

## Chapter 5

# Biofuels for Home Heating Oils

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## Introduction

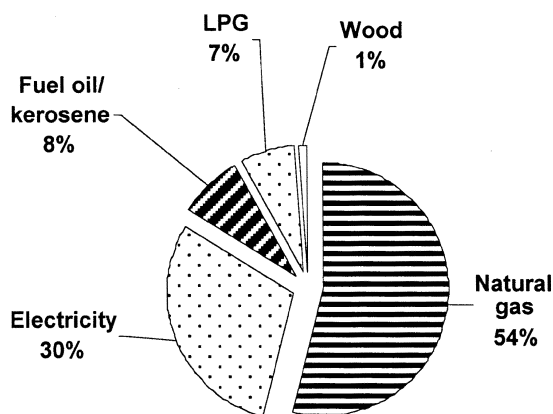
Petroleum-based liquid home heating oil is used to heat over eight million homes in the U.S., predominantly in the northeastern U.S. (1). This comprises ~6.6 billion gallons of fuel oil annually. With recent rises in petroleum prices to over \$50 per barrel, and anticipated future price increases as petroleum resources become less available, many applications that depend on petroleum are searching for alternatives. Additional concerns over environmental issues involving sulfur and nitrogen oxide emissions from oil-based home heating systems have sparked a search for alternative fuels to supply this market. This chapter presents a background on home heating systems and highlights recent research to develop renewable biofuels for home heating applications.

## Home Heating Technologies

### *History of Home Heating*

Historically, interior home heating has progressed from open wood fireplaces to modern enclosed high-efficiency furnaces. Centralized heating systems were initially developed during the early 19th century along with the demand for larger buildings and residences. While wood was the initial fuel used in fireplaces, coal was often preferred due to its higher energy density. As population density in urban settings increased, the environmental impacts of these heating systems became increasingly evident in the form of smoke, soot, and smog, with accompanying health issues. With the growth of the petroleum industry in the early 1900s, liquid fuels replaced solid fuels due to their ease of transportation and simplicity of use. In the mid-1900s, gaseous fuels, such as natural gas, became the fuel of choice, due to its ease of use and clean-burning properties. With the growth of electrical transmission systems, electrical heating/heat pumps have also become popular in the last four decades. Accompanying these changes in fuel technology were improvements in environmental emissions, such as reduced smoke/soot and sulfur oxides.

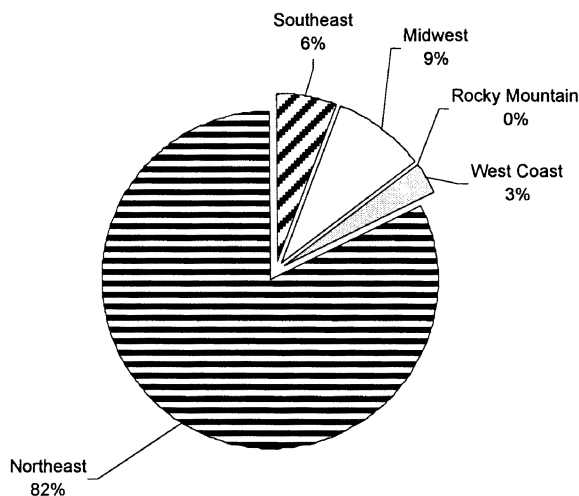
Looking at the U.S., the geographical distribution of home heating systems follows this historical development of fuels technology. The northeast coast has



**Fig. 5.1.** Residential heating fuel types (1).

the largest concentration of liquid fuel home heating systems, with natural gas and electrical systems becoming the majority in the central and western U.S. Figure 5.1 shows natural gas and electrical heat residences made up 55 and 30%, respectively, of the total heated households in the U.S., while fuel oil residences made up ~8%. The geographical distribution of annual sales of heating fuel are shown below in Figure 5.2.

Since the 1970s, the heating oil industry has dropped from 20% of American households to less than 10%. Currently, most new housing is heated by natural gas or electrical energy. However, with recent record high prices in natural gas, the oil heat industry is eager to regain heating fuel markets. The National Oilheat Research Alliance (NORA) was created to address this concern by supporting new oil heat technologies and fuels as well as improving the public perception of oil heat (2).



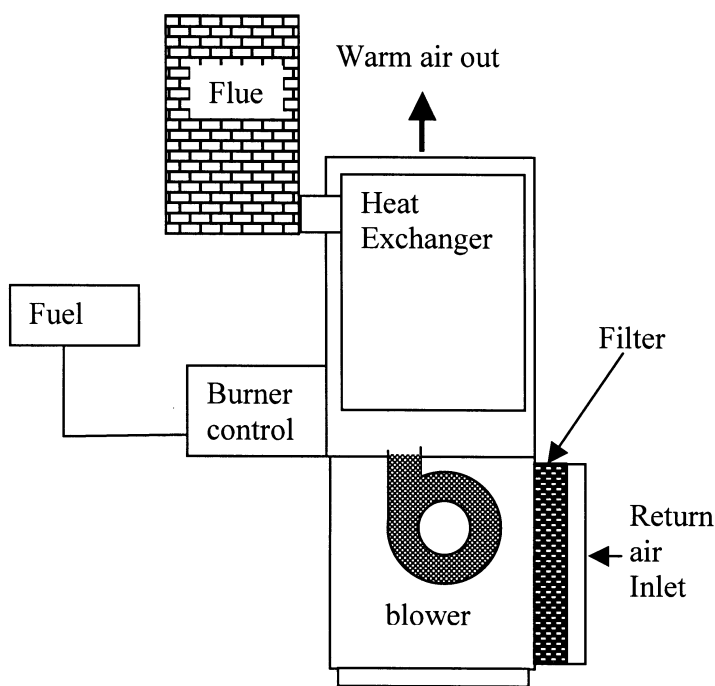
**Fig. 5.2.** Sales of residential heating oil by location.

With the long-term prospect of diminishing petroleum resources, sharply increasing prices, and environmental regulation, the oil heat industry is focusing on developing alternative fuels. Biofuels are particularly attractive due to their renewable nature, environmental benefits, and chemical similarity to petrochemical hydrocarbons. Additionally, there are potential political benefits based on domestic production and partnering with agriculture, which include reduction of national trade deficits, energy security, and domestic job creation.

### ***Fuel Oil Furnace Technology***

A typical home heating furnace is presented in Figure 5.3. Fuel is pumped into the combustion chamber where it is combined with external air and burned. A heat exchanger is used to transfer heat to a separate external air-flow to produce warm air for home heating.

Due to low evaporative volatility, home heating oil furnaces require fuel to be atomized by pumping through nozzles prior to combustion. Atomization is the process of generating droplets from a liquid. The process is controlled by several factors including physical properties of the liquid, operating conditions and atomizer geometry. Nozzle configuration can have a significant effect on both combus-



**Fig. 5.3.** Typical residential heating furnace.

tion and formation of nitrogen oxides. Liquid viscosity is the primary fuel factor in spray formation and hence combustion. Standard pump pressures are normally around 100 psi and produce nearly 55 billion drops/gal of fuel oil droplets which range in size from 0.002 in (5.1  $\mu\text{m}$ ) to 0.010 in (254  $\mu\text{m}$ ) (3).

The efficiency of heat recovery is a critical performance factor. Therefore, controlling combustion air-flow is a key performance parameter. High life-cycle improves fuel combustion and may improve emissions, but results in loss of energy into the exhaust gases. Low air-flow may result in incomplete combustion and increased emissions. Ideally, hydrocarbon fuels composed of carbon, hydrogen, and oxygen would completely combust with oxygen to produce only water and carbon dioxide. In reality, some carbon monoxide forms, even under high-excess oxygen conditions due to incomplete combustion. Along with incomplete combustion, the other main emissions of concern are sulfur/nitrogen oxides. Sulfur oxides (SOx) are considered environmentally undesirable due to the formation of atmospheric sulfuric acid when combined with rainwater. Nitrogen oxides (NOx) function as a catalyst in the chain reaction formation of ozone and carbonyl groups in the upper atmosphere (4), creating smog. Natural sources of petroleum contain varying amounts of sulfur. This can be adjusted by refining; current laws/regulations exist to regulate SOx emissions. In general, SOx emissions are essentially quantitatively related to fuel sulfur content (5).

Due to the presence of high amounts of nitrogen in the air used in combustion, NOx are also formed. Many major cities, such as Los Angeles and Texas, have restrictions on NOx emissions from sources including residential size boilers and furnaces (6). Eastern states have not yet restricted these emissions from residential boilers and furnaces, but that may change in the future. Since high temperatures are believed to be the primary catalyst in NOx formation (4), increased NOx formation occurs at higher combustion temperatures and in the presence of larger excesses of oxygen.

To obtain complete combustion, excess air-flow is used (see Fig. 5.4). Ideally, the amount of air used minimizes carbon monoxide formation/maximizes carbon oxidation while trying to minimize the loss of energy in the outlet gases. However, maximizing the furnace temperature to provide high heat transfer in the presence of excess air produces increased levels of NOx. Therefore, furnaces must be carefully optimized to balance heating performance, while minimizing emissions by controlling air-flow, fuel combustion, and heating temperature.

### ***Fuel Oil Chemical Composition***

Petroleum hydrocarbons are composed of ~86% carbon and 14% hydrogen. Small amounts of sulfur, nitrogen, and oxygen may also be present depending on the source of extraction. Transportation fuel (gasoline, diesel, aviation, etc.) is the major use of petroleum in the U.S. This fuel requires significant refining to produce the highly refined hydrocarbon compositions needed by modern engine tech-

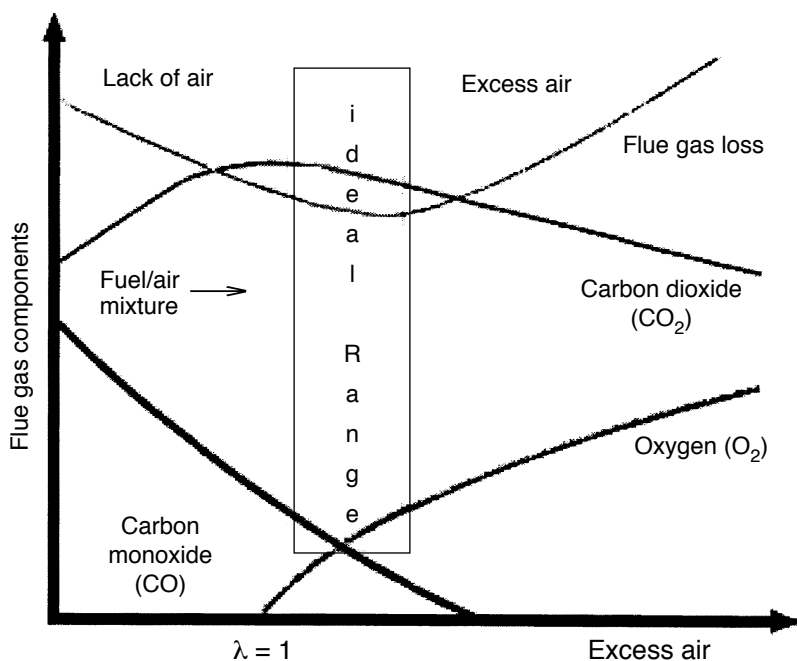


Fig. 5.4. Combustion exhaust gas properties (7).

nologies. Since the fuel oil combustion in furnaces is less stringent, fuel oil is less refined and contains higher molecular weight components (8). Typical carbon number range for #2 fuel oil is from C11 to C20 and may contain higher percentages aromatic hydrocarbons relative to kerosene or diesel fuel (9). Based on cold weather temperatures, different blends with lower freezing points may be created, for example heating fuels #1, #2, and #4 (10).

Similar to automotive and industrial petroleum fuel use, environmental emissions are important for home heating fuels. The sulfur content is an important environmental and economic factor in petroleum heating oil. In 1991, the environmental protection agency (EPA) regulated the sulfur content of on-highway diesel vehicles to 0.05% or 500 ppm. Prior to that time, heating oil and on-highway diesel both shared the maximum sulfur content value of 0.5% or 5,000 ppm. In an attempt to simplify fuel distribution and improve emissions, the NORA board mandated that 80% of the heating oil consumed not contain more than 500 ppm by 2007 (5). This was supported by the recent ASTM adoption of specification for low sulfur (LS) #2 heating oil. Research into ultra-low sulfur (ULS) with less than 15 ppm sulfur heating oil has recently been conducted and approaches nitrogen free status (6). Additional environmental issues involved in fuel combustion technologies are the formation of nitrogen oxides, related to atmospheric smog formation, and particulate emissions (soot/smoke).

## Biofuels

Biologically derived fuels from plant oils have four major benefits versus petroleum or natural gas. First, they are environmentally renewable. The main product of hydrocarbon combustion is carbon dioxide, which is believed to be related to global warming. Since growing plants actively recycle carbon dioxide to build oils and lipids, combusted biofuels are ecologically recycled, resulting in zero net carbon dioxide production. Second, plant oils from crops such as soybeans, corn, canola, etc., are domestically produced versus petroleum from foreign sources. This is a significant issue in today's U.S. environment where the concern for homeland security is paramount. Third, the chemical structure of plant oils is chemically and physically similar to petroleum hydrocarbons. They are composed of triacylglycerols, whose long-chain fatty acid moieties are essentially hydrocarbons, hence the similarity in the common name "oil." Finally, the current economics of plant oils are similar or slightly favorable versus petroleum and this is anticipated to become increasingly beneficial in the long-term future due to diminishing petroleum availability.

With respect to liquid biofuels, there are currently two plant oil-based fuels being studied, degummed oil (triacylglycerides) and biodiesel fuel (monoalkyl esters).

*Degummed Vegetable Oil.* Vegetable oil from common domestic sources, such as soybean oil, is a triacylglyceride composed of a glycerol molecule onto which three long-chain fatty acids are attached (see Fig. 5.5).

The fatty acid chains are essentially linear hydrocarbons, some containing one or more double bonds, and may be different chain lengths at each glycerol position. Soybean oil is extracted from soybean seeds and purified through a series of processing steps, which includes degumming. Degumming is the process of removing phospholipids, such as lecithin, and is the initial processing step in the production of food-grade vegetable oils (Fig. 5.6).

Degummed oil is an intermediate product in the production of food-grade vegetable oil and is approx. \$0.05 to \$0.10/gal cheaper than fully refined oil due to less processing. Approximately 2.8 billion gallons of soybean oil are produced domestically in the U.S. annually, with world production at ~10 billion gallons annually. Recent prices for food-grade soybean oil are in the range of \$0.20–\$0.25/lb or ~\$1.50/gal.

*Mono-Alkyl Esters/Biodiesel.* Alcohol transesterification of triacylglycerides chemically rearranges fats into glycerin and alkyl esters. The most common ester

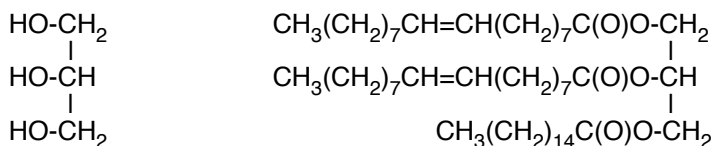


Fig. 5.5. Glycerol and triacylglyceride structures.

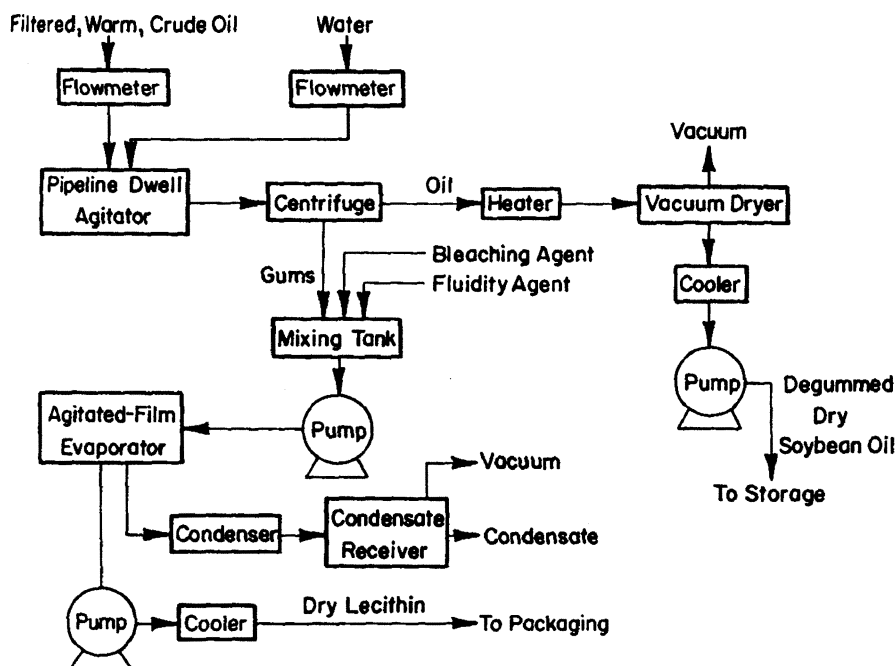


Fig. 5.6. Soybean oil degumming process diagram (11).

currently formed uses methanol as the acceptor alcohol (ROH in Fig. 5.7) to make methyl esters (ROCOR' in Fig. 5.7), which is commonly called biodiesel fuel. More information on this process can be found at [www.biodiesel.org](http://www.biodiesel.org).

Since biodiesel can be made from any triacylglyceride source, significant differences in physical properties have been observed. The use of animal fats or hydrogenated fats which contain higher saturated fat content have much higher freezing temperatures than standard soybean oil, which contains high levels of polyunsaturated fatty acids. In comparison to triacylglycerides, fatty acid methyl esters generally have lower viscosities and are much better solvents toward poly-

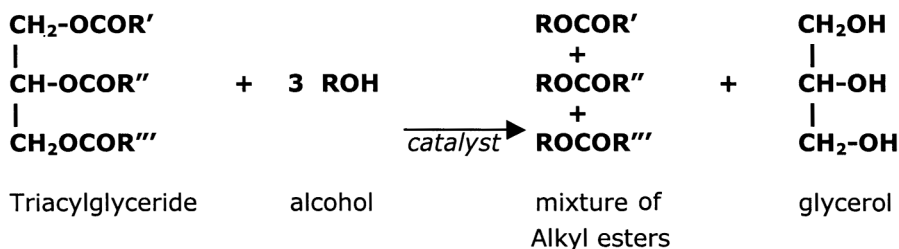


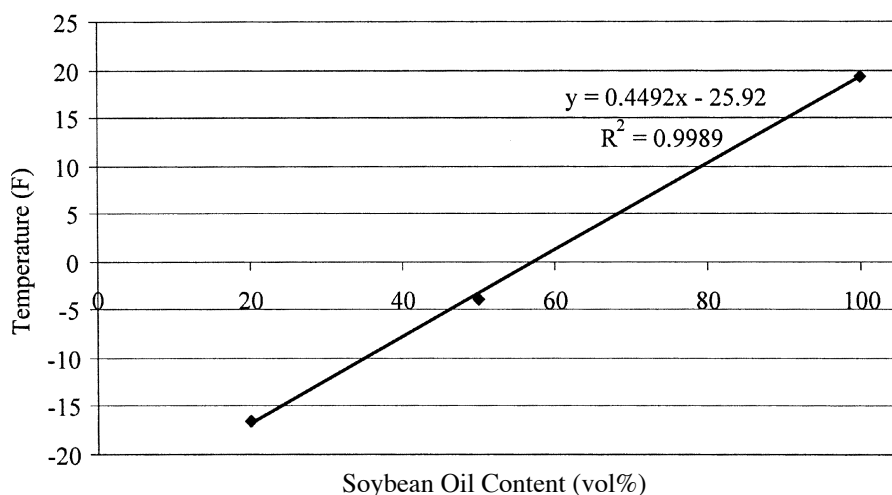
Fig. 5.7. Transesterification of fatty acid methyl esters.

mers and elastomers. Their cold temperature properties are somewhat similar, but strongly depend on fatty acid structure and composition. In the U.S., current production capacity is ~80 million gallons annually with significant investments being made to increase production. Estimates of the current cost of biodiesel soy methyl esters are in the range of \$2.50–\$3.00/gal. Due to recent legislation for transportation applications of biodiesel fuel, subsidized support has been provided for this biofuel to reduce the cost by ~\$1/gal, but it is not clear if this subsidy will apply to home heating fuels.

### ***Recent Research on Biofuels Usage in Home Heating Applications***

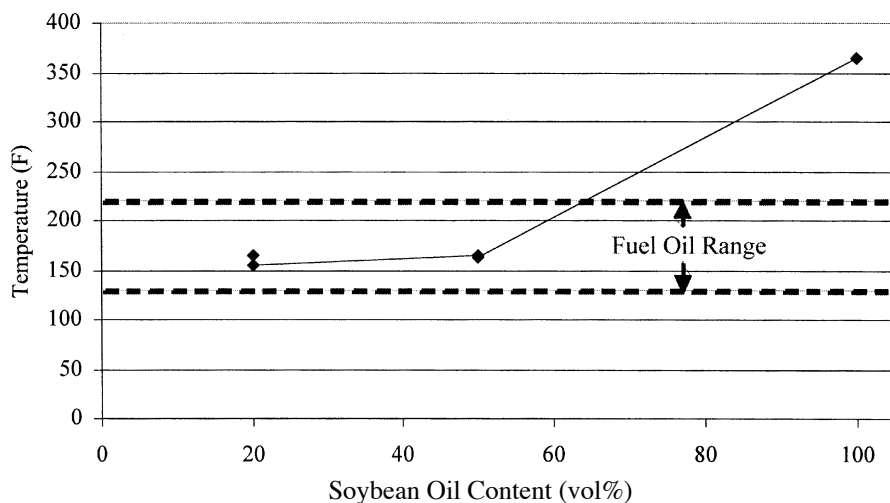
*Low Temperature Behavior of Biofuel Blends.* Solidification or gelling of home heating fuel is a concern due to cold weather climates. This phenomenon is quantified by the cloud point and the pour point temperatures, which are the temperatures at which the first crystals appear (cloud point) and at which the mixture no longer freely flows (pour point). These thermal properties increase with degummed soybean oil content in soybean oil heating fuels (SHO) (see Fig. 5.8). The cloud point is ~7°F (3.9°C) higher than the pour point for each blend. This behavior is similar to the results obtained for biodiesel blends published by Brookhaven National Laboratory (BNL) (12). Therefore, higher blends of biofuels can be an issue with respect to cold temperature fuel crystallization.

*Flash Point.* The flash point of a fuel is a measurement of flammability. Higher flash points indicate fuels which are less flammable and hence safer to handle with respect to volatility. The reported flash points for the degummed soybean heating



**Fig. 5.8.** Cloud point of soybean oil/#2 home heating oil blends (13).





**Fig. 5.9.** Flash point of soybean oil/#2 home heating oil blends (13).

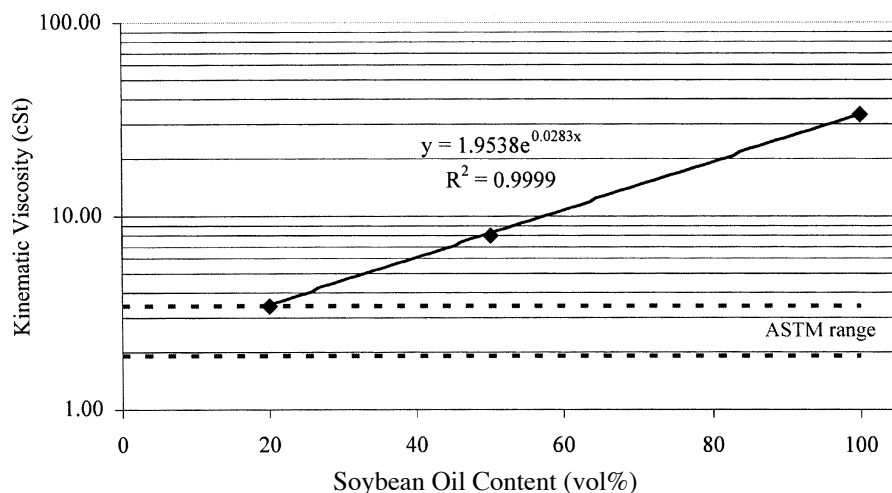
oil blends (13) are similar to biodiesel results published by Krishna and Butcher (12). Analysis of both soybean oil and biodiesel heating oil blends showed a nearly constant flash point up to a 30% blend, then an increase with biofuel component composition (see Fig. 5.9). Therefore, higher blends of biofuels are safer from a volatility perspective.

*Energy Content.* The energy content of the blended fuels is essentially linear with composition. Fuel oil contains ~10% more energy than soybean oil. Soybean oil has slightly higher energy content than methyl esters (see Table 5.1). Obviously, the energy content would be linearly proportional to the amount of biofuel component used. However, in practice, this difference in energy content is probably not significant, given that the operational parameters of furnaces have much greater impact on variations in energy output.

**TABLE 5.1**

Net Energy Content of Biofuels and Blends

	Volume basis BTU/gal (MJ/L)	Mass basis BTU/lb (MJ/kg)
#2 Fuel oil	139,167 (38.8)	19,601 (45.6)
SHO20 (degummed)	135,490 (37.8)	18,871 (43.9)
SHO50 (degummed)	132,441 (36.9)	18,143 (42.2)
Degummed soybean oil	127,631 (35.6)	17,017 (39.5)
Soy methyl esters	125,314 (34.9)	17,405 (40.4)



**Fig. 5.10.** Soybean oil heating fuels kinematic viscosity at 100°F (13).

*Viscosity.* Figure 5.10 shows the kinematic viscosity at 100°F (37.8°C) for SHO heating oil blends. The kinematic viscosity of the SHO20 blend was 3.46 cSt which is within the ASTM recommendation for petroleum fuel oil. The main impact of the viscosity is in atomization of the fuel in the combustion chamber. Higher viscosities tend to increase particle size and reduce combustion efficiency. Research by VanLanningham (13) demonstrated that different atomization nozzle configurations could be used to effectively atomize viscosity biofuel blends higher than 20% if needed. Viscosity measurements by Krishna and McDonald (14) show that biodiesel fuel composition below ~40% falls within the current ASTM standard range for heating fuel.

### ***Environmental Impact of Heating Oil Replacement***

Both VanLanningham (13) and Krishna (14) observed linear decreases in SO<sub>x</sub> emissions with the addition of either biodiesel or vegetable oil fuels to #2 heating fuels. Therefore, SO<sub>x</sub> emissions reduction is basically due to decreased sulfur content of the biofuels.

The nitrogen oxides (NO<sub>x</sub>) results from biofuel blends are less conclusive. Two studies show soy methyl ester blends reduce NO<sub>x</sub> emissions while a third study reports no statistical difference in emissions. The BNL biofuel study suggests higher concentrations of biofuels produce lower NO<sub>x</sub> emissions over most operating ranges (15). Lower flame temperatures and/or the presence of oxygenated compounds within the fuel were considered possible clues to the decrease in NO<sub>x</sub> emissions for biodiesel (12). This is supported by Bowman (16) who demonstrated that reducing either the burned gas temperature or the available oxygen will

reduce the NO formation rate. The Brookhaven study also stated an observed peak in NO<sub>x</sub> emissions, and a general decrease in emissions as the excess combustion air increased. However, it was noted that combustion chamber design and the furnace design in general affected NO<sub>x</sub> emissions (17). This agrees with Vanlanningham's observations that at 20% vegetable oil, different atomizing nozzle designs gave NO<sub>x</sub> levels from 60–120 ppm. Cold temperature combustion tests found NO<sub>x</sub> emissions not to be statistically different for the 20% SME blend and the petroleum heating oil (18).

Krishna and Butcher (12) observed decreased emissions with the addition of biodiesel, but VanLanningham (13) observed no changes in NO<sub>x</sub> emissions with vegetable oil. In both cases, the excess oxygen content in the exhaust gases was ~3% range with NO<sub>x</sub> levels in the 110–120 ppm range. The reason for this disparity is unclear, but the difference may be more dependent on the air-flow operating conditions and fuel atomization than the type of biofuel. If higher excess air-flow is used, the NO<sub>x</sub> concentrations will be lower due to dilution in the outlet gases. Krishna and Butcher's work shows slightly lower NO<sub>x</sub> emissions (115–117 ppm) at 3% oxygen in the exhaust, with decreasing NO<sub>x</sub> with increased air-flow down to ~90 ppm at 8% oxygen. VanLanningham only reports NO<sub>x</sub> levels at 3% oxygen in the exhaust gases which range from 60–120 ppm, depending on atomizing nozzle configuration.

Alternatively, if higher combustion temperatures are obtained, NO<sub>x</sub> formation rates may be greater. In the VanLanningham study of vegetable oil (13), it was noted that increasing vegetable oil content above 50% did result in higher combustion temperatures. However, no significant temperature differences were noted at the 20% biofuel composition, so it is unclear why the observed NO<sub>x</sub> levels were higher. Analysis of emissions from combustion of a mixture of 20% soybean oil with #2 fuel oil showed a slight increase in NO<sub>x</sub> and slight decrease in SO<sub>2</sub> (Table 5.2).

Since environmental impact is a primary benefit of biofuels, a life-cycle analysis of the impacts of using soybean oil heating fuel blends was quantified (19) using the factors indicated in Fig. 5.11.

Using a recently completed life-cycle inventory by the National Institute for Standards and Technology (NIST) for soybean production (20), the energy use and other environmental impacts from an acre of soybean production were calculated. Table 5.3 from the NIST LCI shows the total for inputs and outputs from soy agricultural production. Based on one kg of soybeans produced, the total primary energy requirement is 2 MJ for production. The crushing process requires 92,880 kcal/ton of soybeans or an additional 0.39 MJ/kg, bringing a total of 2.39 MJ/kg of oil or meal, if energy is allocated equally. Combustion data shows 17113.5 BTU/pound which equates to 39.7 MJ/kg of fuel burned for a net gain of 37.31 MJ/kg of oil. One kg of heating oil would produce 45.8 MJ/kg of energy. The NREL biodiesel life-cycle estimated a process energy requirement for diesel fuel of 9.16 MJ for extraction transportation and refining, leaving a net gain of 36.6 MJ/kg.

**TABLE 5.2**

Emissions from #2 Fuel Oil/Soybean Oil Blends

Fuel	T gas °C	CO <sub>2</sub> %	O <sub>2</sub> %	CO ppm	SO <sub>2</sub> ppm	NOx ppm
Fuel Oil	252	10.7	6.5	11.2	99	72
Fuel Oil	252	11.4	5.6	11	78	84
Fuel Oil	247	11.3	5.8	10.9	74	81
Fuel Oil	240	10.4	6.9	10.3	104	75
Fuel Oil	238	10.1	7.3	9.7	83	76
Fuel Oil	238	9.9	7.5	9.8	79	77
Fuel Oil	239	9.7	7.9	9.6	78	78
SHO20	246	11.9	4.8	11.3	92	91
SHO20	245	11.9	4.9	11.5	90	91
SHO20	239	10.3	7.1	10.9	94	92
SHO20	253	10.3	7	10.6	93	93
SHO20	258	11.3	5.7	11	82	98
SHO20	262	11.3	5.7	10.5	81	99
SHO20	239	11.9	4.8	9	77	93
SHO20	235	11.3	5.6	8.6	69	85
SHO20	236	11.3	5.7	8.5	69	84

Source: Reference 13.

Another significant and favorable difference is the sequestration of CO<sub>2</sub> from the atmosphere during the growth of the soybean crop. Combustion data shows that both soybean oil and #2 oil fuels release CO<sub>2</sub> in equal amounts, but the NIST life-cycle shows that soybeans take up 1561 g of CO<sub>2</sub>/kg soybeans. Soybean oil is actually more dense in carbon than whole soybeans, containing ~75% elemental carbon by weight. Converting elemental carbon to CO<sub>2</sub> shows that each kg of oil contains the equivalent of 2.77 kg of CO<sub>2</sub>. Allocating the CO<sub>2</sub> release from agriculture based on the oil yield of 12.5% yields a net sequestration of 2.76 kg of CO<sub>2</sub> with a release from combustion of ~1,200 g of CO<sub>2</sub>/kg of fuel burned for either soybean oil or #2 distillate. Therefore, the use of soybean oil for combustion shows a net sequestration of CO<sub>2</sub> of between 1.5–1.6 kg/kg of fuel burned versus #2 fuel oil. Assuming a blend of 20% soybean oil with #2 distillate, the total CO<sub>2</sub> contribution to the atmosphere is reduced from 1.2kg/kg of fuel to 0.66 kg/kg of fuel, a reduction in global warming potential of 45%.

### ***Testing of Biofuels in Home Heating Systems***

Current field testing of biofuels for home heating has focused on using blended fuels which do not require any modification of existing furnaces or fuel delivery infrastructures to minimize costs. Recent results reported by Batey (17) and Batey *et al.* (21) indicate that lower emissions of SOx, NOx, and CO<sub>2</sub> based on single burner/boilers using 20% soy-based biodiesel blended with low sulfur (~0.05%) diesel fuel. In 2003, a blend of 20% biodiesel was used by the Warwick School

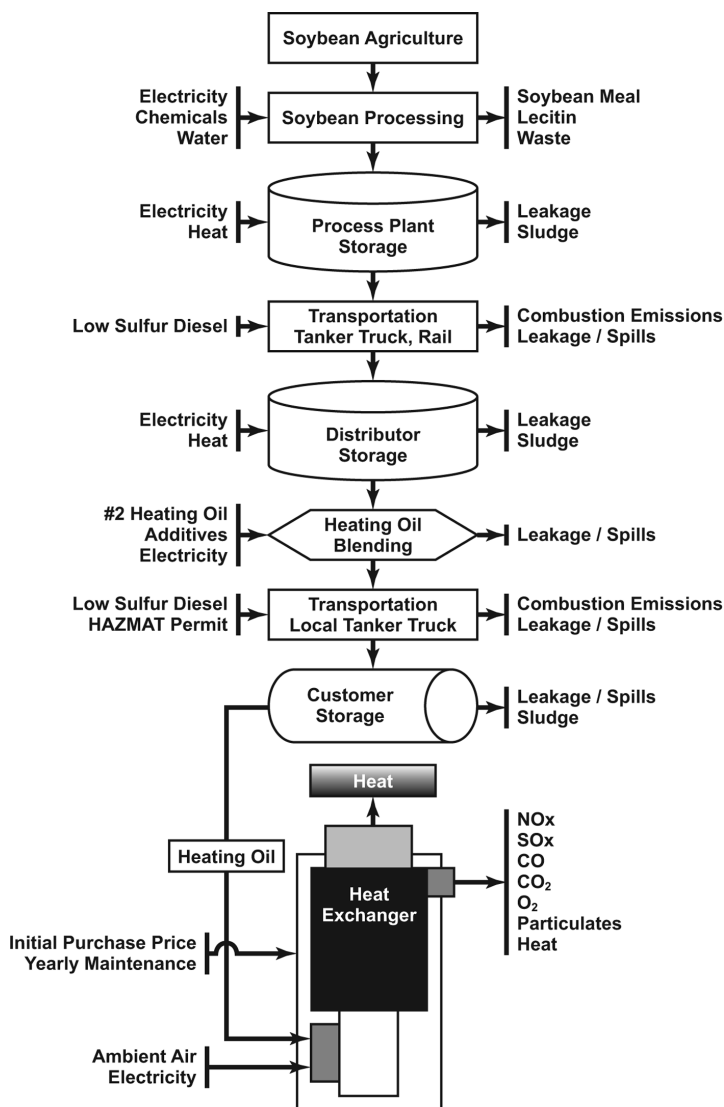


Fig. 5.11. Life-cycle analysis parameters for soybean oil heating fuel blends.

Department in Rhode Island following a successful one year field testing where 10%, 15% and 20% blends of biodiesel were used experimentally (22).

Field testing of 20% SHO heating fuel blends was conducted at two private residences over the past two years and demonstrated normal operations (14). Industrial furnace field tests have not been performed for soybean oil fuel blends to date. In all cases, no adverse performance or efficiency issues were noted.

**TABLE 5.3**

NIST Life-Cycle Analysis Parameter Values

Inventory: Soybeans		Soybean Cultivation	
Flow		Units	Total
Input	(r) Coal (in ground)	kg	0.0049
	(r) Limestone ( $\text{CaCO}_3$ , in ground)	kg	0.15
	(r) Natural Gas (in ground)	kg	0.014
	(r) Oil (in ground)	kg	0.025
	(r) Phosphate Rock (in ground)	kg	0.014
	(r) Potash ( $\text{K}_2\text{O}$ , in ground)	kg	0.0078
	(r) Uranium (U, ore)	kg	1.3E-07
	Land Use: Cropland (Conservation Tillage)	m <sup>2</sup> /yr	2.3
	Land Use: Cropland (Conventional Tillage)	m <sup>2</sup> /yr	1.0
	Land Use: Cropland (Reduced Tillage)	m <sup>2</sup> /yr	0.81
	Water Used (total)	liter	42
	Water: River	liter	26
	Water: Well	liter	15
Output	Carbon Dioxide ( $\text{CO}_2$ , biomass) <sup>a</sup>	g	(1,561)
	Carbon Dioxide ( $\text{CO}_2$ , fossil) <sup>a</sup>	g	188
	Carbon Monoxide ( $\text{CO}$ ) <sup>a</sup>	g	0.60
	Methane ( $\text{CH}_4$ ) <sup>a</sup>	g	0.16
	Nitrogen Oxides ( $\text{NO}_x$ as $\text{NO}_2$ ) <sup>a</sup>	g	1.1
	Nitrous Oxide ( $\text{N}_2\text{O}$ ) <sup>a</sup>	g	2.5
	Particulates (unspecified) <sup>a</sup>	g	11
	Sulfur Oxides ( $\text{SO}_x$ as $\text{SO}_2$ ) <sup>a</sup>	g	0.40
	Nitrogenous Matter (unspecified, as N) <sup>b</sup>	g	0.14
	Phosphorous Matter (unspecified, as P) <sup>b</sup>	g	0.021
	Suspended Matter (unspecified) <sup>b</sup>	g	2,816
	Soybeans	kg	1.0
	Soybean Residues	kg	2.1
	Soybean Residues (collected)	kg	
Reminders	Waste (total)	kg	0.036
	E Feedstock Energy	MJ	0.10
	E Fuel Energy	MJ	1.9
	E Nonrenewable Energy	MJ	2.0
	E Renewable Energy	MJ	0.018
	E Total Primary Energy	MJ	2.0

<sup>a</sup>Air emission.<sup>b</sup>Water emission.

Abbreviation: NA, not available.

## Economics

The partial replacement of #2 fuel oil through blending with crude degummed soybean oil demonstrated that up to 40% soybean oil mixtures produced a clean flame at manufacturer-recommended settings for air intake. On a heating energy basis, the energy content of soybean oil or methyl esters is roughly 10% less than #2 fuel oil on a weight basis (Table 5.4) and 8% less on a volume basis (Table 5.5).

**TABLE 5.4**

Energy Content of Heating Fuels (Mass Basis)

Material	BTU/lb	% Difference vs. #2 Fuel oil
#2 Fuel oil	19,601	0
Methyl soyate	17,405	-11
Crude degummed soybean oil	17,114	-13

Assuming 20% blends, the blended fuel would contain ~99% of the heating energy of #2 fuel oil, which would most likely not be significant for the average fuel user. Additionally, due to lower volatility, soybean oil and methyl esters would minimize the volatilization losses of the fuel during storage.

### ***Relative Prices of Soybean Oil, Methyl Esters, and #2 Heating Oil***

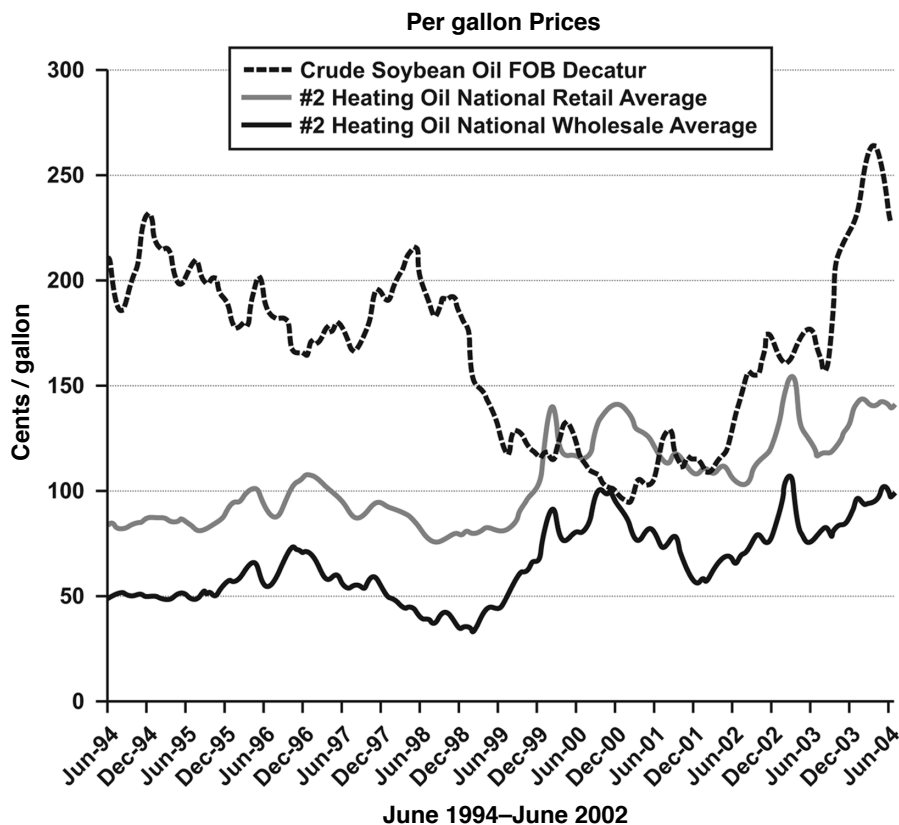
The prices of commodities such as heating oil and soybean oil fluctuate significantly. Since methyl esters are made from soybean oil, their prices are directly linked. Currently, methyl esters are ~\$1/gal higher than the price of soybean oil. Historically, the price of soybean oil per pound is twice the price of raw soybeans per pound. Therefore, if soybeans are selling at \$6.00/bu (\$0.10/lb) the recovered crude oil should be selling at \$0.18–\$0.22/lb or \$1.31–\$1.60/gal. For comparison, recent soybean oil prices at the Chicago Board of Trade were at \$0.2014/lb or \$1.47/gal, whereas #2 heating oil was selling at \$1.40–\$1.50/gal range (wholesale) and ~\$2.00/gal (retail) in December of 2004. (Note: Degummed soybean oil is not traded but would carry a price of ~\$0.03–\$0.05/lb less than the CBT price.)

Historical trends indicate that soybean oil prices have declined overall and appear to be trending downward despite the rise in 2003–2004 due to short crops. Crude oil prices and therefore on-season prices for #2 heating oil prices have increased more or less steadily with some fluctuation. The ten-year historical prices of soybean oil and #2 diesel fuel are shown below. During 2000–2002 soybean oil prices were actually lower than #2 heating fuel, despite being significantly higher previously. The recent spike in soybean oil prices in 2003–2004 to historical highs was due to decreased production due to weather and availability, but have

**TABLE 5.5**

Energy Content of Heating Fuels (Volume Basis)

Material	Weight lbs/gal	BTU/gal	% Difference vs. #2 Fuel oil
#2 Fuel oil	7.1	140067	0
Methyl soyate	7.6	127984	-8.63
Crude degummed soybean oil	7.3	130217	-7.03



**Fig. 5.12.** Historical prices for heating oil and soybean oil.

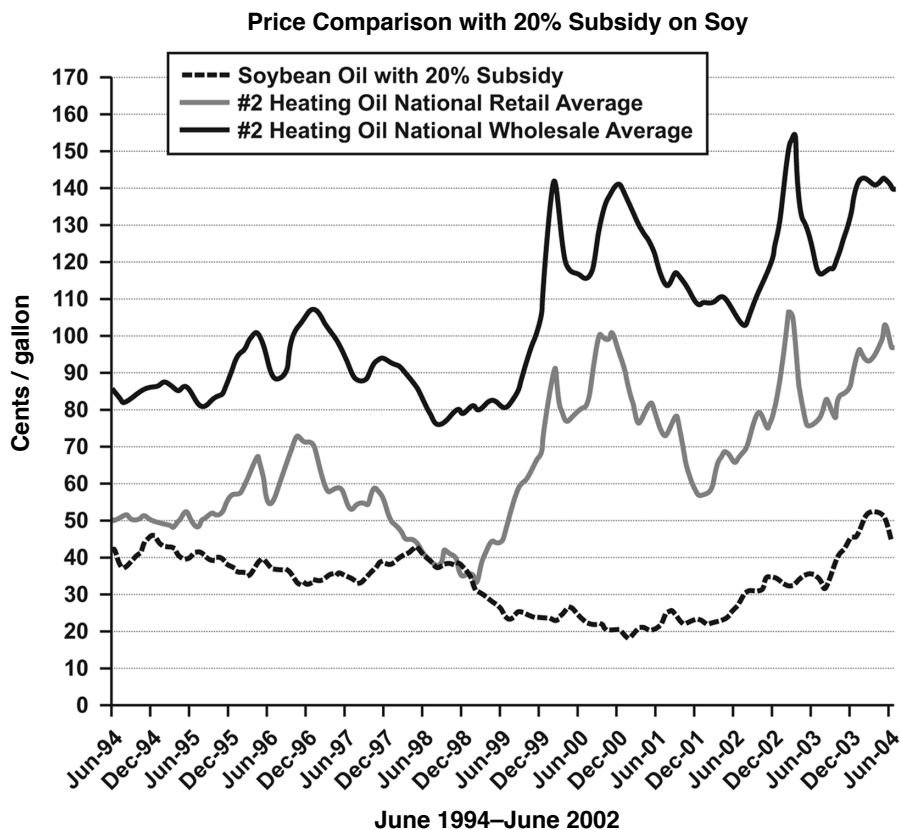
now returned to the \$1.40/gal range in late 2004. Figure 5.12 shows the ten-year price history of soybean oil to #2 heating oil.

The #2 heating oil prices are all national averages and do not account for local differences. An investigation of Energy Information Agency price history shows that retail heating oil spot prices on season have been by as much as \$0.32/gal above the national average. Prices are generally highest in the east coast states with the highest prices occurring in the mid-Atlantic.

In their March, 2004, U.S. Baseline Briefing Book, the Food and Agricultural Policy Research Institute (FAPRI) noted that “U.S. soybean yields in 2003 fell to the lowest level in ten years.” This, in turn, resulted in “sharply higher soybean prices in 2003–2004” (23). Looking forward, FAPRI projects a rebound of soybean production in 2004 to 2.87 billion bushels or an increase of 450 million bushels nationally. At this level, farm prices should fall from an average of \$7.24/bu to \$5.63/bu.

FAPRI also projects soybean oil prices to fall steadily over the next decade from an average of \$27.97/cwt in 2003–04 to only \$19.45/cwt in 2013–2014. This





**Fig. 5.13.** Comparative historical prices for heating oil and subsidized soybean oil.

happens due to a gradual increase in carryover stocks from 1 billion to 1.6 billion lbs. During this same period production increases by 500 million lbs while total utilization increases by 400 million lbs. If this is correct, the price of soybean oil as a biofuel for heating purposes would be ~\$1.42/gal. One can only speculate what the price of petroleum may be in 2014 for comparison.

### ***Potential Economic Impact of Biodiesel Subsidies***

For biodiesel alkyl esters, the Commodity Credit Corporation (CCC) of the USDA has subsidized sales of biodiesel fuel replacements for petro-diesel fuel. While subject to a variety of constraints, the subsidies generally pay ~20% of the cost of the raw commodity soybeans. If this same subsidy were applied to soybean oil for use as a heating fuel, Figure 5.13 shows the relative prices versus #2 heating fuel. As this chart indicates, at subsidized levels similar to biodiesel fuel, historical soybean oil prices would have been consistently below wholesale prices for #2 heating oil for the last decade.

Recently, the passage of the American JOBS Creation Act of 2004 created an economic incentive for the use of biodiesel fuels, including use as heating fuels. This incentive essentially reduces the heating fuel cost approximately one cent per percentage of biodiesel used in fuel blends. While this type of incentive does not yet exist for soybean oil used as heating fuel, a low level of subsidy would certainly be beneficial in opening new markets for soybean oil utilization and could help stabilize consumer cost for heating oil, as well as providing long-term domestic economic stimulus.

## Conclusions

### *Technical Advantages/Limitations of Biofuels*

The main technical advantages of vegetable-based biofuel blends are lower SO<sub>x</sub> emissions, potentially lower NO<sub>x</sub> emissions, zero net carbon dioxide emissions, and ease of use in existing fuel delivery and home furnaces without modification. Both biofuels have limitations with respect to cold temperature behavior and viscosity which restrict blends to ~20–30% to meet existing ASTM standards. These fuels also have significant benefits as domestically produced fuels to replace petrochemical fuels, with the commensurate benefits in energy security and support for domestic agricultural industries. As noted by VanLanningham (13) it may be possible to use higher levels of biofuels in home heating applications provided furnace designs can be modified to handle higher fuel viscosities. However, there are some significant differences between these fuels as summarized in the Table 5.6.

It is unclear that the NO<sub>x</sub> emissions are significantly different for these fuels, given the differences in air-flow and operating conditions. The higher viscosity of vegetable oil is significant in that it affects the atomization process and hence the combustion process. This can be managed by changing fuel nozzles. The issue of methyl esters as excellent solvents may be an issue for existing furnaces. Methyl ester blends have been anecdotally observed to actually clean old residues and precipitated materials from fuel oil tanks and systems. It has been noted that methyl esters can swell and dissolve a variety of elastomers used in fuel applications, so care must be taken to replace seals in older pumps/furnaces if this biofuel is to be used. These issues do not occur with soybean oil biofuel blends.

**TABLE 5.6**  
Advantages and Limitations of Biofuels

Type of biofuel	Advantages	Limitations
Vegetable oil	Low cost Ready availability	Higher viscosity Possibly higher NO <sub>x</sub> emissions
Biodiesel/methyl esters	Lower viscosity Higher blend compositions	Higher cost Pump elastomer compatibility

The partial (20%) substitution of crude degummed heating oil or biodiesel for #2 heating oil is technically feasible with little or no change in existing equipment or infrastructure. The economic feasibility of using biofuels in heating fuel depends on the relative commodity prices of the fuels, which fluctuates significantly. Historically, the price of soybean oil has been above that of #2 fuel oil, other than for the 2000–2002 period, but with recent trends of increasing petroleum prices and future trends of soybean oil prices declining, soybean oil is predicted to be lower in cost than #2 heating oil. Therefore, use of soybean oil in home heating fuel applications appears to have a significant economic advantage. Biodiesel is currently significantly more expensive than #2 heating oil, almost twice as much. The use of biodiesel as a substitute for home heating oil is economically feasible only on a spot basis and only when subsidies are applied. If current subsidies available for biodiesel as a transportation fuel (roughly \$1/gal) are available for home heating applications, this would bring the price of biodiesel to approximately the same level as current #2 heating oil. If such a subsidy were available for degummed soybean oil as a heating fuel, it would be a tremendous economic advantage, bringing the price down to ~\$0.40/gal. Of course all this must be compared to the cost of petroleum as a heating fuel. Given the assumption that the price of petroleum will significantly rise over the next decade, the use of either biofuel in home heating applications promises to be both economically and environmentally beneficial.

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