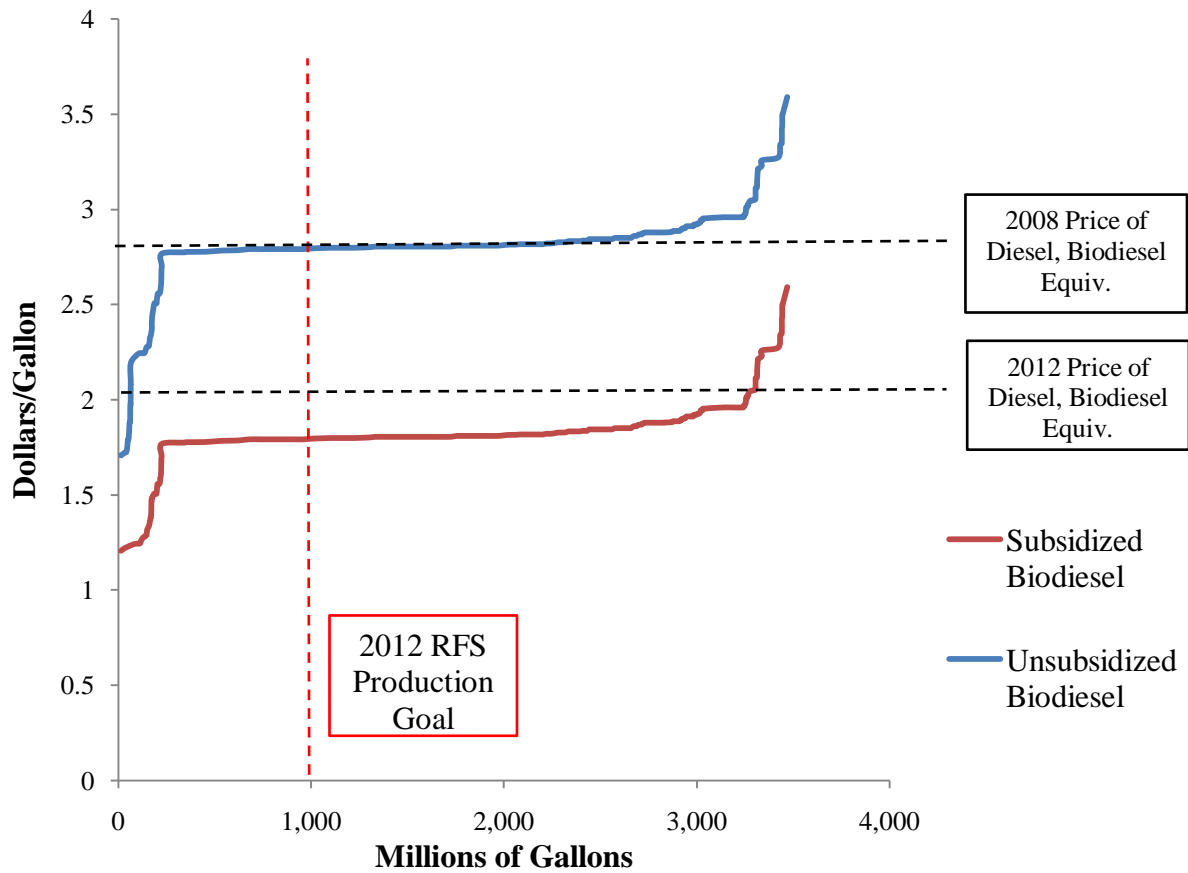


Figure 35: Forecasted subsidy requirements.

Conclusions

Because biodiesel must fit into the diesel infrastructure, the future growth of biodiesel is entirely dependent on the persistence and growth of diesel demand. This dependence is likely to benefit rather than hinder the future of biodiesel because diesel is becoming a more popular fuel in the United States and other regions as well. Demand for diesel and biodiesel fuel is directly related to the use of diesel engines, and because diesel engines are more efficient and diesel fuel is becoming more clean, the use of diesel engines is projected to increase. Considering the strength of diesel forecasts, biodiesel refiners and marketers will benefit from blending their product with diesel and emphasizing the ability of biodiesel to function in diesel infrastructure.

The success of the biodiesel industry is highly dependent on the price and availability of feedstocks. Soybean oil has been the primary source for biodiesel production in the United States, accounting for over 90% of biodiesel production. This has required only up to 15% of the available soybean stock in the United States, but as production mandates increase, biodiesel may require up to 40% of soybean oil stocks at current production levels. Animal fats and waste vegetable oil remain good economic choices for feedstocks, but are not as widely available as vegetable oils. In addition, animal fat production is driven by demand for livestock, so increasing demand of the oil byproduct will not encourage the market to produce more animal fats.

Another production cost component that biodiesel refiners have some control over is capital costs. Capital costs vary greatly with the size of the plant; larger plants cost increasingly and significantly less per gallon than smaller plants. Thus, it is more economic for producers to build larger plants. Larger plants require feedstocks to be transported in from further distances, but because transportation of feedstocks is such a small percentage of production costs, larger plants are a better choice for most producers.

With current subsidies and refinery capacity, it is likely that the biodiesel industry will be able to produce the amount of biodiesel mandated by the Renewable Fuel Standard at a price that is competitive with conventional diesel fuel. The United States biodiesel industry only operated at about 26.4% of the available capacity in 2007, and this capacity is expected to double by the end of 2008. Meeting RFS 2012 mandates will only require 28.8% of the refining capacity that will be online by 2009. In order for this to be possible, however, the biodiesel subsidies need to remain above at least \$.72 through 2012 for virgin feedstocks. Waste oils would not require a subsidy, however, because they are less expensive to produce than conventional diesel under all scenarios considered. The importance of the subsidy and the potential of the biodiesel industry are both based on assumptions about the price and availability of two volatile prices: the price of vegetable oils and the price of diesel. These prices are the key factors in determining the success of the industry and the public and private costs of meeting the Renewable Fuel Standard.

References

- ASTM International. 16 April 2008. <http://www.astm.org/cgi-bin/SoftCart.exe/ABOUT/index.html?L+googleorgstore+upfz9233+1208425800>.
- BQ-9000 Quality Management Program. 7 April 2008. <http://www.bq-9000.org>.
- Canola Council of Canada. "Canola Facts: An Industry that Depends on Trade." 3 April 2006. 2 December 2007. www.canola-council.org/facts_trade.html.
- The CRM Commodity Yearbook 2006. Commodity Research Bureau. 2006. John Wiley & Sons, Inc.
- Coyle, William. "The Future of Biofuels: A Global Perspective." 2007. Economic Reserve Service. United States Department of Agriculture. 26 November 2007. <http://www.ers.usda.gov/AmberWaves/November07/PDF/Biofuels.pdf>.
- Daily Auto Insider "World Demand for Diesel-Powered Cars Seen Doubling." 17 April 2006. 21 September 2007. www.caranddriver.com/dailyautoinsider.
- Durbin, Dee-Ann. "Automakers predict diesel sales will grow in U.S. market as gas prices rise." 2006. 21 September 2007. www.autonews24h.com.
- European Biodiesel Board. "Statistics: The EU Biodiesel Industry." 20 February 2008. <http://www.ebb-eu.org/stats.php#>.
- Energy Efficiency and Renewable Energy. Department of Energy. 20 November 2007. "Ultra-Low Sulfur Diesel Benefits." http://www.eere.energy.gov/afdc/fuels/emerging_sulfur_diesel_benefits.html.
- Energy Efficiency and Renewable Energy. Department of Energy. "Clean Cities Alternative Fuel Price Report." 2005-2007.
- Energy Information Administration. "Sales of Distillate Fuel Oil by End Use." Department of Energy. 2005. 11 November 2007. http://tonto.eia.doe.gov/dnav/pet/pet_cons_821dst_dcu_nus_a.htm.
- Energy Information Administration. Department of Energy. "The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply." 2001. 12 September 2007. <http://www.eia.doe.gov/>.
- Energy Information Administration. Department of Energy. 2006. "U.S. Primary Energy Consumption by Source and Sector, 2006." http://www.eia.doe.gov/emeu/aer/pdf/pecss_diagram.pdf.

- Energy Information Administration. Department of Energy. "Diesel Fuel Prices: What Consumers Should Know." 24 May 2007. 21 September 2007. <http://www.eia.doe.gov/>.
- GS Clean Tech. 2007. "GS Clean Tech's Patent Pending Corn Oil Extraction System." http://www.gs-cleantech.com/pdf/Coes_Data_Sheet.pdf.
- Howell, Steve. "Time to Take the Biodiesel Plunge?" *Render Magazine*. February 2005. 23 October 2007. www.rendermagazine.com.
- Jessen, Holly. "BQ-9000: Gaining Momentum." *Biodiesel Magazine*. May 2006. 2 August 2007. www.biodieselmagazine.com.
- Kotrba, Ron. "The Glycerin Spread." *Biodiesel Magazine*. September 2007. 10 April 2008. www.biodieselmagazine.com.
- National Biodiesel Board. 2005. "Energy Content." http://www.biodiesel.org/pdf_files/fuelfactsheets/BTU_Content_Final_Oct2005.pdf.
- National Cottonseed Products Association. 2002. "Cottonseed and its Products." 18 April 2008. <http://www.cottonseed.com/publications/cottonseedanditsproducts.asp>.
- "NBB aggressive in finalizing B5 and B20 specs." *Biodiesel Magazine*. July 2007. 2 August 2007. www.biodieselmagazine.com.
- Organisation for Economic Co-operation and Development. "IEA Oil Information." v. 2007, release 01. 10 November 2007. <http://massetto.sourceoecd.org>.
- Polk Automotive Intelligence. "Diesel Technology Form Report." R.L. Polk & Company. 2005.
- Stroup, Robert L. "Feedstock Considers for Future U.S. Producers." *Biodiesel Magazine*. Jan/Feb 2004. 2 August 2007. www.biodieselmagazine.com.
- Thurmond, Will. "Biodiesel's Bright Future." World Future Society. *The Futurist*. July-August 2007. pp. 27-30.
2006. United States Department of Agriculture. "Bioenergy." 2006. http://www.fsa.usda.gov/Internet/FSA_File/bioenergy.pdf.

Appendix

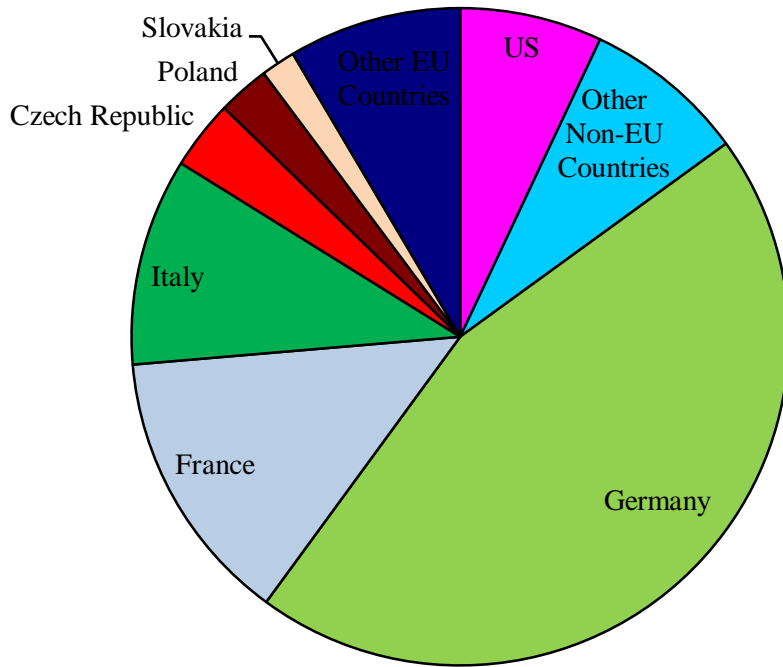


Figure 1: 2005 biodiesel production by country (World Future Society).

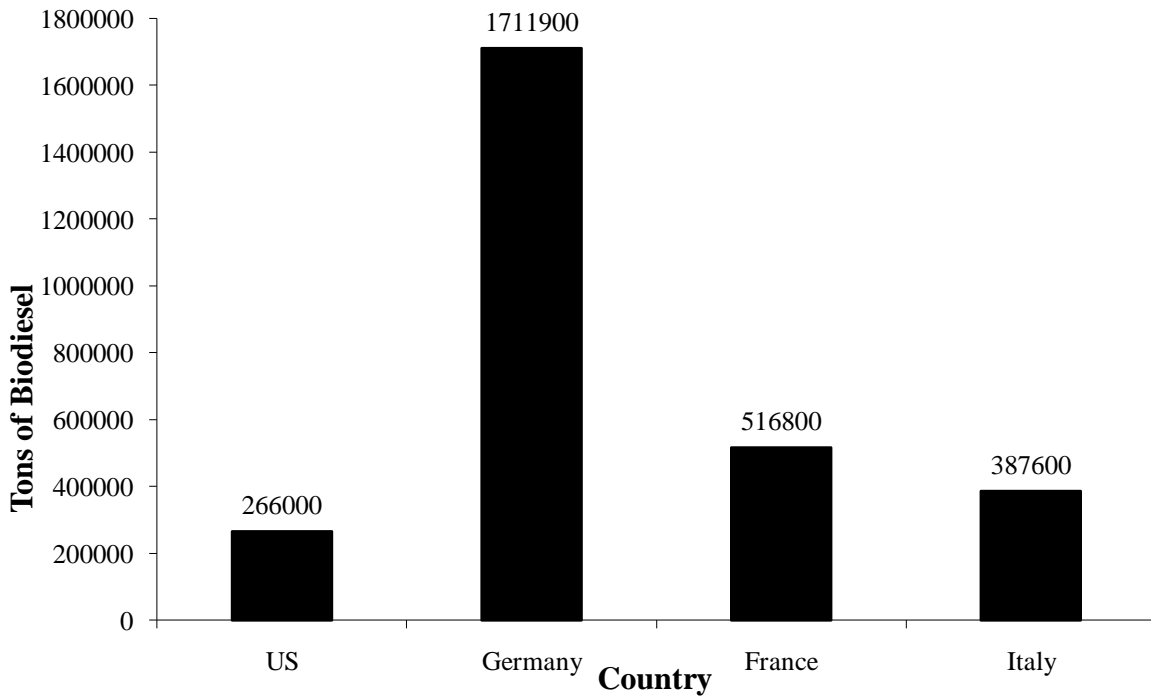


Figure 2: Top biodiesel producing countries in 2005 (World Future Society 2007).

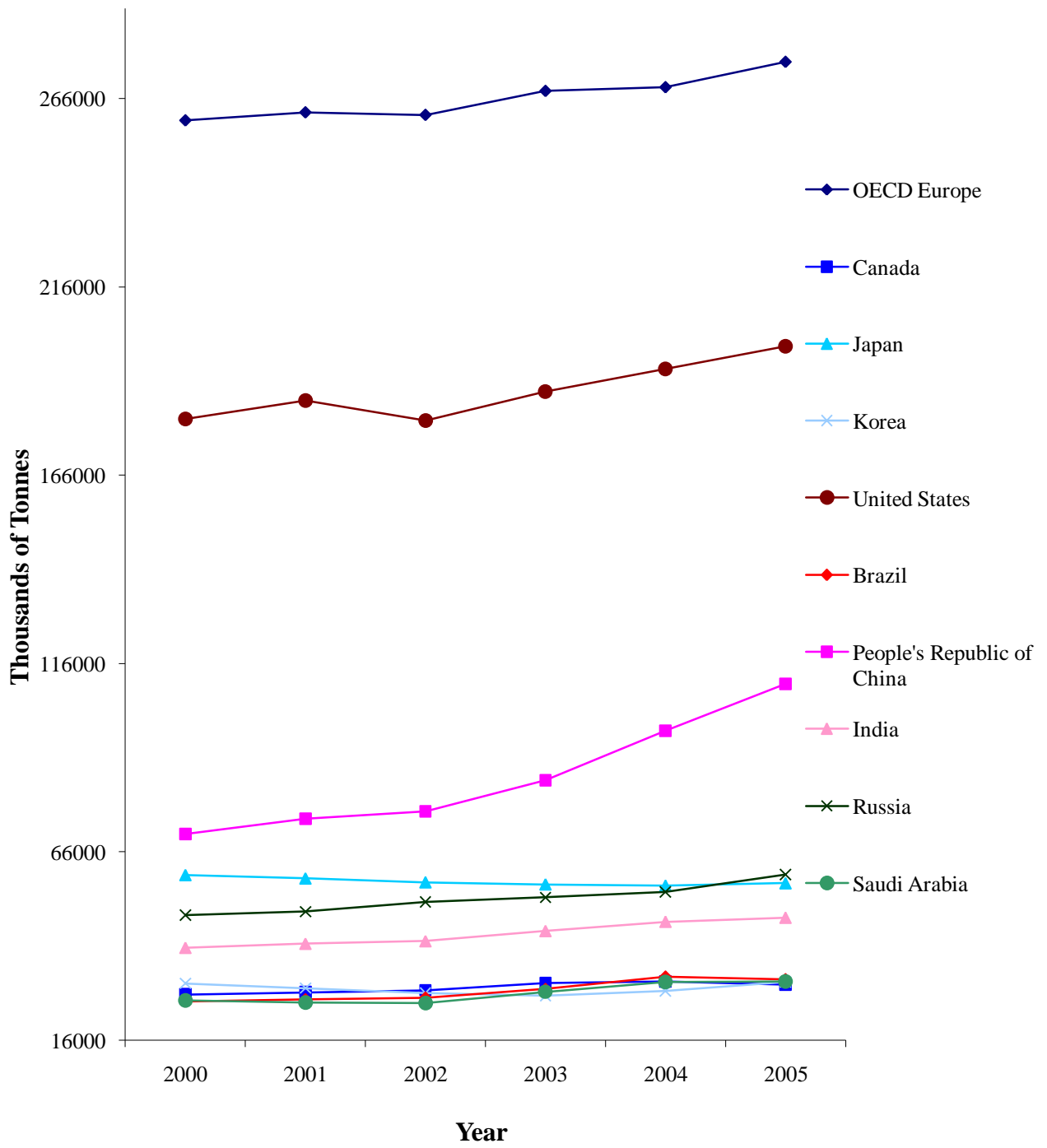


Figure 3: Largest diesel suppliers by country/region (OECD 2007).

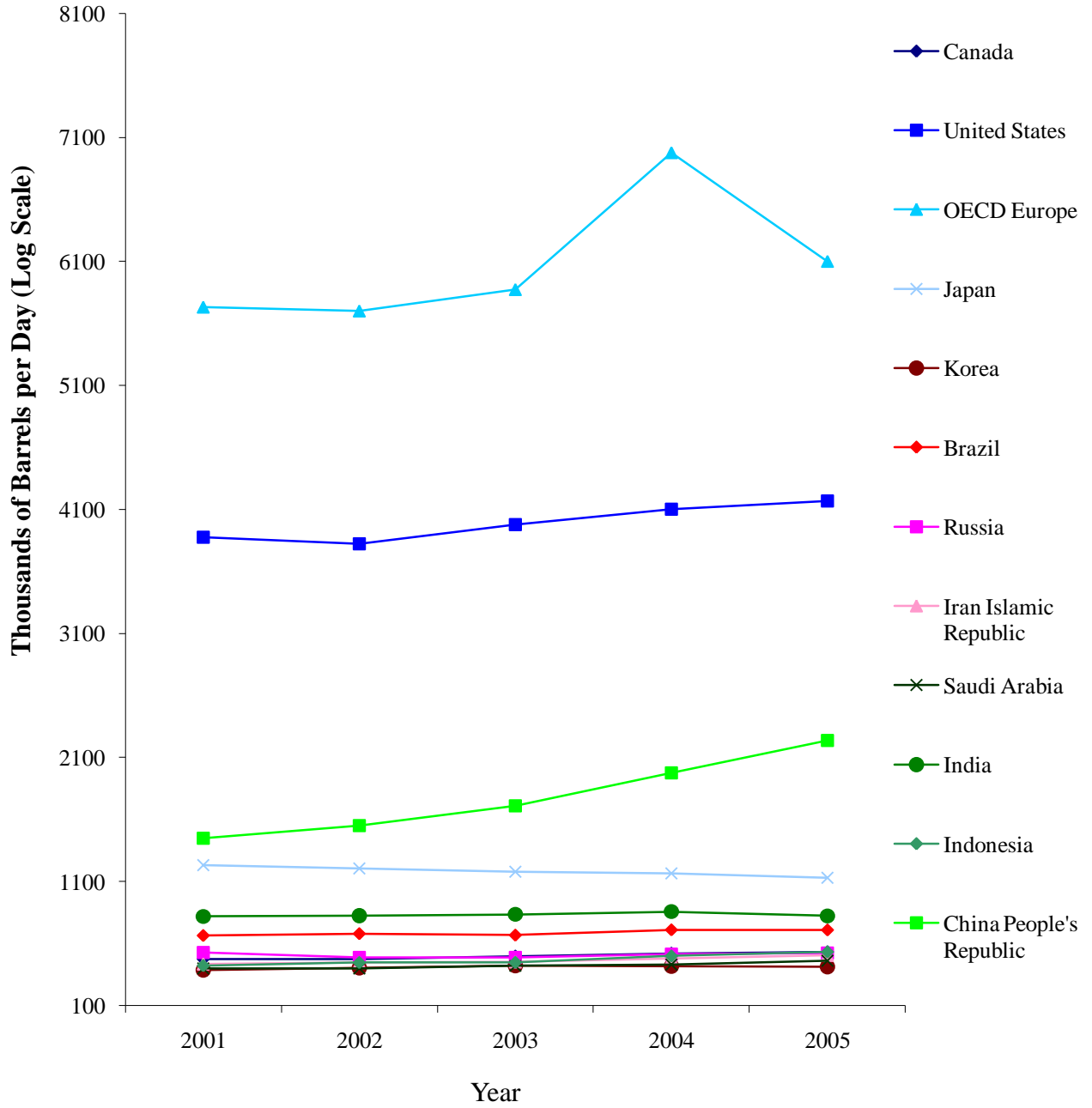


Figure 4: Diesel demand by highest demanding countries/regions (OECD 2007).

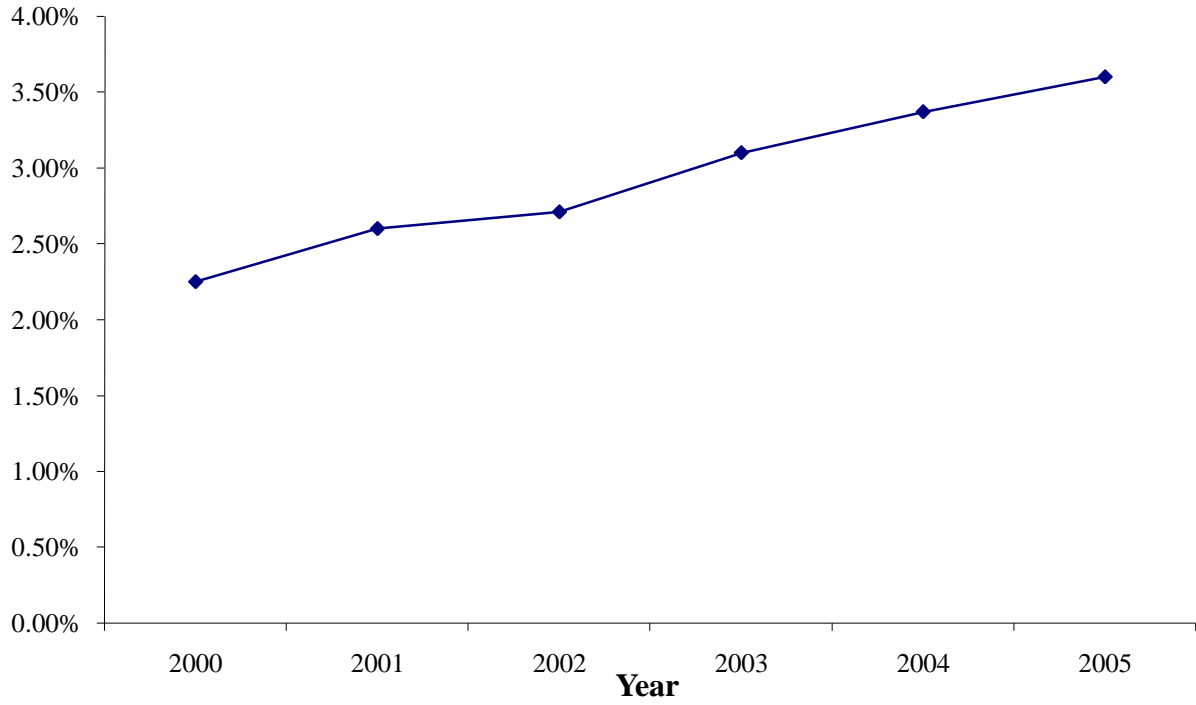


Figure 5: Diesel percent share of passenger vehicle market (Polk 2005).

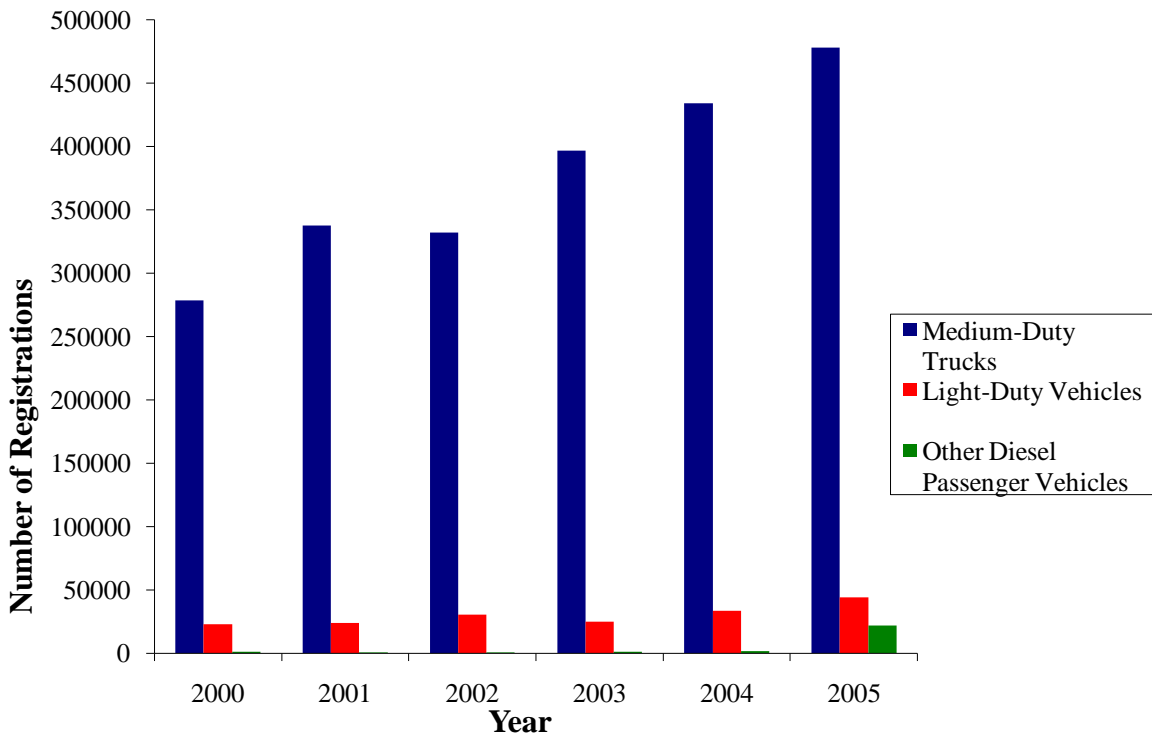


Figure 6: Diesel passenger vehicle registration by type (Polk 2005).

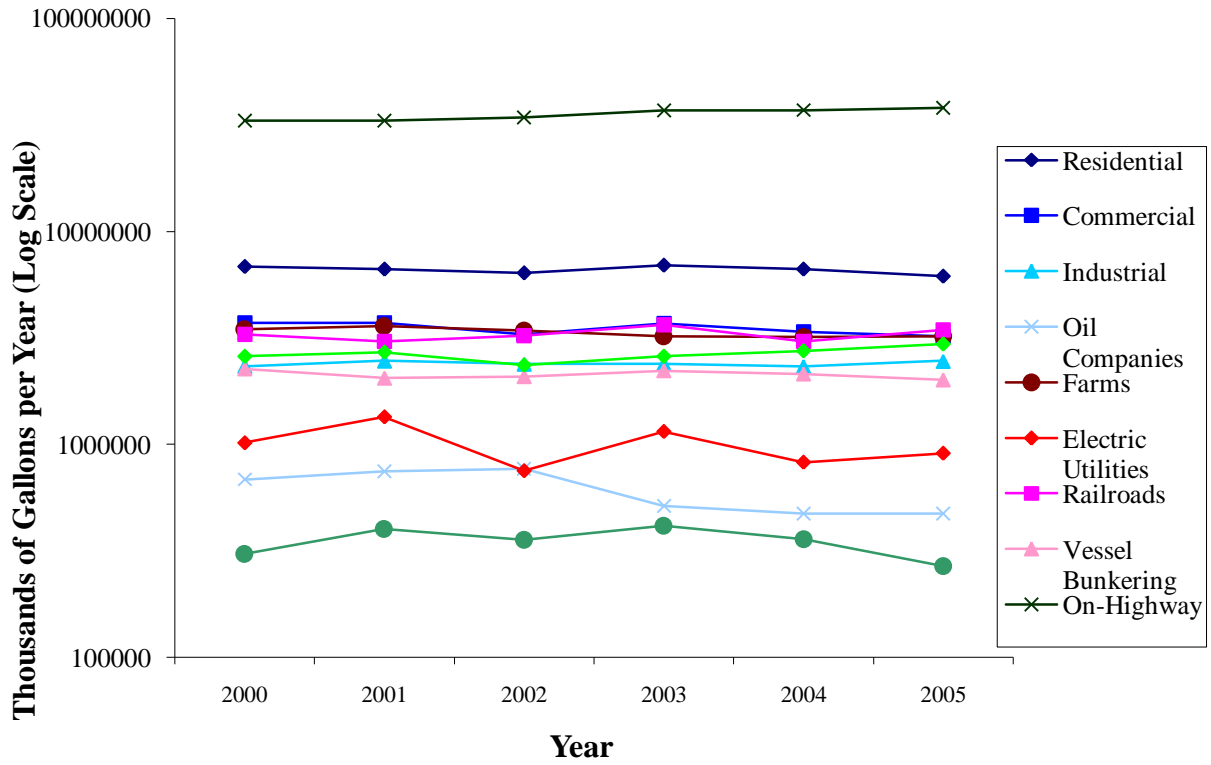


Figure 7: US diesel consumption by end use (Polk 2005).

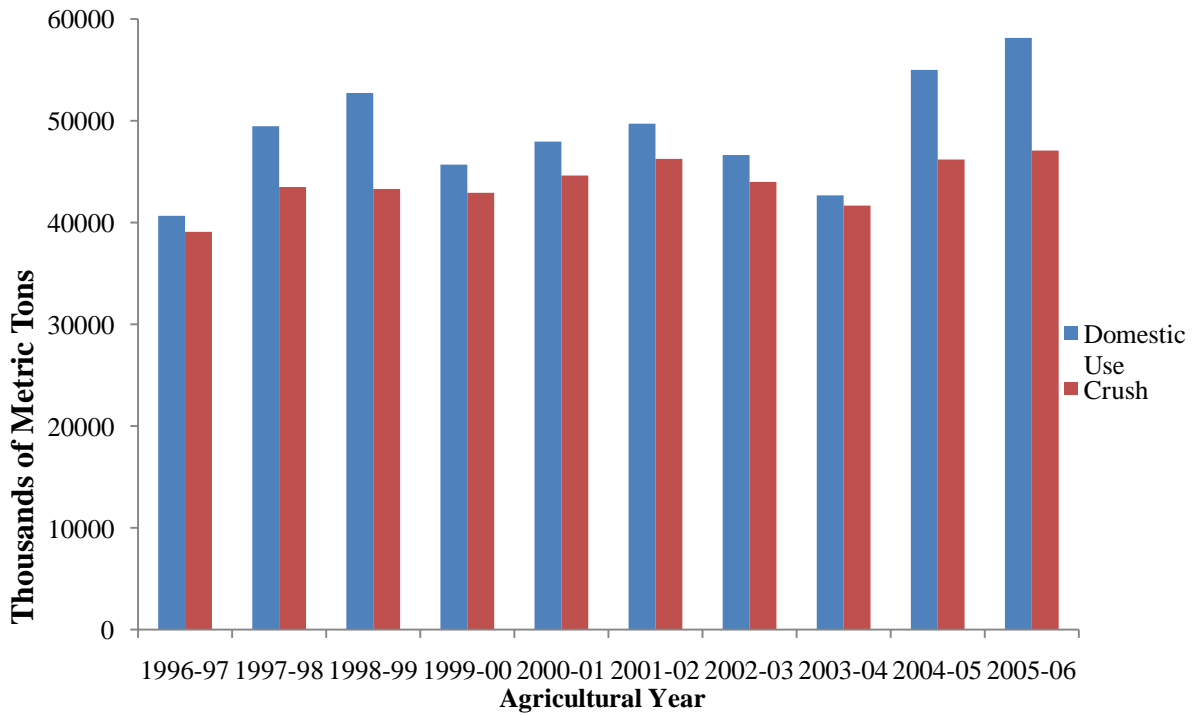


Figure 8: United States domestic consumption and crush (CRB 2006).

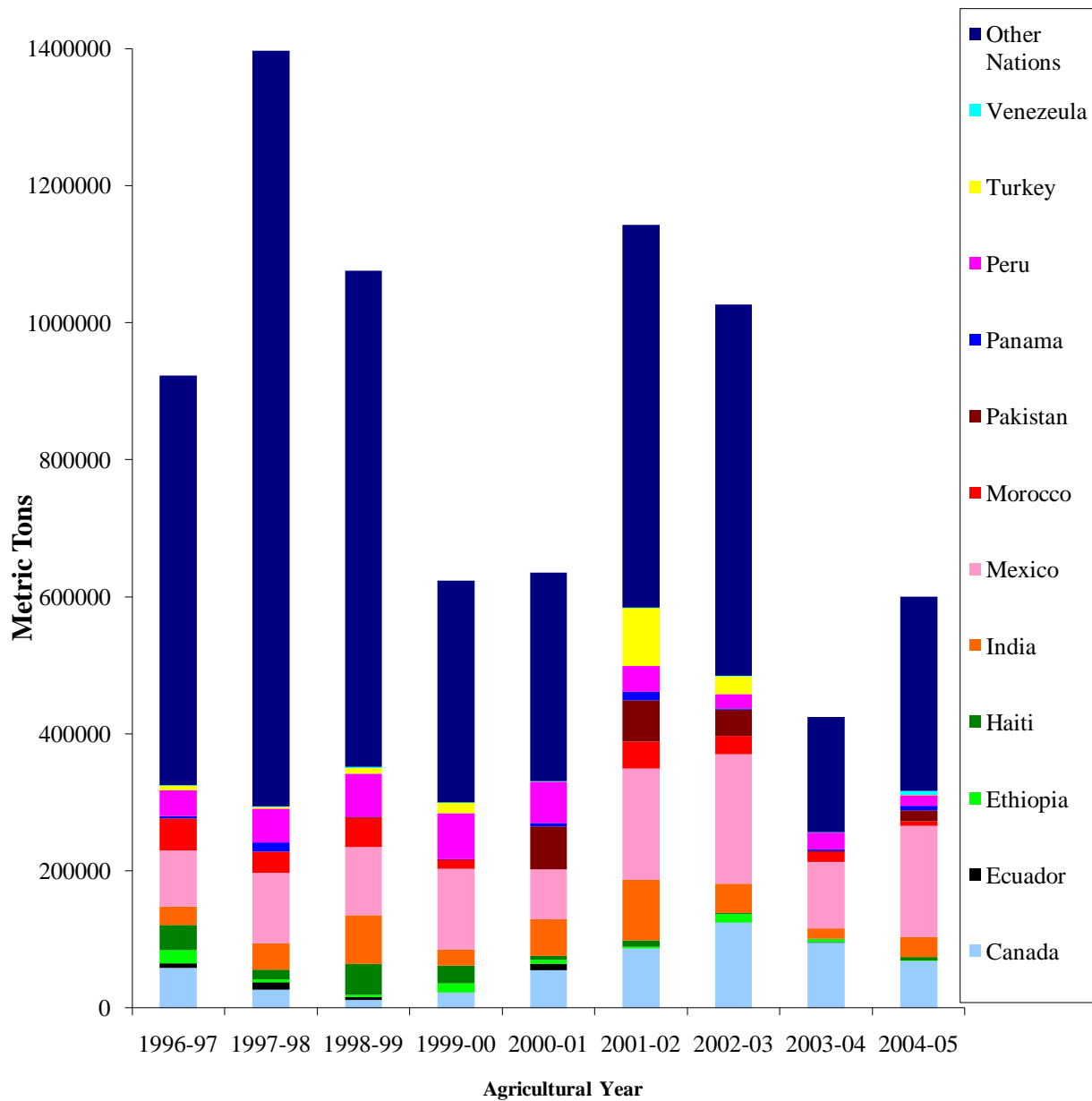


Figure 9: Destinations of US exports of soybean oil (CRB 2006).

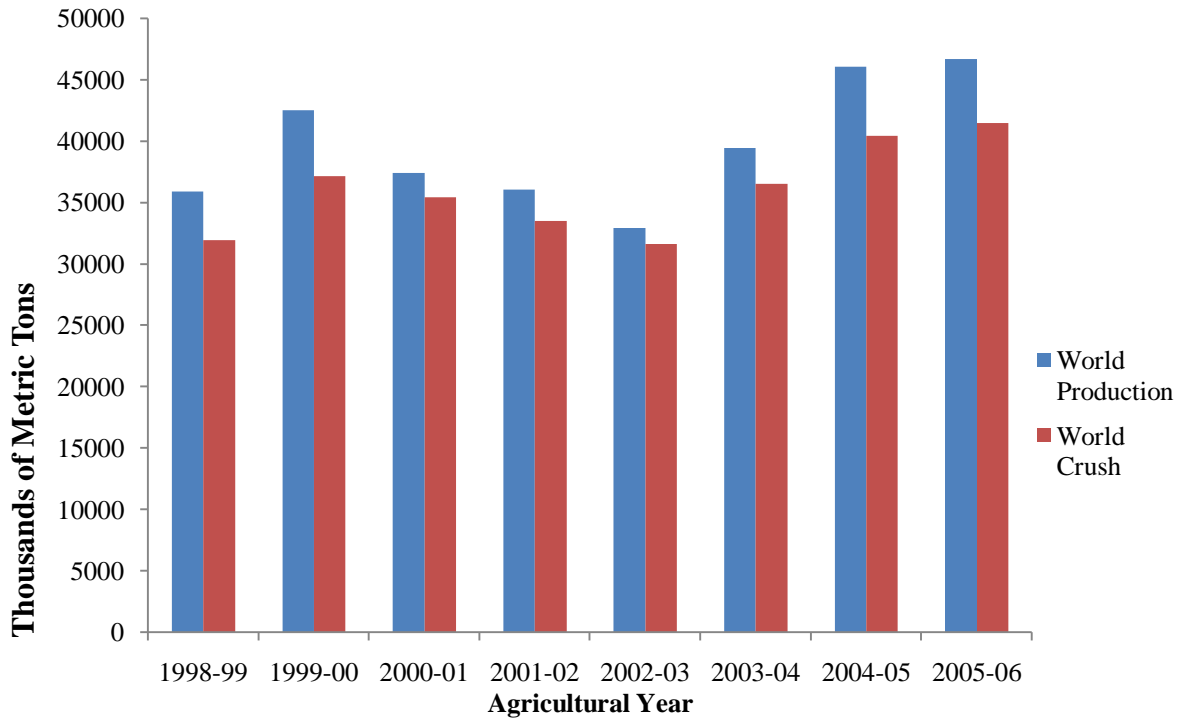


Figure 10: World production and crush of canola (CRB 2006).

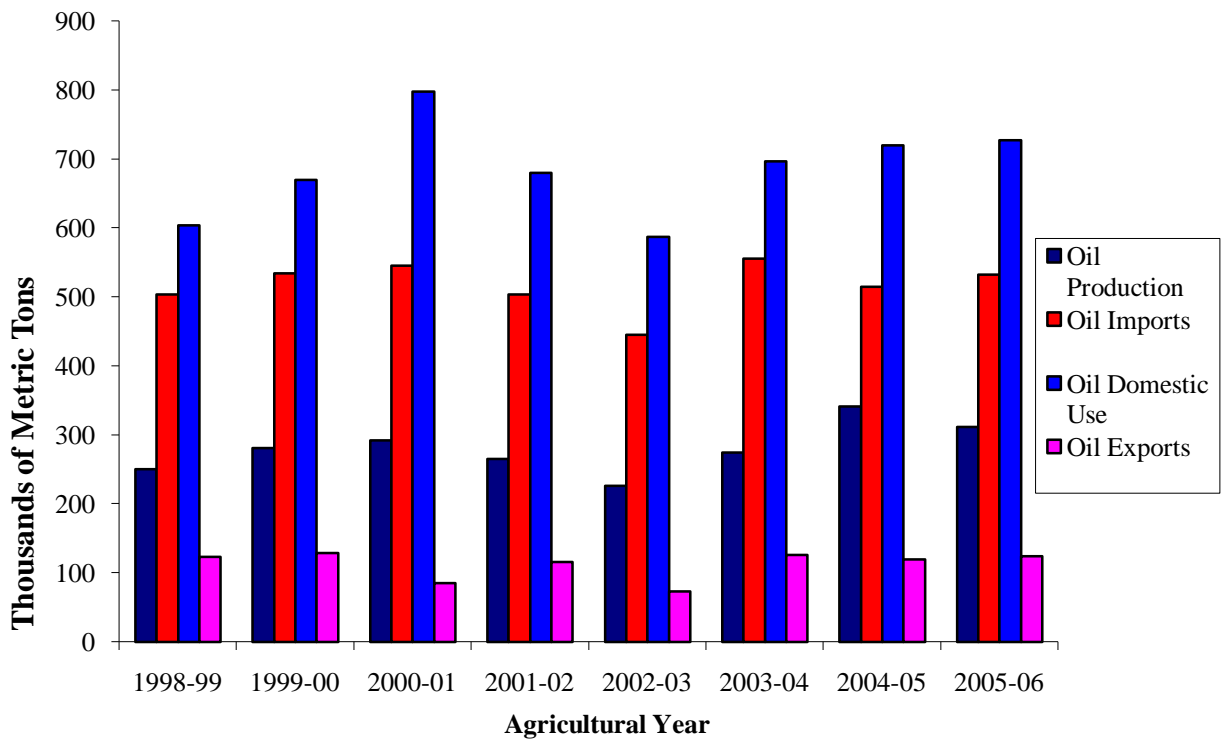


Figure 11: US Acquisition and disappearance of canola oil (CRB 2006).

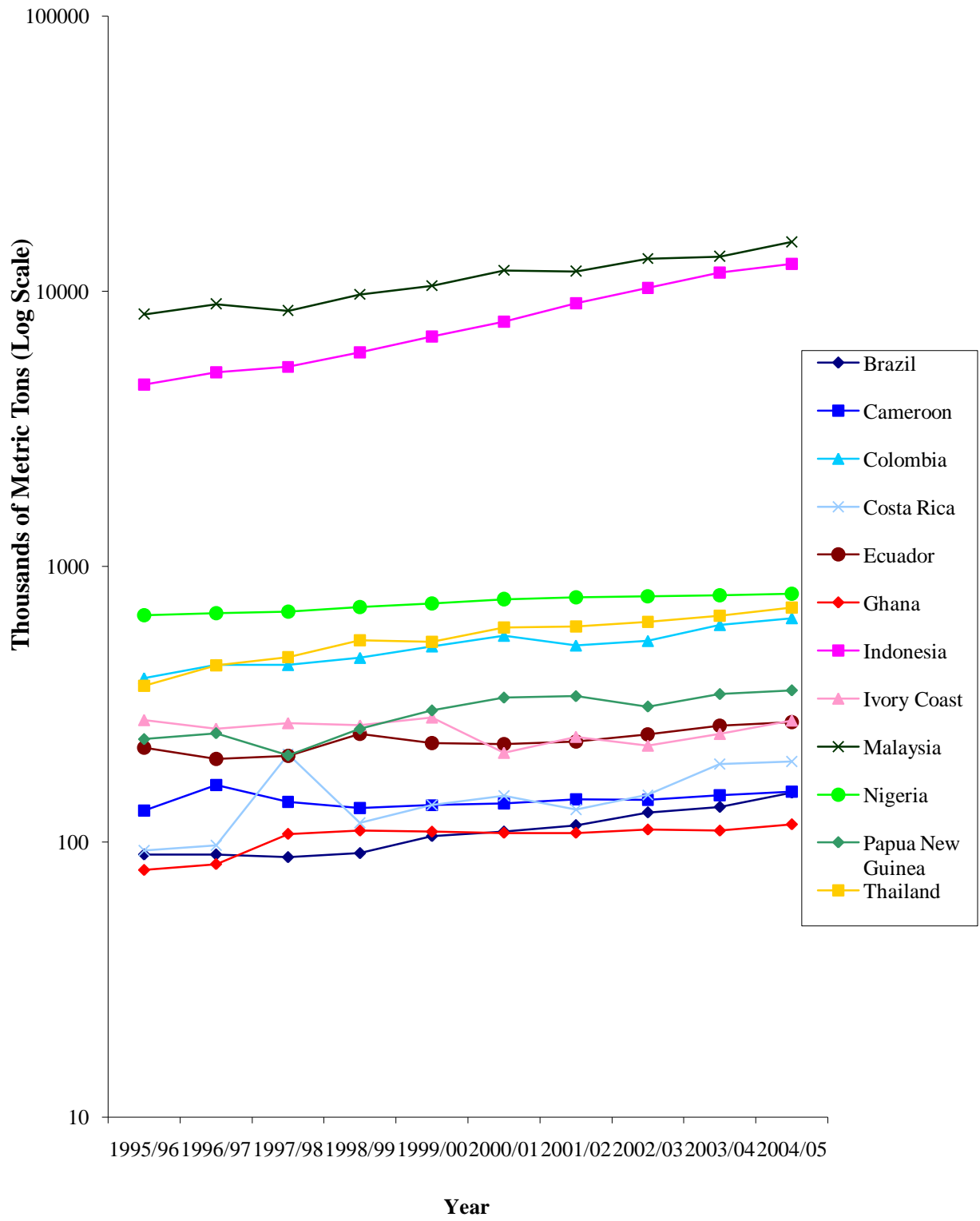


Figure 12: World production of palm oil (CRB 2006).

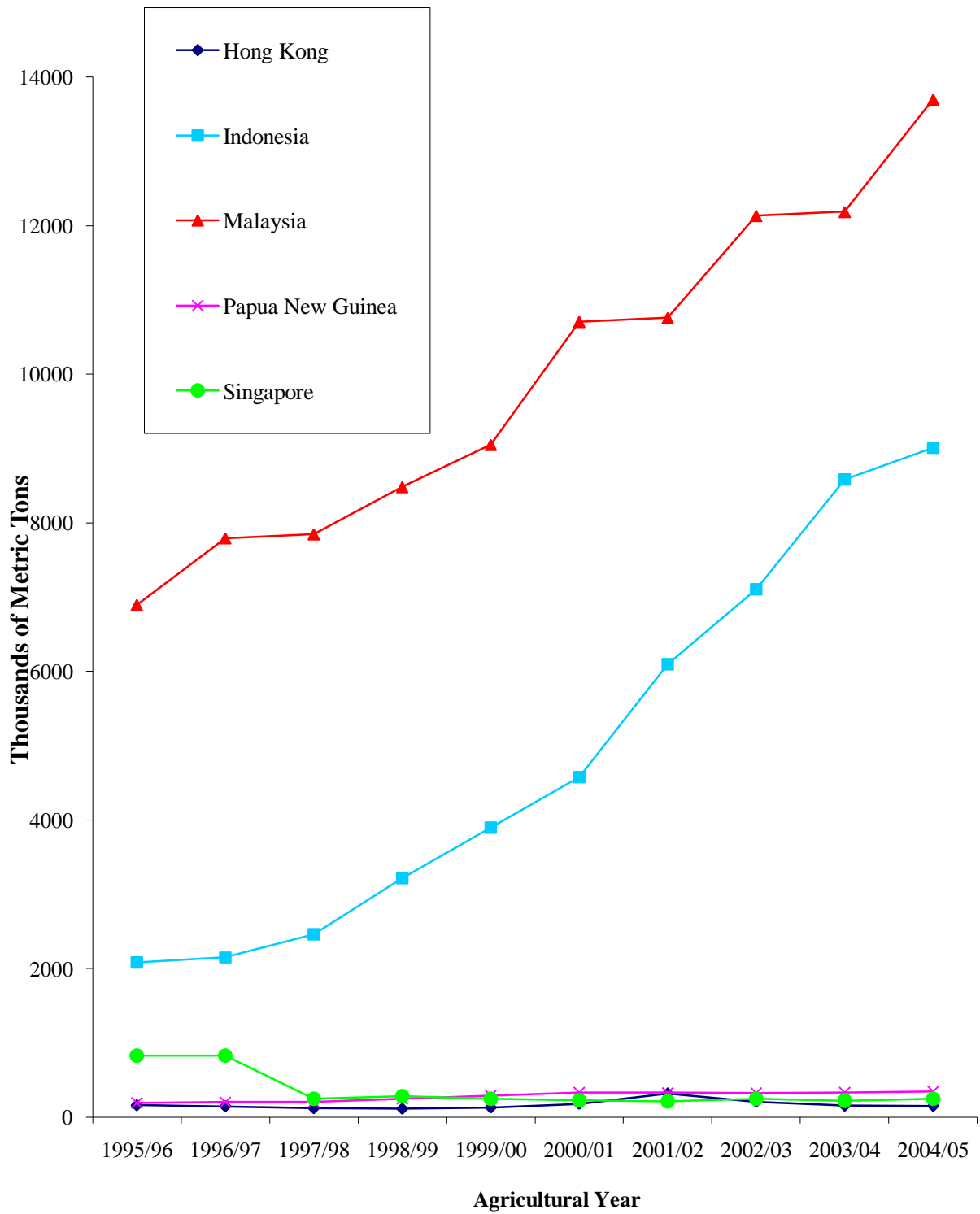


Figure 13: Major palm oil exporting nations (CRB 2006).

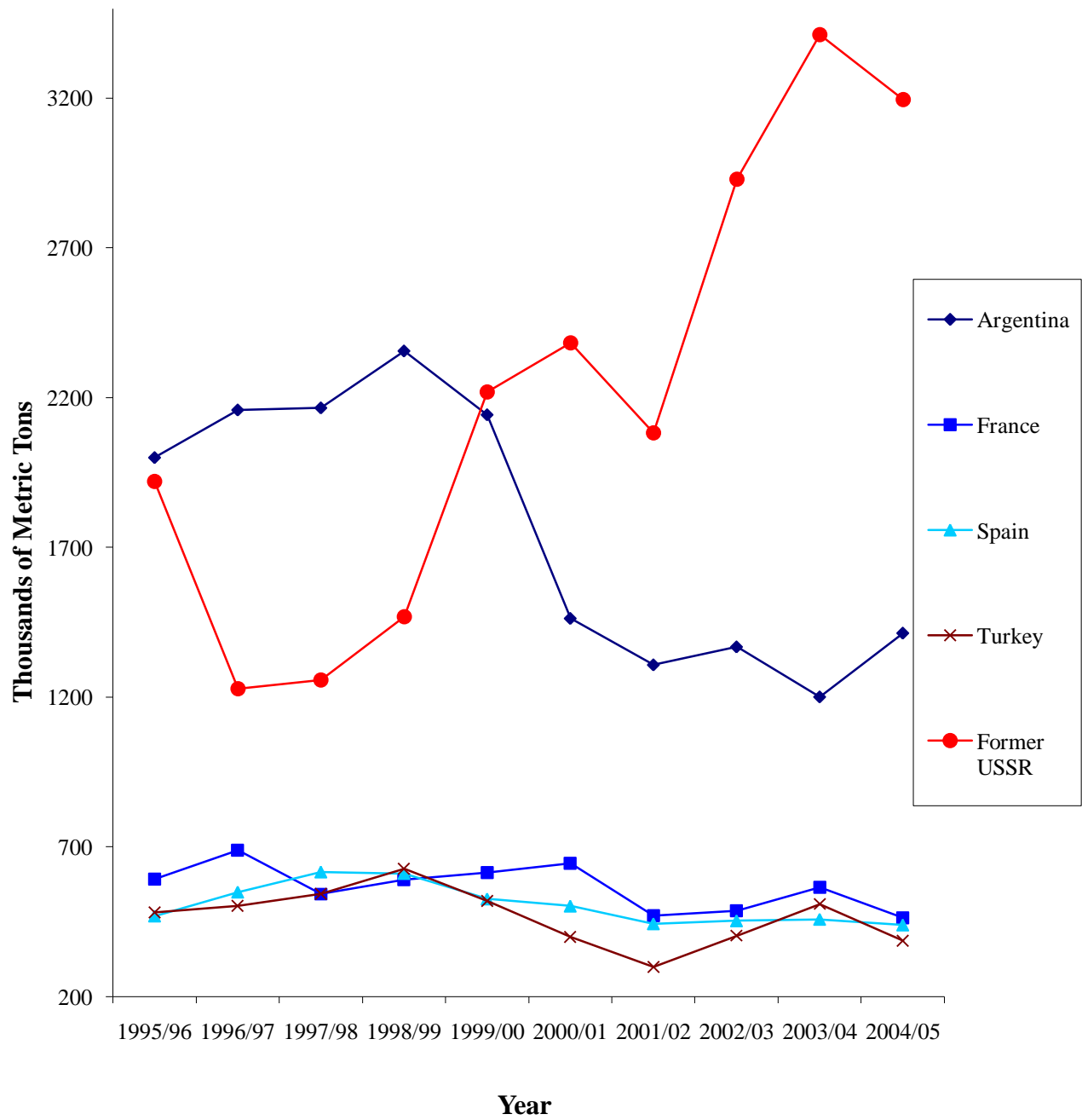


Figure 14: World production of sunflower seed oil (CRB 2006).

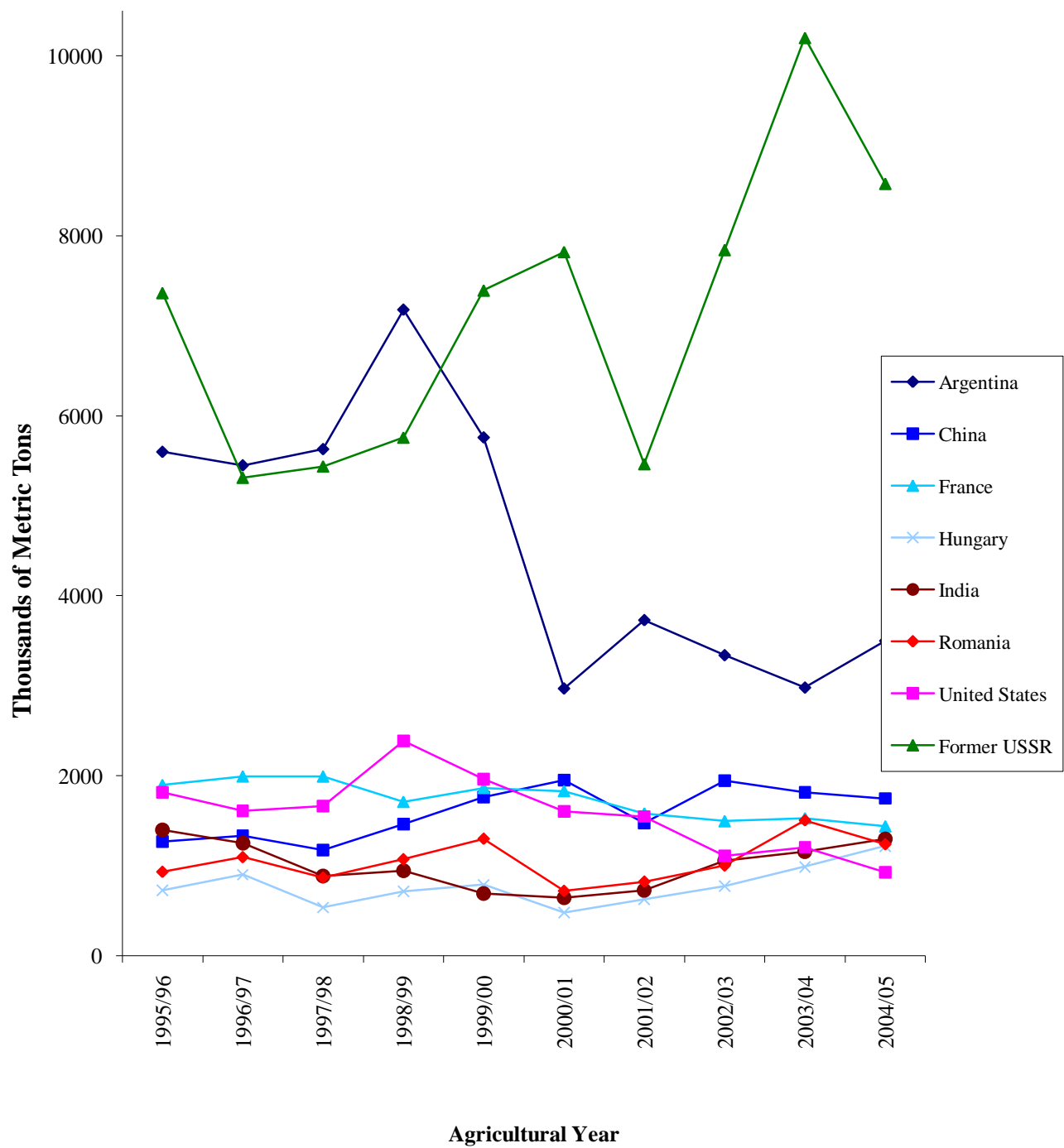


Figure 15: Top world producers of sunflower seed (CRB 2006).

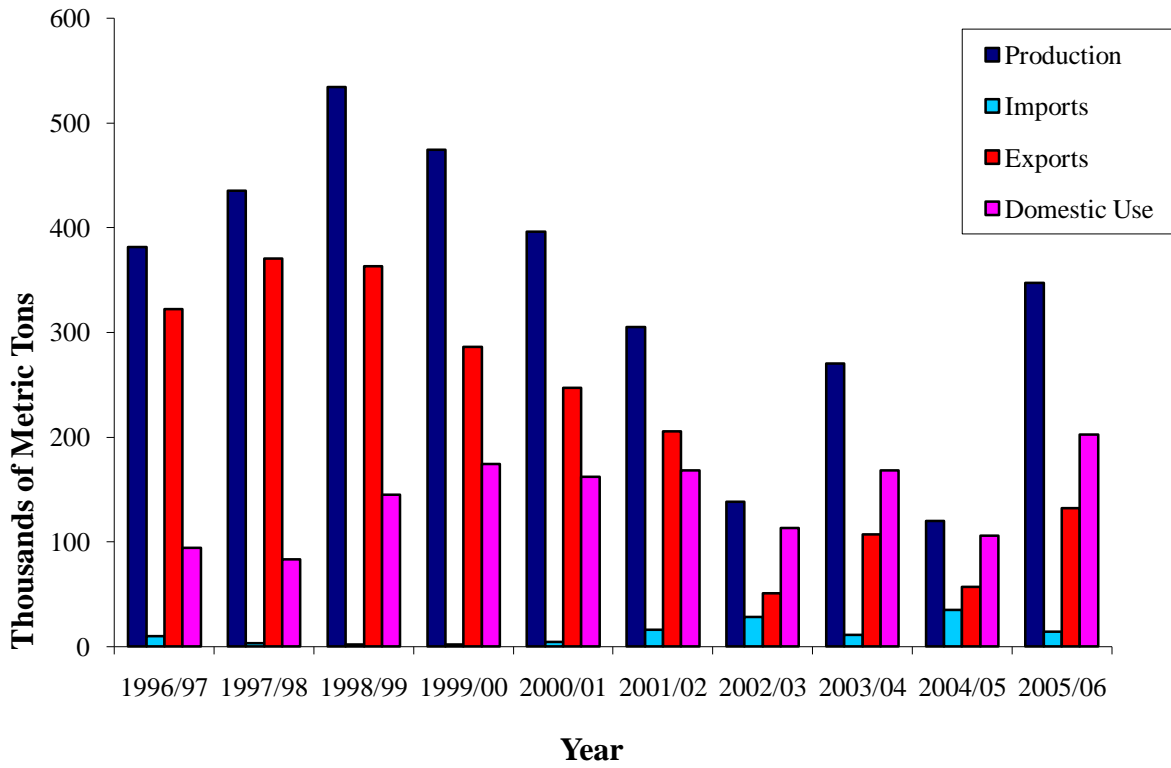


Figure 16: US sunflower seed oil (CRB 2006).

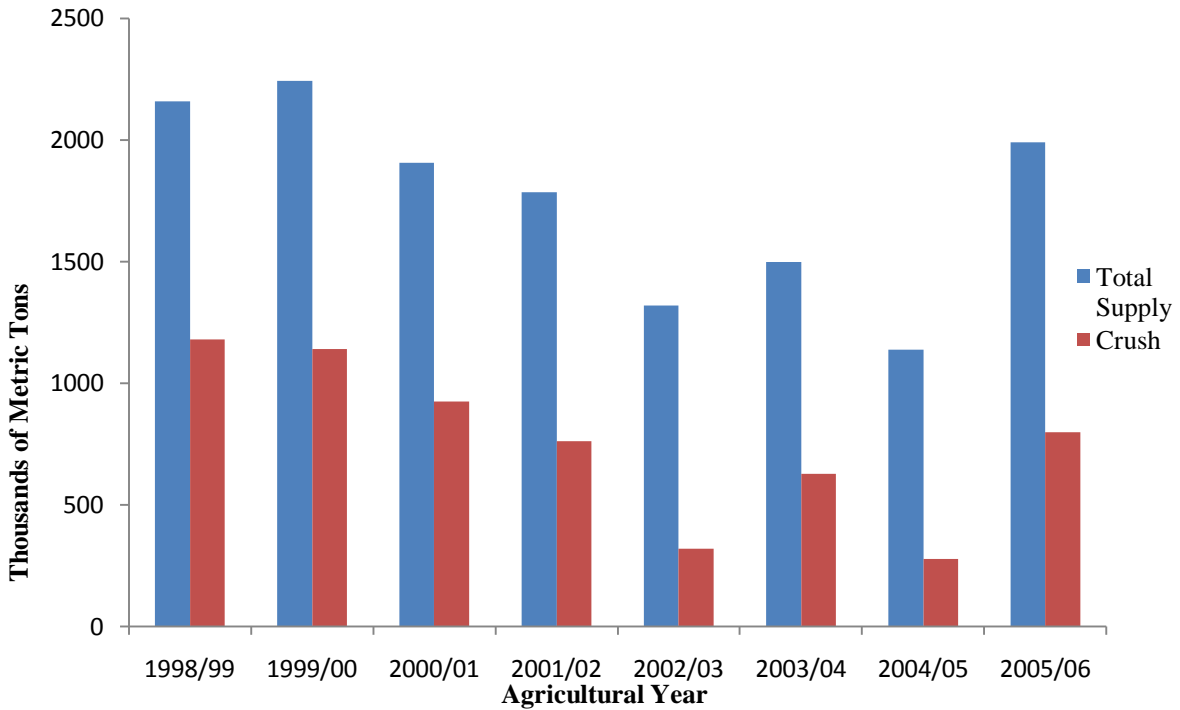


Figure 17: United States crush of sunflower seed (CRB 2006).

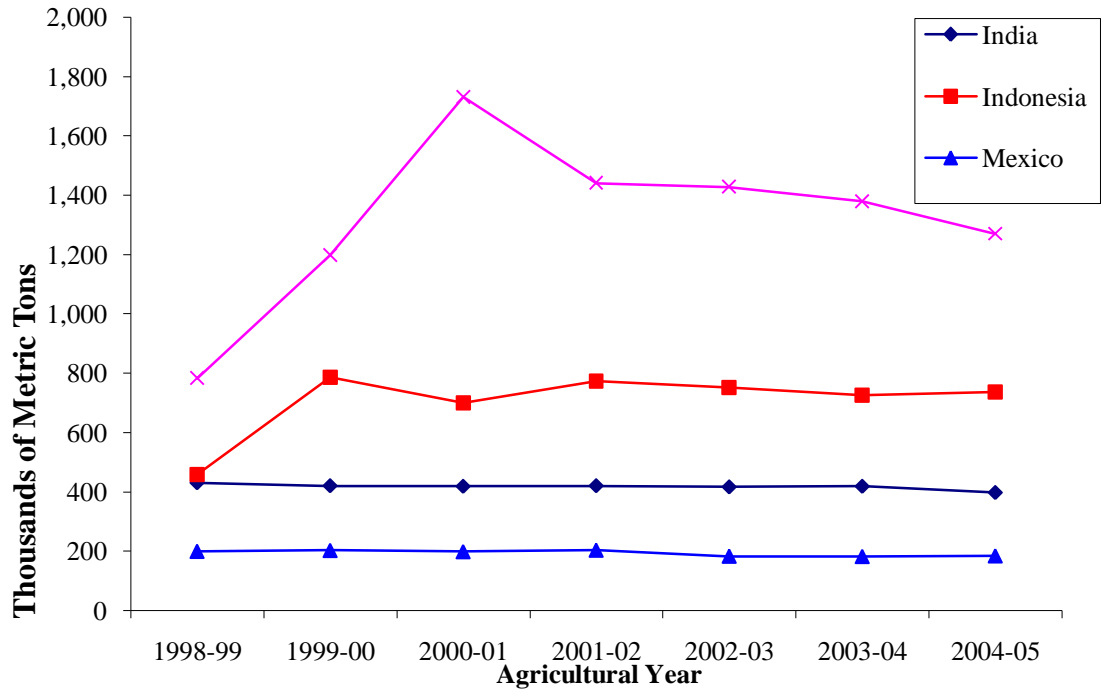


Figure 18: Top coconut oil producers (CRB 2006).

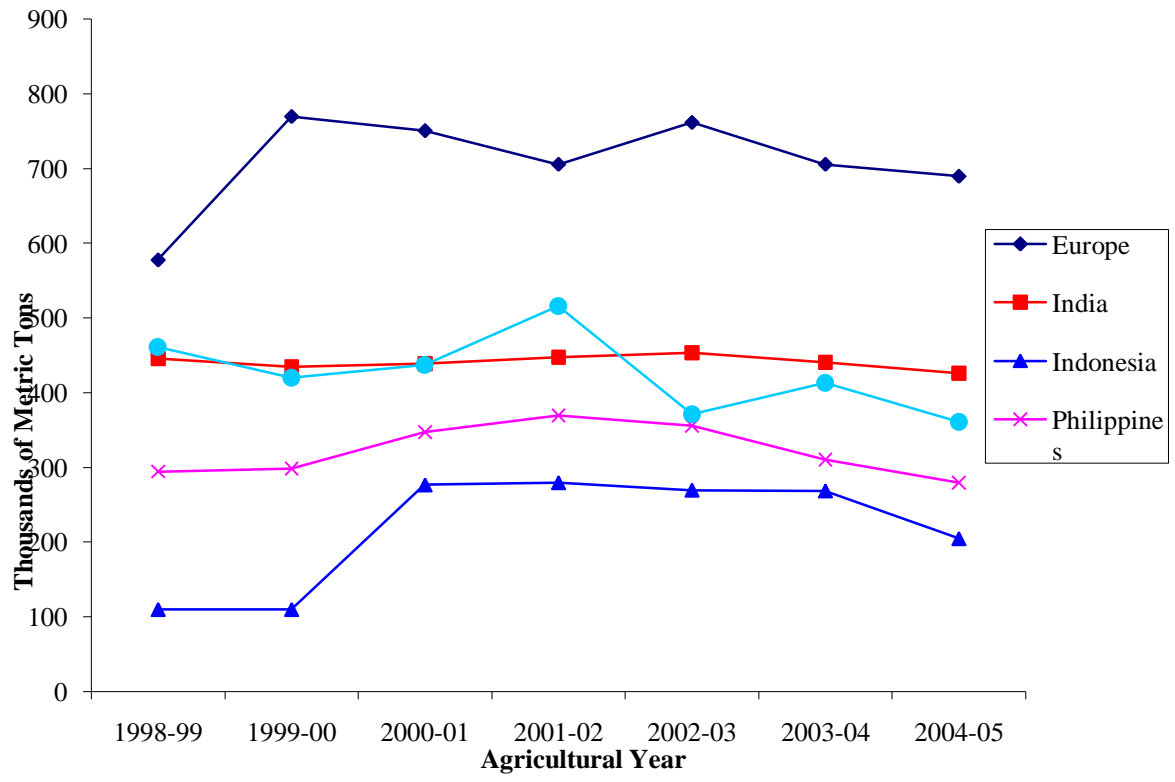


Figure 19: Top coconut oil consumers (CRB 2006).

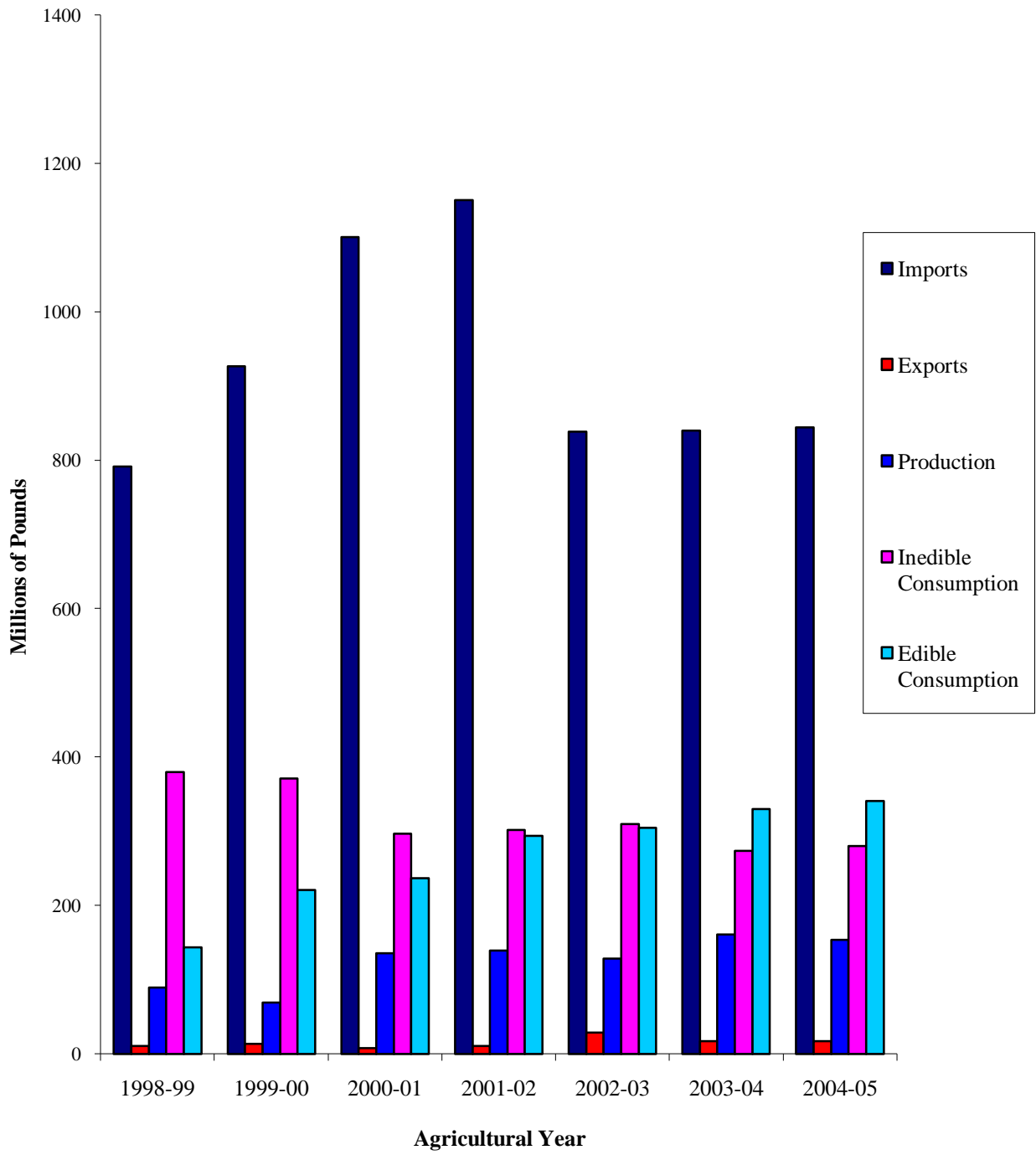


Figure 20: Supply and disappearance of coconut oil in the US (CRB 2006).

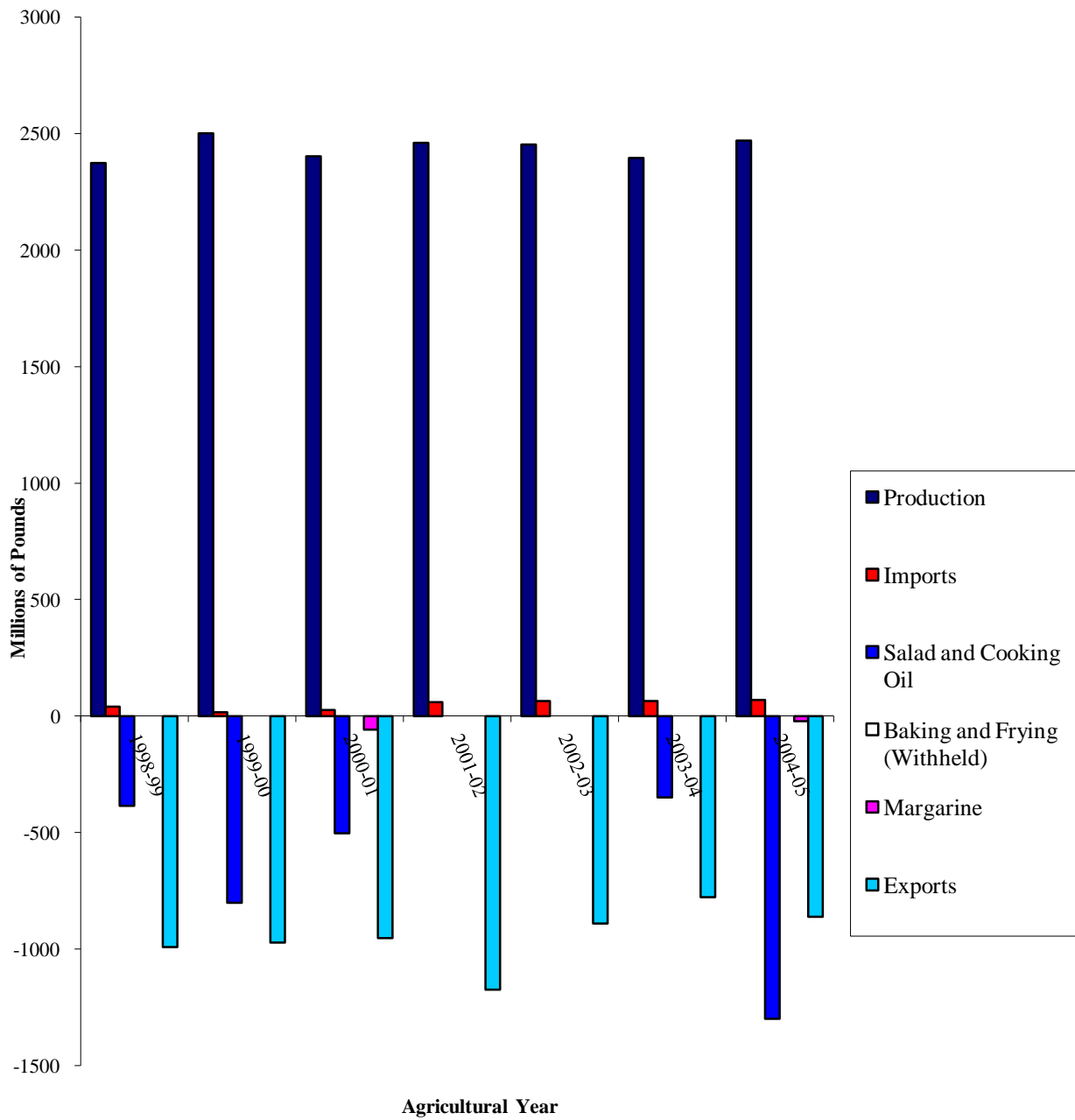


Figure 21: US corn oil supply and disappearance (CRB 2006) (For years with no data, numbers with withheld)

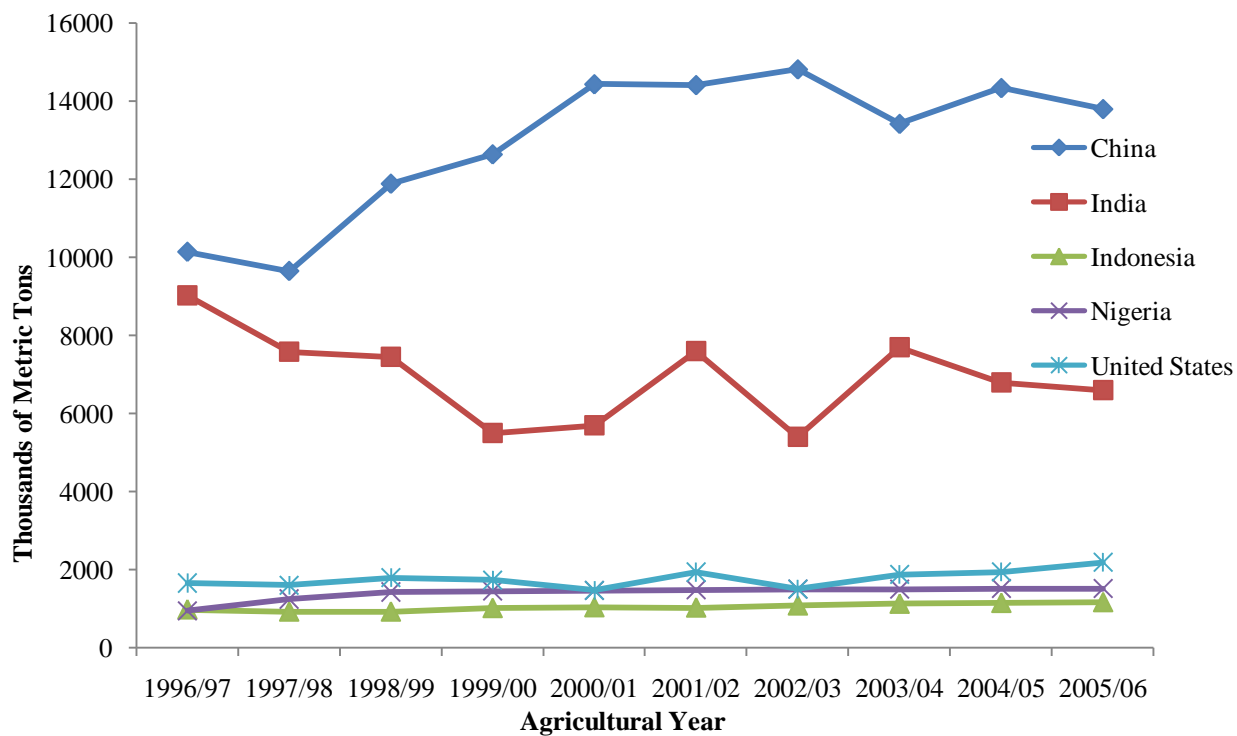


Figure 22: Top producers of peanuts (in the shell) (CRB 2006).

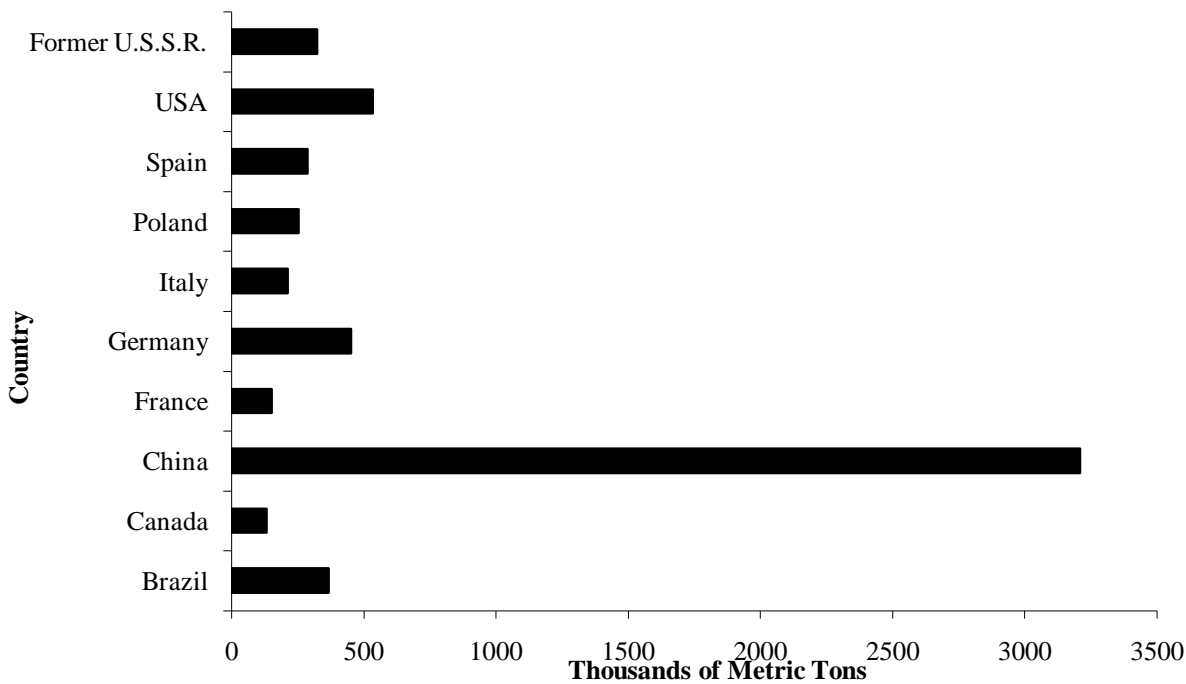


Figure 23: 2005 top producers of lard (CRB 2006).

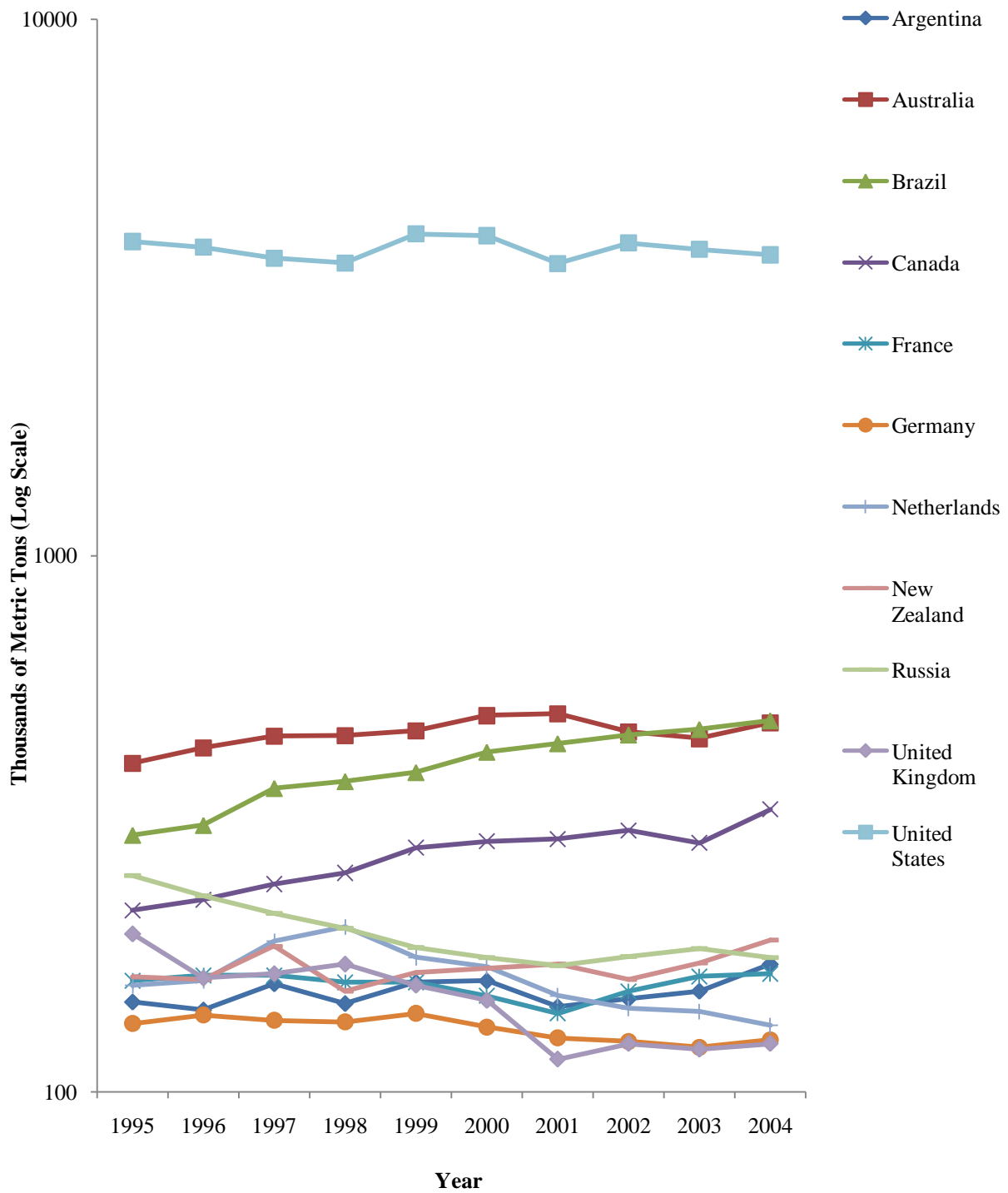


Figure 24: World production of tallow and grease (CRB 2006).