

From the Fryer to the Fuel Tank

**The Complete Guide to
Using Vegetable Oil
as an Alternative Fuel**

Second Edition

Joshua and Kaia Tickell



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P R A I S E F O R

FROM THE FRYER TO THE FUEL TANK:

“Even if you have no understanding of chemistry, [*From the Fryer to the Fuel Tank*] is written in such a way as to make it all seem far less daunting – indeed, almost fun...After reading this book, I really felt like going out and making some biodiesel!” Lance Turner, *ReNew Magazine*

“This informative guide is much more than a book of instructions on how to run a car on vegetable oil...it offers not only clear explanations of the nuts and bolts of its subject matter, but also incisive social and political commentary, information about the environmental issues associated with our transportation choices, a strong ecological ethic, and some great stories.” Chris Roth, *Talking Leaves Journal*

“In the United States alone over three billion gallons of used vegetable oil is produced every year. This free fuel source can be easily modified to burn in Diesel engines by following the simple instructions in this book.” *Real Goods Catalog*

“The bottom line is that you and I can make our own bio-diesel fuel. We the people can run our diesel cars, tractors, generators, boats, and all with recycled cooking oil...It’s a slick way to a less polluted world and a little more self-reliance. I would recommend this book for the slightly skilled alternative energy enthusiast. It’s good reading.” Tim Reed, *Earth Quarterly Magazine*

“Joshua and Kaia Tickell’s ‘Gretta, the Greasy Jetta’ and ‘Veggie Van’ run on user-‘refined’ worn-out fryer grease, leaving the aroma of fish & chips in their wakes...*From the Fryer to the Fuel Tank* details the how-to aspects.” J. Baldwin, *Whole Earth Magazine*

“With a minimal investment and a willingness to get your hands greasy, make diesel fuel from waste vegetable oil. *From the Fryer to the Fuel Tank* tells you how, in a clear and entertaining fashion!” *Jade Mountain Catalog*

“I’m sold on biodiesel as a result of reading this book.”
Kelly Larson, Alternative Energy Engineering, Redway, California

“I just read *From the Fryer to the Fuel Tank*. I’m selling all my vehicles, converting them to diesel, and buying a diesel generator to back up the power in my Earthship!” Keith Lindauer, Rico, Colorado

“I bought *From the Fryer to the Fuel Tank*...and now am driving around on my homemade fuel. The fuel is clear amber, the exhaust smells like a BBQ, the truck runs fine, over 500 miles so far...The only downside I can see is that I’m always craving a burger, and I don’t even eat beef!” Tim Gerrits, Kelseyville, California

“*From the Fryer to the Fuel Tank* is a serious book on making your own waste vegetable oil biodiesel. Good theory and practice in one book – a must read.”
Dr. Thomas B. Reed, Director, Biomass Energy Foundation, Golden, Colorado

“Joshua and Kaia Tickell have given a whole new meaning to the expression ‘Now you’re cooking with gas!’...*From the Fryer to the Fuel Tank* makes this fascinating concept fun and easy to understand!”
Reed Berry and Kenny Morse, Co-Hosts “Traffic Jam,” KRLA Radio, Los Angeles, California

"This is the way the world changes...Josh and Kaia Tickell...are truly great humans and I'm proud to be on the same planet with them." Richard Perez, editor of *Home Power Magazine*

"Joshua and Kaia Tickell...have inspired thousands world-wide to look into a fossil fuel-free future."
The Scotsman, Edinburgh, Scotland

"Joshua and Kaia...educate millions by spreading the word about cost-effective renewable energies kept in kitchen cabinets and restaurant alleys...they encourage people to enhance their environment by looking in places they would never imagine." *Prism Magazine*

"*From the Fryer to the Fuel Tank* is incredibly informative and very inspiring."
Ricky Baruc and Deb Habib, Seeds of Solidarity Farm and Education Center, Orange, Massachusetts

"If you have any interest in biodiesel at all, run, do not walk, and buy this book. It not only explains the how, but the why." Steve Spence, New York City, New York

"If you are serious about learning all the ins and outs of biodiesel, *From the Fryer to the Fuel Tank* is worth every penny and very well written for details. I would highly recommend it."
Steve Ferguson, Louisville, Kentucky

"I got *From the Fryer to the Fuel Tank* Friday, and couldn't put it down until I read the whole thing. I am 47 years old and still remember the fuel shortages of the early 70s. As soon as the shortage was over, everyone seemed to forget about it. I haven't forgotten." George Yeagley, Uniontown, Pennsylvania

"I have read and re-read *From the Fryer to the Fuel Tank* and have enjoyed it both for style and certainly for content." Leon Hale, Commonwealth of Dominica

"*From the Fryer to the Fuel Tank* has my head swimming with ideas. Thank you for the information in your book and the inspiration you have handed me." Ron Cascio, Ocean City, Maryland

"I just got *From the Fryer to the Fuel Tank* yesterday and am now trying to scrounge components. Great book, thanks for writing it!" Jerry Simons, Austin, Texas

"I have read *From the Fryer to the Fuel Tank* and am very impressed...I thank you deeply for writing such a wonderful book." Michael Menzies, Estacada, Oregon

"I would like to say many thanks to you for your good book. Very interesting, very literary."
Dr. Guanyi Chen, Hong Kong

"You have a real talent for presenting technical information in informative and entertaining ways. Additionally, your social and political comments are right on. I look to individuals of your caliber to lead us well into the 21st century." Forrest Hadfield, Seattle, Washington

"I firmly believe that it is through grassroots efforts like yours that renewable energy will become a reality. Your efforts demonstrate for people first-hand that renewable energy is not just a dream for the future."
Dr. John J. Sheehan, Biotechnology Center for Fuels and Chemicals, National Renewable Energy Laboratory

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TABLE OF CONTENTS

DISCLAIMER	1
PREFACE	3
INTRODUCTION	5
SECTION ONE	
WHY VEGETABLE OIL?	7
CHAPTER 1	
THE PROBLEM: FOSSIL FUELS	9
Fossil Fuel	10
Problem #1: Fossil Fuel is Running Out	11
Problem #2: Fossil Fuels Shrink Our Economy	14
Problem #3: The Earth is Getting Warmer	16
CHAPTER 2	
THE SOLUTION: RENEWABLE FUELS	19
Advantage #1: There is an Infinite Supply of Renewable Energy	19
Advantage #2: Renewable Fuels are Carbon Neutral	20
Advantage #3: Renewable Fuels Strengthen the Economy	21
CHAPTER 3	
DIESEL ENGINES	23
How the Diesel Engine Works	24
Types of Diesel Vehicles	26
Fueling Diesel Engines with Vegetable Oil	29
Diesel Engines in Cold Weather	31
Bugs and Bacteria	33
The Future of the Diesel Engine	34
CHAPTER 4	
BIODIESEL FUEL	35
Overview of Biodiesel	35
Biodiesel Emissions	38
Engine Warranties and Biodiesel	39
Economics of Biodiesel	40
International Status of Biodiesel	42
U.S. Biodiesel Legislation	44
Other Uses for Biodiesel	46

CHAPTER 5

GROW YOUR FUEL	47
Ten Common Oil-Producing Crops	47
Small and Large Scale Oil Presses	51
How Much Can We Grow?	52
Fuel From Algae	53

SECTION TWO

DO-IT-YOURSELF EXPERIMENTS	57
----------------------------------	----

CHAPTER 6

HOW TO MAKE BIODIESEL	59
Transesterification	59
Supplies for a Biodiesel Blender Reaction	61
Transesterification Procedure	64
Step 1. Determine the Quantity of Catalyst	66
Step 2. Measure the Reactants	67
Step 3. Dissolve the Lye into the Methanol	67
Step 4. Mix the Reactants	67
Step 5. Allow the Glycerin to Settle	68
Step 6. Separate the Glycerin and the Biodiesel	68
Step 7. Cleanup	68
Glycerin	69
Using KOH Instead of NaOH	69
Using Ethanol Instead of Methanol	69
Trial and Error Mini Batches	70
Water Wash	70
Testing Biodiesel	72

CHAPTER 7

HOW TO BUILD A BIODIESEL PROCESSOR	75
Commercial Biodiesel Facilities	75
Small Scale Biodiesel Processors	75
A Single Tank Biodiesel Processor	76
Building a Single Tank Biodiesel Processor	78
Making Biodiesel in the Single Tank Processor	80
A Dual Tank Biodiesel Processor	82
Building a Dual Tank Biodiesel Processor	83
Making Biodiesel in the Dual Tank Processor	86
Filtering the Biodiesel	87
Storing the Biodiesel	87

CHAPTER 8

HOW TO RUN A DIESEL ON VEGETABLE OIL AND KEROSENE	89
Vegetable Oil Kerosene Fuel	89
Supplies for a Second Fuel Tank	92
Installation Procedure	93

CHAPTER 9	
HOW TO RUN A DIESEL ON STRAIGHT VEGETABLE OIL	99
Heating the Vegetable Oil	99
Straight Vegetable Oil Conversions	100
Safety Precautions	101
Parts for Modifying a Diesel to Run on Straight Vegetable Oil	102
Parts Lists	106
Preparation and Assembly Procedures	107
Installation Procedures	111
Putting It All Together	115
CHAPTER 10	
TROUBLE SHOOTING AND SUCCESS STORIES	117
Troubleshooting: Used Cooking Oil	117
Troubleshooting: Methanol	118
Troubleshooting: Biodiesel Reaction	118
Troubleshooting: Making Soap	120
Troubleshooting: Diesel Engines	122
Troubleshooting: Cold Weather	123
Success Stories	124
NOTES	133
APPENDIX 1	
DIESEL VEHICLE CHART	139
APPENDIX 2	
MATERIAL SAFETY DATA SHEET	140
APPENDIX 3	
EXAMPLE WARRANTY FROM A U.S. BIODIESEL MANUFACTURER	142
APPENDIX 4	
CUMMINS DIESEL FUEL SPECIFICATIONS	143
APPENDIX 5	
OIL-PRODUCING CROPS	144
APPENDIX 6	
BIODIESEL FORMULAS	145
APPENDIX 7	
GLYCERIN SOAP RECIPES	146
APPENDIX 8	
ASTM STANDARDS FOR BIODIESEL	148
RESOURCE GUIDE	149
INDEX	159

D I S C L A I M E R

Details in this book are believed to be correct at the time of writing. The authors have researched all sources to ensure the accuracy and completeness of the information contained in this book. However, no responsibility is taken by the authors for any errors, inaccuracies, omissions, or any other inconsistency herein. Any slights against people or organizations are unintentional.

The information presented in *From the Fryer to the Fuel Tank* is for educational purposes only and is not intended as an instructional manual. This book is not intended as an addendum to or a replacement of any technical manuals or training materials. The authors assume no legal liability or responsibility for any choice made by a reader to use this information as a guide for experimentation or modification to any automobile or other machinery. The authors assume no legal liability or responsibility for any damage caused to persons or property as a result of the actions taken by any person who reads the information contained in this book.

Any person considering modification to an automobile should first check with local authorities regarding automobile regulations and safety precautions. Any person considering the use of any engine fuel other than the fuel specified by the manufacturer of the engine is responsible for ensuring that the fuel meets fuel and warranty specifications set forth by the manufacturer of the engine. Any person who uses a fuel that is not specifically made and taxed for “on-road” use is responsible for paying the appropriate fuel tax.

Any person considering storing hazardous chemicals or constructing a facility for making biodiesel is responsible for checking zoning laws. The authors assume no legal liability or responsibility for any use of biodiesel or vegetable oil by the reader. If a device does not carry specific instructions and warranties for the use of biodiesel or vegetable oil, then the reader’s use of biodiesel or vegetable oil in conjunction with such a device is at his or her own risk.

P R E F A C E

We made our first batch of biodiesel in a test tube. It was a small, but very significant accomplishment. We made our next batch of biodiesel in a blender. The next morning when we awoke, almost a full liter of yellow liquid was sitting inside the blender. Excited, we siphoned off the biodiesel into a flask and took it to our unmodified Diesel motor home. We poured the liter of biodiesel into a tank full of 15 gallons (57 liters) of petroleum diesel, a 1.75% blend. The engine roared to life and we waited for the smell. And we waited. And waited. And just as we were about to give up hope that our 1.75% blend of biodiesel would smell like french fries, the aroma began to fill the air like a sweet pollen in spring. We laughed nervously as we waited for the engine to go BANG! But instead it just kept going. And going.

And going. In fact, our “Veggie Van” went all the way from the Eastern seaboard of the United States to the West Coast. It went from the border of the U.S. and Mexico to the border of the U.S. and Canada. All told, it went 10,000 miles (16,000 kilometers) on 100% biodiesel in 10 weeks and was seen by over 40 million people – a big trip for a little van. We towed a home-built biodiesel processor behind the Veggie Van, the “Green Grease Machine,” which made fuel from used cooking oil for an average of 75 cents a gallon. Every time we turned used grease into clean fuel, we proved that we can create clean energy resources using our current technology.

Life on the American road was a non-stop, colorful adventure. The first question people always asked us was “Does it *really* run on vegetable oil?” One whiff of the exhaust was enough to convince most skeptics because it does, believe it or not, smell like french fries. During the tour, the Veggie Van was featured on the Today Show, Dateline, CNN, The Discovery Channel and many other news broadcasts. The Associated Press circulated an article about the Veggie Van to newspapers across the country. The Veggie Van website logged over half a million hits in two months. Our biodiesel journey transformed the fast food restaurant fryers of America into a network of low-cost gas stations and served as an effective public awareness campaign.

During our cross-country journey, we talked with farmers who want to run their equipment on oil from the crops that they grow. We found that urban dwellers want public transport without the asphyxiating pollution. We met with CEOs, environmental organizations, and students of all ages who want to study clean technologies. We talked to “snowbirds” in campgrounds, truckers in truck stops, and young men in fast red cars in traffic jams. We talked a little and we listened a lot. We heard the voices of a proud, caring people who love their country, their land, and their air. They want to use clean fuels in their cars and renewable energies in their homes.

We wrote *From the Fryer to the Fuel Tank* to give you the power to make clean, sustainable energy. Instead of feeling like a cog in the great unstoppable social machine, you hold the power to fuel that machine and to change its direction. We wrote this book to educate, to inspire, and to empower you. We believe that together, we have the power to create a cleaner, safer future.

Power to The People!

Joshua and Kaia Tickell
April 22, 1999

I N T R O D U C T I O N

In the pages of this second edition of *From the Fryer to the Fuel Tank*, we explain how fuel from vegetable oil fits into the larger scheme of global economics and energy, and we describe how to use vegetable oil to fuel a Diesel engine.

We ask that you read the whole book once before doing any experiments. We suggest that you begin your biodiesel experimentation at a small scale in a blender and increase the scale of experimentation only when you are proficient.

A quick note is in order here about the correct use of the words “diesel” and “Diesel.” Diesel with a capital “D” refers to Dr. Rudolf Diesel and the engine he invented. The fuel, diesel with a small “d” refers to the fuel that the petroleum industry recommends for Diesel engines.

From the Fryer to the Fuel Tank is organized into two sections. **Section One: Why Vegetable Oil?** gives historical, economic, and scientific context to using vegetable oil as a fuel. **Section Two: Do-It-Yourself Experiments** gives directions for making biodiesel, building a biodiesel processor, running a Diesel engine on a mixture of kerosene and vegetable oil, and running a Diesel engine on straight vegetable oil.

The parts and equipment which are described in each chapter are listed in the Resource Guide in the back of the book. The Resource Guide also lists biodiesel resources, methanol and ethanol producers, Diesel generator suppliers, books and magazines, and alternative energy resources. The chapters are organized as follows:

SECTION ONE: WHY VEGETABLE OIL?

Chapter 1, The Problem: Fossil Fuels, describes how and why fossil fuels are running out, contributing to global warming, and weakening the economy.

Chapter 2, The Solution: Renewable Fuels, describes how and why renewable fuels can provide an unlimited fuel supply, are carbon neutral, and strengthen the economy.

Chapter 3, Diesel Engines, gives the history of the Diesel engine, describes the principles of the Diesel engine, and compares the different methods for running a Diesel engine on vegetable oil.

Chapter 4, Biodiesel Fuel, explains the advantages, disadvantages, emissions, legislation, and other uses of biodiesel fuel.

Chapter 5, Grow Your Fuel, provides a summary of ten oilseed crops, a description of the presses needed to extract vegetable oil, and a description of what may be the oil crop of the future: algae.

SECTION TWO: DO-IT-YOURSELF EXPERIMENTS

Chapter 6, How to Make Biodiesel, delves into the chemistry of biodiesel and gives a step-by-step process for making biodiesel fuel.

Chapter 7, How to Build a Biodiesel Processor, gives step-by-step instructions for building two types of biodiesel processors.

Chapter 8, How to Run a Diesel on Vegetable Oil and Kerosene, provides the parts and instructions for modifying a Diesel vehicle to run on a mixture of vegetable oil and kerosene.

Chapter 9, How to Run a Diesel on Straight Vegetable Oil, gives the parts and instructions for modifying any Diesel engine to run on straight vegetable oil.

Chapter 10, Troubleshooting and Success Stories, answers common questions and problems encountered when using vegetable oil as a fuel. The success stories are written by people who have used numerous techniques to fuel Diesel vehicles with vegetable oil.

SECTION ONE

WHY VEGETABLE OIL?

C H A P T E R 1

THE PROBLEM: FOSSIL FUELS

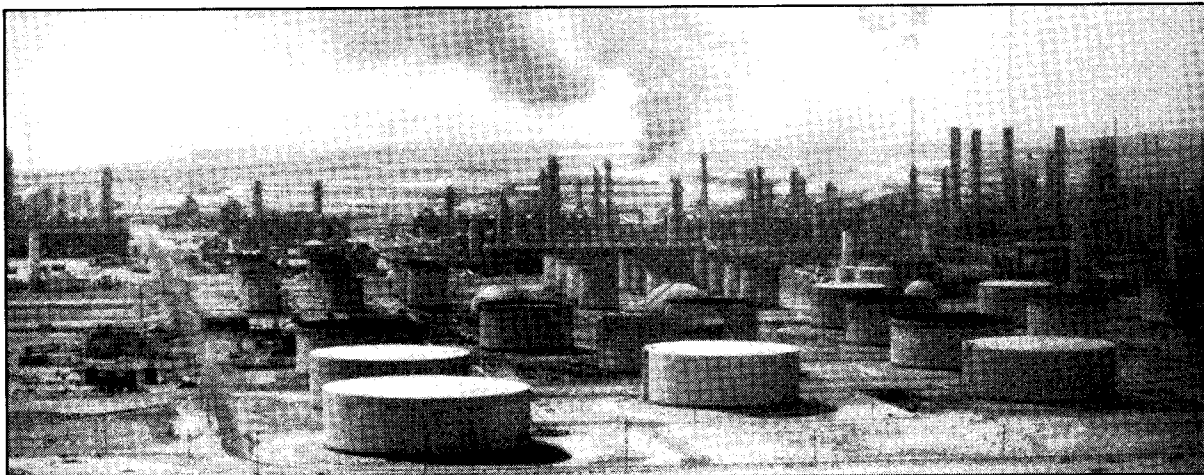
Imagine if there was a certain amount of food on Earth and no more could be grown. No matter how it was divided and rationed, there was only a finite amount of food. You would have enough to eat today and tomorrow and probably next week. But what about next year? What about in ten years? Would everyone on Earth get the same amount of food every day, or would it change depending on what you needed? And who would decide how it was rationed out? Perhaps the nations of the world would get together and elect one governing body to divide up the food and give it out to everyone. But probably not.

People would probably react to a finite amount of food like they deal with fossil fuels today. The majority of food would be stored in a few key locations. Instead of giving it out on the basis of need, the controlling governments would give it out to the highest bidder, or the most powerful people. There would be wars over who controlled the food and how much they controlled. Food would be more expensive as time went on, but everyone would have to buy it no matter what. There would be black markets in food. Sometimes, there would be food shortages and people would have to stand in line to get their meager rations. Inevitably, there would be people left without. And inevitably, we would all be without.

Inevitably, there would be people left without. And inevitably, we would all be without.

As unpleasant as this analogy might sound, it is a fair description of how we deal with the finite amount of fossil fuels left on Earth today. Petroleum fuel that we buy at the gas station is made from oil. Although it looks light and pours easily, gasoline starts out as thick black gunk. This “black gold” has been made over a period of hundreds of millions of years.

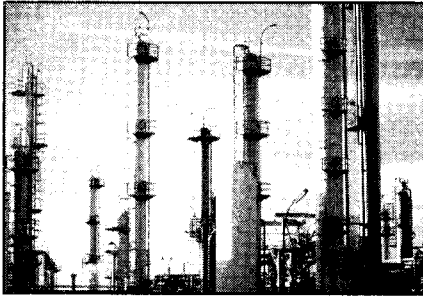
Crude oil is processed into fuel at an oil refinery in Saudi Arabia.



FOSSIL FUEL

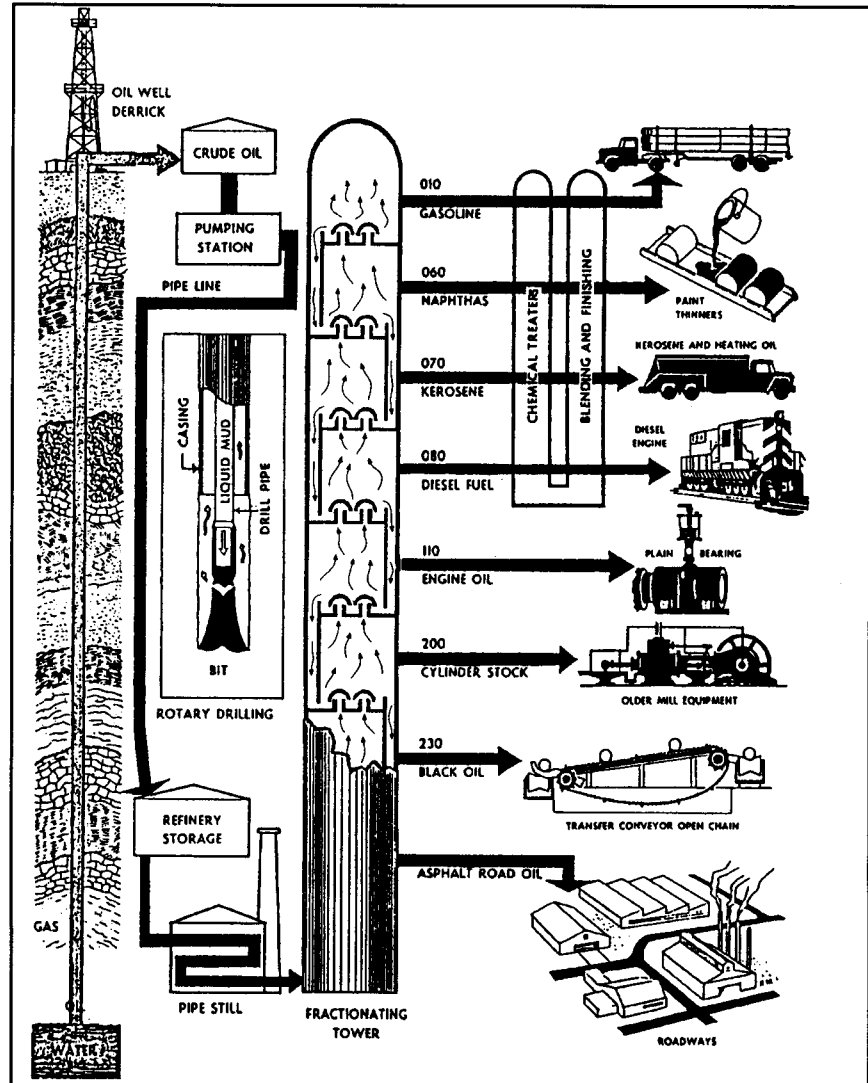
Over 300 million years ago, algae and other plants were trapped in silt where they were heated and compacted until they became oil.¹ During the past 150 years, we have developed a system to extract and refine oil to make fuel. Oil is extracted from the ground and transported to a refinery where it is heated until it boils. This *distillation* of oil cracks the oil molecules apart. Oil distillation occurs inside a tall, silver pole called a *distillation tower*. Hot oil vapors rise up the center of the tower where they meet with cool air. The vapors condense into liquid which is caught in gutters around the insides of the pole. The gutters are placed at different levels to catch the different grades of oil and fuel. Heavy oils, like motor oil, condense on the bottom of the tower while light oils, like gasoline, condense at the top of the tower.

The first commercial oil well in the United States was established in 1859 near Titusville, Pennsylvania.² The extraction of and demand for crude oil increased exponentially as new uses for oil were discovered. It is astonishing how fast humans learned to make and use fuel from fossils. Even more astonishing is the fact that it will only take human civilization about 200 years to consume the oil reserves that the cycles of nature took hundreds of millions of years to create.



Top: Networks of distillation towers operate around the clock to process crude oil into fuel.

Right: Processing crude oil is complex and resource intensive. Crude oil is drilled, transported, distilled, and further processed into final products.



PROBLEM #1: FOSSIL FUEL IS RUNNING OUT

Fossil fuels such as diesel and gasoline will soon be too expensive for most people to afford. Fossil fuel could become unaffordable as early as the year 2010.³ It is quite likely that fossil fuel will suddenly become too expensive, as it did during the oil shocks of the 1970s.⁴ An *oil shock* occurs when there is a sudden and sharp price increase in oil followed by a decrease in availability.

What Happened During the Oil Shocks of the 1970s?

During the 1970s, the nations in the Middle East restrained oil production, controlled the worldwide price of oil, and created a series of oil shocks. The Organization of Petroleum Exporting Countries (OPEC) is the group of mostly Middle Eastern nations that created the 1970s oil shocks. In 1973, the OPEC nations of Iran, Iraq, Kuwait, Saudi Arabia, and the United Arab Emirates controlled 36% of the world's oil production. Acting together, these Middle Eastern countries increased the world price of oil from \$10 to over \$56 a barrel, pushing the United States into economic shock.⁵

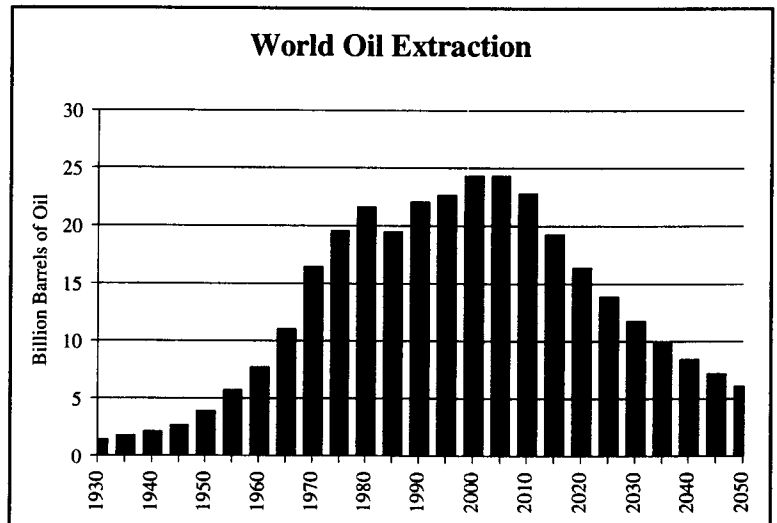
Acting together, these Middle Eastern countries increased the world price of oil from \$10 to over \$56 a barrel, pushing the United States into economic shock.

Realizing its vulnerability, the United States turned to other sources of oil. Alaska, the North Sea, and other locations began supplying more oil than ever before. By 1986, the Middle Eastern share of oil had fallen to 16% and the price of oil had dropped to \$6 a barrel.⁶ This price decrease in oil has cost the U.S. dearly. During the 20 years since the oil shocks, the oil business in the United States has gone from boom to bust, and the yearly oil extraction from the North Sea and other U.S. controlled fields has dropped to an all time low.⁷

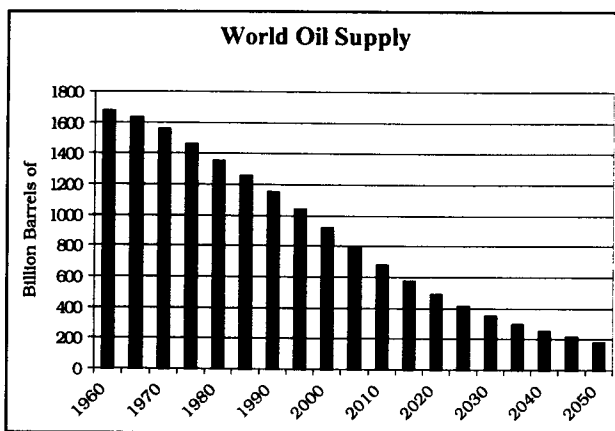
If you were shaken by the oil shocks of the 1970s, wait until 2010. By then, the Middle Eastern nations will have the power to reenact an oil crisis and the United States will have no backup sources of cheap oil.

The Point of No Return

We will soon pass the halfway point in world oil extraction.⁸ This is the point when we have consumed more than half of the available, affordable oil in existence. When we pass the halfway point, the 5 main oil-producing Middle Eastern nations will control the world oil market.⁹ Those nations will undoubtedly use their control to increase world oil prices, a move which could result in a permanent, international oil shock.



World oil extraction will peak at the beginning of the 21st century. Meanwhile, demand for liquid fuels will continue to climb. Source: *The Coming Oil Crisis*.

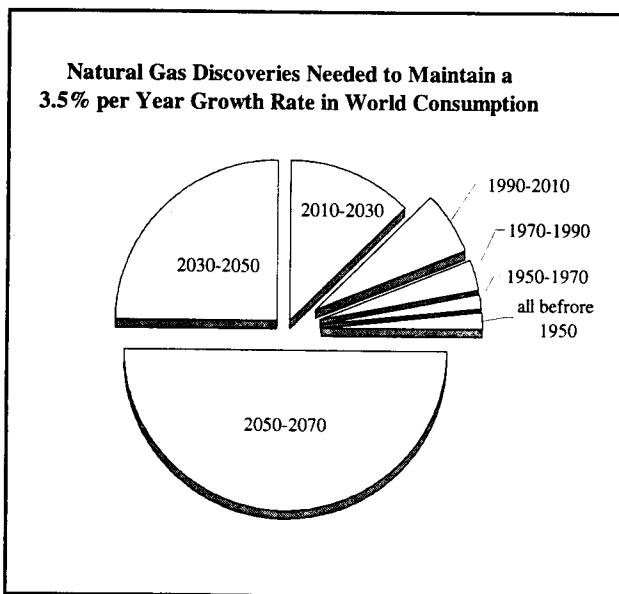


Within the next 25 years, fossil fuel prices will increase sharply due to the decrease in world oil supply. Source: *The Coming Oil Crisis*.

At some point between 2010 and 2025, all fuel from fossil oil will be too expensive for the average Western consumer to afford.¹² Exactly when that point comes will depend largely on the actions of Middle Eastern countries.

Cheap Natural Gas Will Also Dwindle

Automakers, power companies, and fossil fuel corporations are promoting compressed natural gas (CNG) as a “future fuel.” However, natural gas is a non-renewable fossil fuel and natural gas supplies will dwindle at the same time as oil supplies, as early as 2040.



Every 20 years, the amount of natural gas which must be discovered to maintain consumption is equal to all of the previous natural gas discoveries combined. Like crude oil, most of the natural gas on Earth has already been discovered. Demand for natural gas will soon outpace supply. Source: *Beyond the Limits*.

How Much Oil is Left?

By 1930, 17 billion barrels of oil had been extracted worldwide. By 1970, over 17 billion barrels of oil were being extracted each year. As of 1997, 807 billion barrels of crude oil had been extracted from the Earth’s crust and 995 billion barrels remained which could be extracted at current production costs.¹⁰

If the worldwide rate of consumption of oil remained constant at the current amount of 24 billion barrels of oil per year, we would run out of oil in 2040.¹¹ But consumption is not static. Instead, it is increasing by about 2% per year. Even our rate of increase is increasing. Demand for oil will overshoot supply well before 2040.

In 1970, worldwide annual consumption of natural gas was 30 trillion cubic feet.¹³ Today, annual natural gas consumption is over 70 trillion cubic feet and is increasing at 3.5% per year.¹⁴ A 3.5% annual increase in consumption will deplete natural gas reserves by 2050. However, the increase of consumption of natural gas is itself increasing at an astonishing rate.

Power companies are building new natural gas power stations to give customers in their area cheaper electricity. By 2010, experts believe that the U.S. supply of electricity from new natural gas power facilities will jump to 100,000 megawatts.¹⁵ Natural gas power plants are attractive to investors due to an average six year investment turnaround and the fact that natural gas facilities produce electricity for a cheap 2 to 3 cents a kilowatt-hour.¹⁶

As city smog laws become more stringent, natural gas cars are on the rise. With them will come an increase in the demand for natural gas fuel. Due to the rapidly increasing consumption of natural gas for power generation and for fuel, natural gas supplies cannot be relied upon to provide fuel for our long term transportation infrastructure.

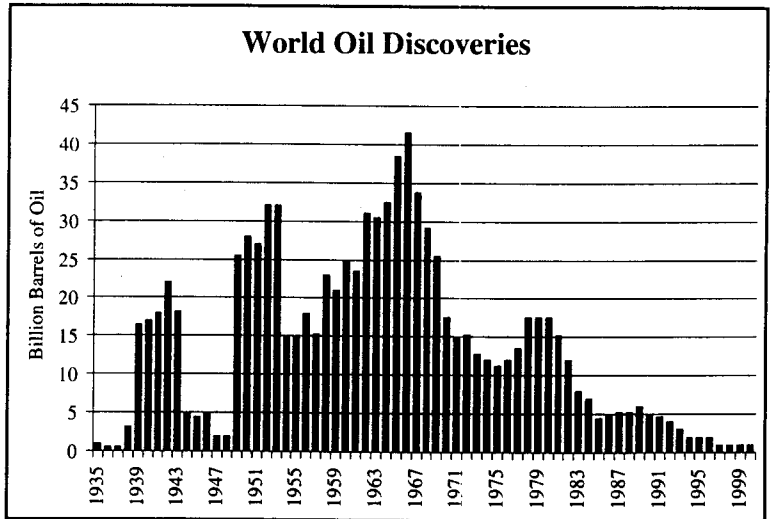
To its credit, natural gas burns more cleanly than any other fossil fuel. Natural gas can also be produced renewably from landfill and sewage waste. Methane, the main ingredient of natural gas, is produced at waste treatment facilities and can be burned in generators which produce electricity for the grid. Used in this way, "natural" gas has a powerful future as a renewable fuel.

The Coming Oil Shock

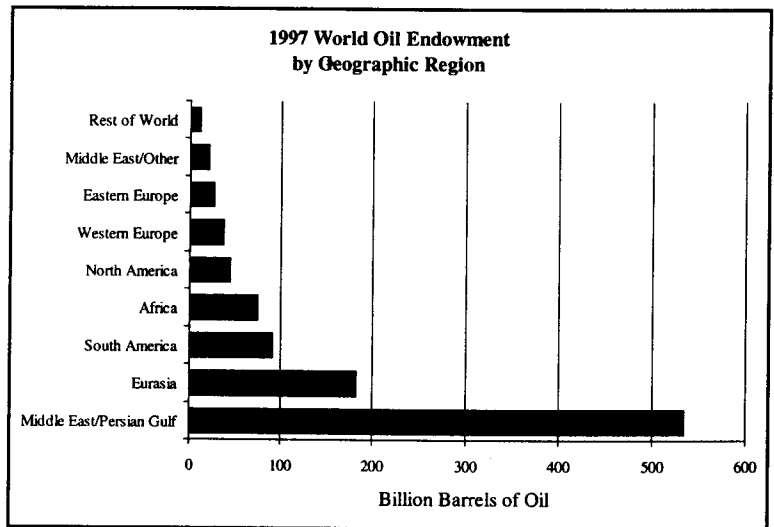
The United States' capacity to produce inexpensive oil has fallen since the 1980s. By 2010, the U.S. Department of Energy (DOE) estimates that 62% of U.S. oil will be imported.¹⁷ The U.S. is relying on the Middle Eastern nations to provide it with liquid fuel. In 1996, five Middle Eastern nations held 27% of the world's share of oil production. By 2000, they will hold 30%. By 2010, the Middle Eastern share of world oil production will rise to 40%. By 2025, as worldwide production dwindles, the Middle Eastern share of oil production will rise to 50%.¹⁸

Although we may offset Middle Eastern control of the world oil market by a few years through extracting recently discovered endowments and by using expensive extraction methods, we must eventually face the reality that 50% of the remaining oil in the world lies in the Middle East. Unless we change our energy use, we will pay a high price, both in human life and in dollars, for the oil which remains in and around the Persian Gulf and the Caspian Sea. Soon, the Middle Eastern nations will control the energy which fuels our Western society.

Buying time will not save the world from a permanent oil shock. At some point in the near future, demand will overshoot supply, production will outpace discovery, and the Middle Eastern nations will take full control of their own energy resources. The supply of cheap liquid petroleum fuel will stop.



Discoveries of world oil peaked in the 1960s. Since then, almost all of the remaining oil on Earth has been discovered. Source: *The Coming Oil Crisis*.



We must soon face the fact that the majority of the world's oil is in the Middle East. Source: *The Coming Oil Crisis*.

PROBLEM #2: FOSSIL FUELS SHRINK OUR ECONOMY

When we use fossil fuels, we send our money overseas and get fuel in return. We also send military troops, jobs, and infrastructure overseas. We do this because our

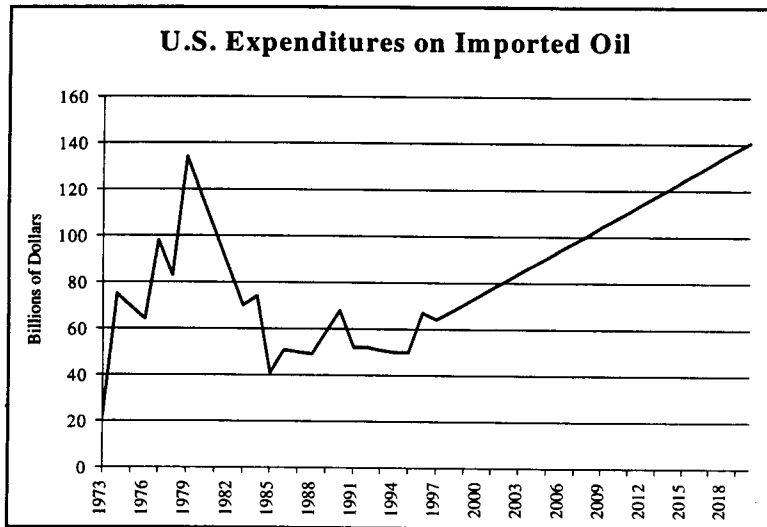
economy is unable to produce fossil fuels. Our land is depleted of fossil resources, and rather than produce our own renewable fuel, we procure fossil fuel from the Middle Eastern countries – no matter what the cost to human life or to our own economy.

In order to get fuel today, we fill tanker ships with diesel fuel and send them to the Persian Gulf. When those ships arrive, they are guarded and defended by “peacekeeping” forces which we help fund with our tax dollars. The tanker ships are filled with fuel again for their engines, they are loaded with millions of gallons of oil or fuel, and they return to the United States.

This fossil fuel economy undermines itself by sending money and resources away to other economies and not receiving the value of that money in goods and services. It would seem that fuel prices should increase to reflect the increasing costs of oil production and procurement. But the price of fossil fuel is kept low via industry and governmental price controls. Instead of being paid at the pump, the increased cost of fossil fuels is paid by tax dollars.¹⁹

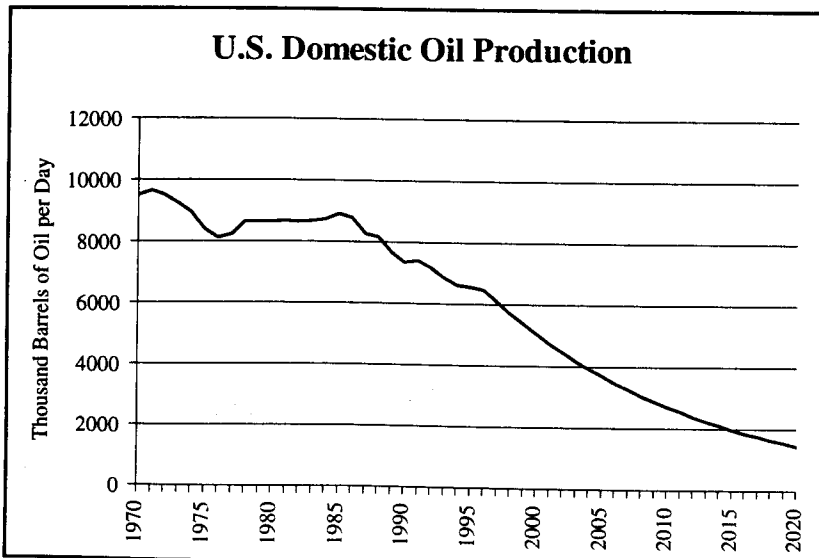
Paying the excess costs of fossil fuels with tax dollars has a three-fold purpose. First, it keeps the price of fuel deceptively low. Second, it allows oil companies to work from a huge base of government funding and support, rather than having to seek that support directly from consumers via higher fuel prices. Third, it evenly distributes the excess costs of fossil fuels among taxpayers. Therefore, everyone pays for fossil fuels regardless of how much fuel each individual uses.

Each year, the United States gives the fossil fuel industry \$5 billion in tax money.²⁰ Some of this money is in the form of tax writeoffs and some of it is in the form of subsidies. \$5 billion is just a drop in the bucket of U.S. tax support for the fossil fuel economy.



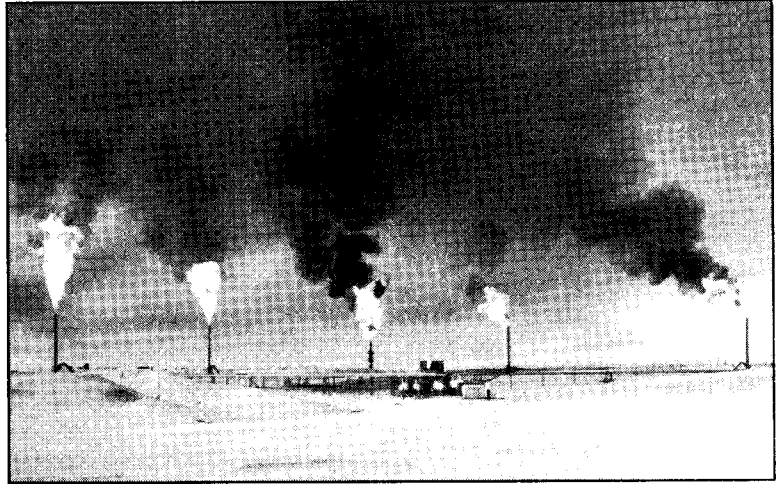
U.S. expenditures on imported oil are directly related to events in the Middle East. After the oil shock of 1973, U.S. expenditures on imported oil rose sharply. Expenditures rose again in 1979 after the second wave of Middle Eastern induced oil shocks. Expenditures fell briefly during the 1980s as the U.S. pumped oil from Alaska, Texas, and the North Sea, only to rise again in the early 1990s as a result of the Gulf War. The line after 1997 represents a DOE estimate of the upcoming trend in expenditures on imported oil. According to the DOE, the shortage of U.S. oil combined with a steady increase in demand for oil will raise U.S. expenditures on imported oil dramatically in the next 20 years. The above graph is adjusted for 1997 dollars and does not include military expenditures. Source: Energy Information Administration/DOE.

As U.S. oil production decreases, oil imports must rise to fill the continuing demand. Source: *The Coming Oil Crisis*.



The Cost of Defending Fossil Fuel

Wars such as the Persian Gulf War deplete resources from our economy to ensure that we have a healthy flow of energy from overseas. The people of the United States consider wars such as the Persian Gulf necessary tradeoffs. There is some loss of human life and there is some expense to the economy. In the case of the Persian Gulf War, the cost was approximately \$70 billion of U.S. taxpayer money, 100,000-200,000 Iraqi lives, and approximately 150 American and NATO lives.²¹ Since our country does not make its own fuel, we make these sacrifices to keep fuel flowing and to keep our economy alive.



There are U.S. and NATO military forces in the Persian Gulf all of the time. The war with Iraq has not stopped, it has just become less interesting to the media. Each year, the United States spends \$50 billion to maintain its military presence in the Middle East.²² In addition to the U.S./NATO battle against Iraq, between 6 and 10 other wars are simultaneously being fought around the Middle East.²³

If we had to pay the military costs of our activities in the Middle East when we paid for our fuel at the gas station, it would cost us at least twice as much to buy a gallon of gasoline.²⁴

This does not mean that having a national military is a waste of money. We expect that by paying the U.S. military over \$250 billion in tax money every year, we pay for a military that will protect our country.²⁵ Nevertheless, we use our military to wage offensive campaigns in the Middle East. The objective of these wars is to maintain the supply of oil from energy reserves which are legally owned and operated by other countries.

The way we pay for fuel today is similar to using a national credit card – we get the bill later. We are already being billed for our fossil fuel system in different ways. The first costs are the social services that we forgo because we send so much of our tax money overseas. As the United States' debt spirals higher and we wage more military campaigns to secure oil, the quality of our education, health care, and social services falls.

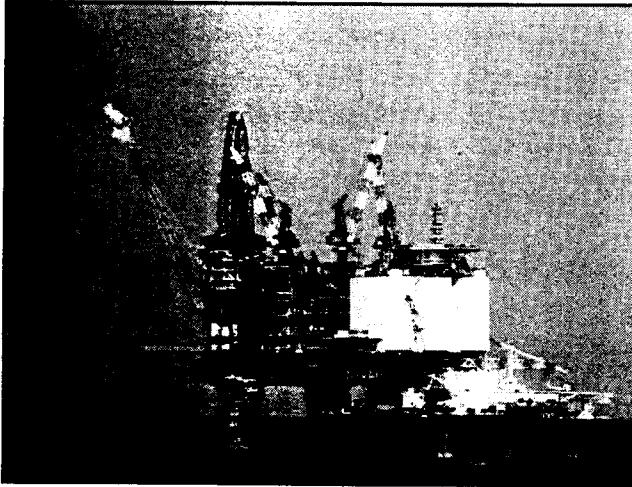
Our nation is addicted to fossil fuel. Since we do not produce our own liquid fuel, we are forced to go to war when the tiniest shortages occur. The United States is extremely vulnerable to oil price controls, production stoppages, and the whims of the Middle Eastern nations who we have cultivated as enemies.

The United States has an abundance of natural resources. Yet we continue to set the example for the rest of the world that fossil fuel is more important than education, health care, social services, national security, and human life itself. Our fossil fuel energy policy endangers us and speaks to a pathetic set of national values.

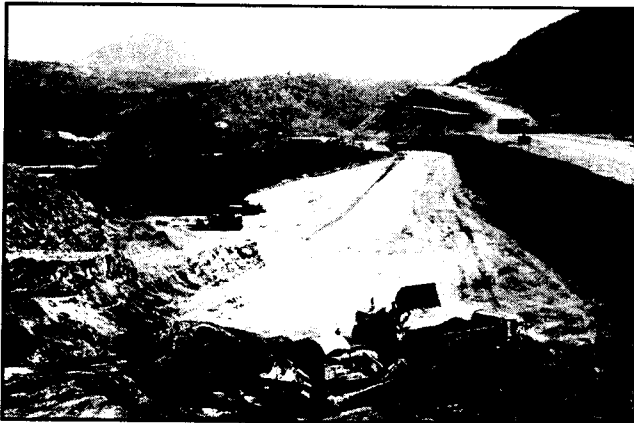
Oil wells in the Middle East burn off natural gas. During the Gulf War, hundreds of oil wells were intentionally ignited. The black soot resulting from these oil fires covered hundreds of square miles. At what price does oil from the Middle East become too expensive?

PROBLEM #3: THE EARTH IS GETTING WARMER

Our planet is currently undergoing a period of *global warming*. Average worldwide temperature is increasing.²⁶ Although there are a number of factors which could be contributing to this trend, we know that the level of carbon dioxide in the atmosphere is increasing. Scientific evidence shows that we are increasing atmospheric carbon dioxide, and thereby contributing to global warming, by burning fossil fuels.²⁷



Human civilization is removing carbon that was stored millions of years ago in the form of oil (top) and coal (bottom). By burning these fossil fuels, we release billions of tons of carbon dioxide into the atmosphere every year.



The Carbon Cycle

Carbon and hydrogen are the basic building blocks of nature. Almost everything you see and touch is made primarily of carbon and hydrogen. Throughout the life of planet Earth, there has been a finite amount of carbon, hydrogen, and all of the other elements. Sometimes the elements are primarily in the atmosphere, sometimes they are in the ground or the ocean, and sometimes they are contained in plants and animals. Although they move around, the amount of the elements on Earth never varies.

During the time of the dinosaurs, there was more carbon dioxide in the atmosphere and the planet experienced warmer average temperatures than it does today. Over time, plants breathed in carbon from the atmosphere and breathed out oxygen. Gradually, the concentration of carbon in the atmosphere decreased and the concentration in the ground increased. That carbon was stored in high concentrations in oil and coal.

Oil, coal, and other fossil fuels are called *hydrocarbons* because they are made of both carbon and hydrogen. Millions of years ago, plants took hydrogen out of water and combined it with carbon to create plant tissue. Some of this plant tissue became the hydrocarbons we know as fossil fuels.

The middle of a hydrocarbon molecule is made up of carbon atoms, and the outside of a hydrocarbon molecule is made up of hydrogen atoms. We call hydrocarbon molecules *chains* and we measure them by the number of carbons that are linked together in the middle. For example, gasoline hydrocarbon chains are each about 10 carbons long.

There are almost one billion internal combustion engines in operation on our planet.²⁸ Energy that plants stored millions of years ago fuels these engines. Consequently, carbon that was stored millions of years ago is released by these engines. In the combustion process, engines combine carbon with oxygen to form carbon dioxide.

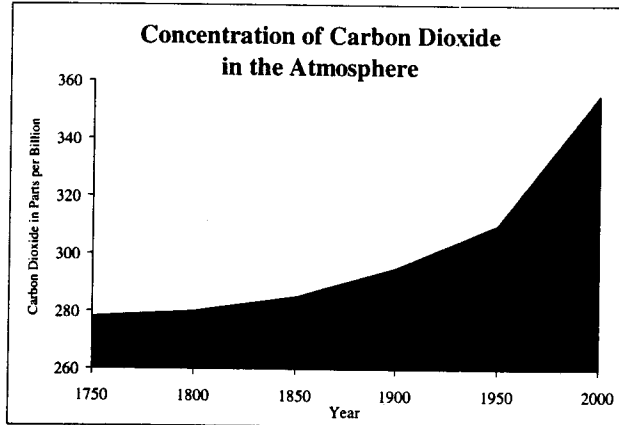
The Greenhouse Effect

Many scientists and concerned people believe that global warming is caused by the *greenhouse effect*. The greenhouse effect refers to the ability of the gases in Earth's atmosphere to keep the planet warm. Evidence shows that we have amplified the greenhouse effect by emitting billions of tons of *greenhouse gases*.

Greenhouse gases let sunlight into Earth's atmosphere, but they do not let heat out.

It is natural and necessary to have a certain amount of carbon dioxide and other gases in Earth's atmosphere to protect us from solar radiation. But too much of these gases act like a glass bubble around Earth. It gets hotter inside the bubble, but the heat cannot escape.

Internal combustion engines emit billions of tons of carbon dioxide into the atmosphere every year. Although some scientists continue to debate whether increased carbon dioxide is causing higher temperatures, there is proof that global warming is occurring. There is also proof that levels of man-made atmospheric greenhouse gases are increasing in the atmosphere. Consider the following facts:



Increased levels of carbon dioxide in the atmosphere are contributing to global warming. Source: *The End of the Road*.

- For every gallon (3.8 liters) of gasoline that a car burns, 22 pounds (10 kilograms) of carbon dioxide are released into the atmosphere.²⁹
- The levels of carbon dioxide in the atmosphere today are higher than they have been in 160,000 years. These levels are increasing each year. The level of free oxygen (O₂) in the atmosphere is decreasing.³⁰
- It's getting hotter on Planet Earth. The hottest years in recorded history occurred between 1980 and 1999.³¹

To stop the increase of these gases, we must first stop burning fossil fuels.

Burning fossil fuels contributes to higher levels of carbon dioxide and other gases in the Earth's atmosphere. To stop the increase of these gases, we must first stop burning fossil fuels.

C H A P T E R 2

THE SOLUTION: RENEWABLE FUELS

R*enewable fuels* are fuels that are replenishable. They can be produced in any climate using already developed agricultural techniques. Renewable means that something comes back after it is used. When you pick an apple from a tree you do so knowing that another will grow to replace it. This is similar to using renewable fuel. Vegetable oil is an example of a renewable fuel. When you use vegetable oil as a fuel, more crops will grow and more vegetable oil will be produced. This cycle can go on endlessly as long as there is good land on which to grow crops. As long as we take care of our land, renewable fuels will never run out.

ADVANTAGE #1: THERE IS AN INFINITE SUPPLY OF RENEWABLE ENERGY

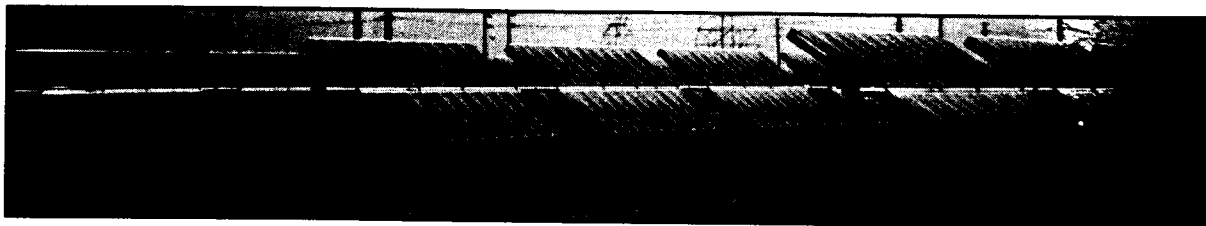
There is a finite amount of each element on Earth, but there is an infinite amount of energy. The sun is the source of all energy on Earth. Every hour, enough energy in the form of sunlight hits the Earth to fuel all of humankind's activities for one year.¹ Most of that energy turns into heat and some of it is absorbed by plants. Plants transform solar energy into chemical energy in the form of hydrocarbons. Whereas fossil fuels came from plants which grew millions of years ago, *biofuels* come from plants which are constantly grown and replenished. Compared to fossil fuels which took 40 million years to produce, biofuels are "liquid solar fuels" that can be produced in as little as a couple of months.



Forms of Renewable Energy

There are many forms of renewable energy. *Ethanol* is a renewable fuel made from grains which works in a gasoline engine. *Photovoltaics (PV)* are solar panels that generate electricity from sunlight. *Wind turbines* are machines that generate energy from wind. *Hydropower* is produced from flowing water. *Producer gas* is a gas made from waste wood that can be used as a renewable fuel. Vegetable oil is one of a whole range of renewable energies. Each renewable energy serves a specific purpose.

Plants (top) transform solar energy into chemical energy and store the energy in hydrocarbons. Solar panels (bottom) transform solar energy into electrical energy. All forms of renewable energy come from the sun, which can provide Earth with limitless energy.

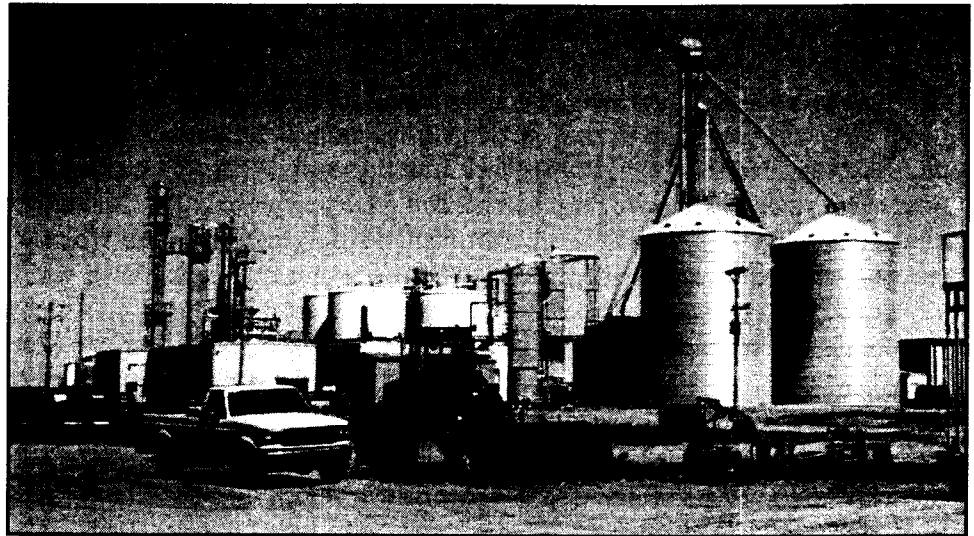


ADVANTAGE # 2: RENEWABLE FUELS ARE CARBON NEUTRAL

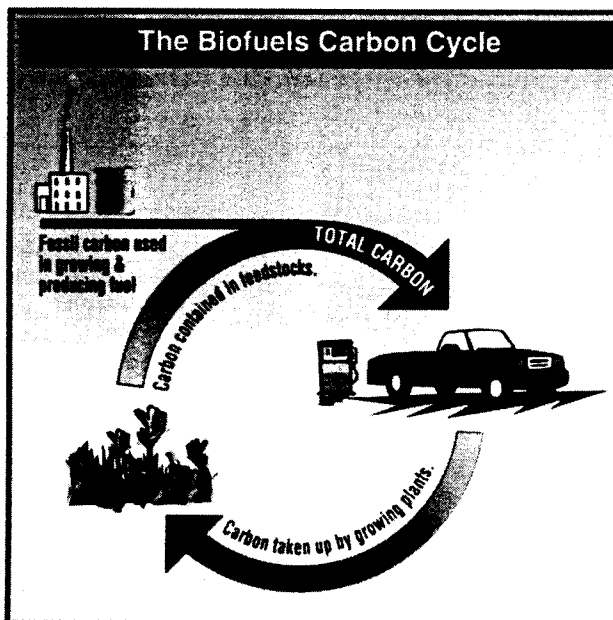
Plants can capture all of the carbon dioxide emitted from burning renewable fuels. Plants separate carbon dioxide into carbon and oxygen, put some of the carbon back in the ground, and release the oxygen into the atmosphere. When we use renewable fuels, plants naturally balance the carbon dioxide emissions.



Renewable fuels can significantly reduce the amount of carbon dioxide emitted each year while helping farmers (top) and creating new jobs at agricultural fuel plants (right).



Vegetable oil that certain plants store in their seeds is full of carbon and hydrogen. The hydrocarbons found in these oils are fats. As anyone who exercises to “burn fat” knows, it takes a lot of work to use the energy stored in fat. When you burn fat, or vegetable oil, carbon dioxide is released. Humans release it from their lungs, cars release it from their exhaust pipes.



Reprinted from “The Biodiesel Industry in the United States: An Industry on the Move,” an update by the American Biofuels Association.

When we burn vegetable oil in an internal combustion engine, the carbon in the oil is turned into carbon dioxide and is released into the atmosphere. The next batch of plants grown for vegetable oil will consume carbon dioxide. The plants will release oxygen and combine the carbon with hydrogen to make vegetable oil hydrocarbons. Instead of a system where hydrocarbons are extracted from the ground and carbon dioxide is emitted into the atmosphere, the use of renewable fuels creates a cycle where hydrocarbons are grown and carbon is moved out of the atmosphere and into plants.

A crop of oil-producing plants will absorb exactly the same amount of carbon dioxide in order to produce a gallon of vegetable oil as a gallon of vegetable oil emits when it is burned in an engine.² Because plants produce hydrocarbons and absorb carbon dioxide, renewable fuels do not contribute significantly to global warming.³

ADVANTAGE # 3: RENEWABLE FUELS STRENGTHEN THE ECONOMY

At the time of writing, the renewable fuels industry in the United States is so small that it does not account for 1% of the gross domestic product.⁴ However, the renewable fuels industry has the potential to create over a million jobs, add over \$50 billion to the economy each year, and decrease the trade deficit by at least 30%.

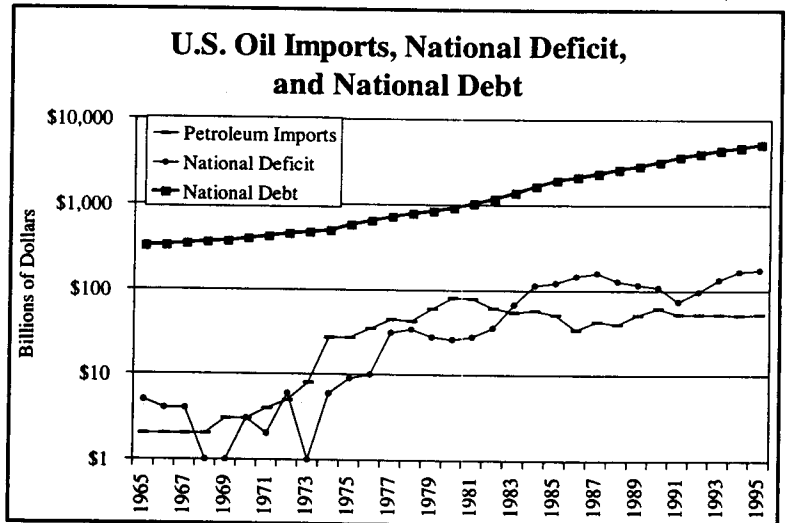
Jobs Gained by Reducing the Trade Deficit

The trade balance of a country is the ratio of the value of exports to the value of imports. When the value of imports exceeds the value of exports, a trade deficit occurs. When a country has a trade deficit, it has produced less than it has consumed and its wealth has decreased. If a trade deficit occurs every year, the monetary reserves of a country will eventually be depleted and it will go into debt.⁵ If left unpaid, the national debt can destabilize the country.

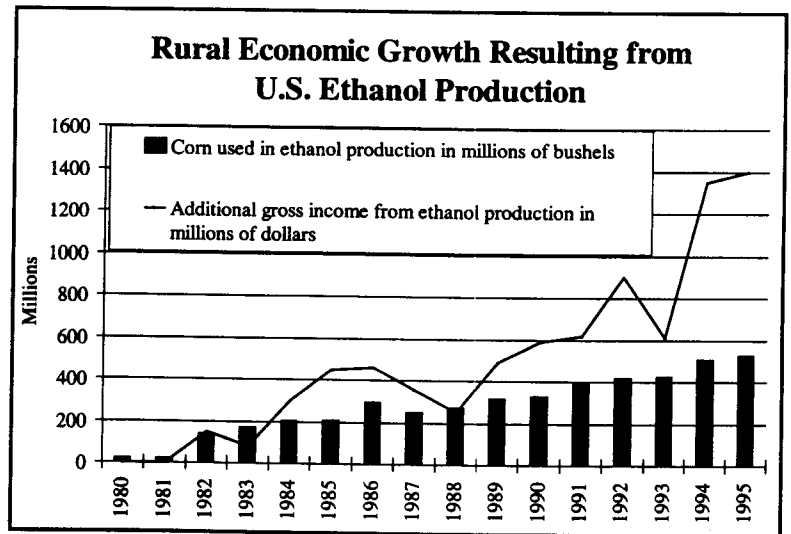
In 1965, the U.S. trade deficit was \$5 billion.⁶ That year, petroleum imports accounted for \$2 billion of the deficit.⁷ At that time, the national debt was roughly \$320 billion.⁸ By 1995, the U.S. trade deficit had increased to \$174 billion with petroleum imports accounting for \$53 billion of the deficit.⁹ In 1995, the national debt stood at almost \$5 trillion.¹⁰ The DOE estimates that for every \$1 billion reduction in the trade deficit, the U.S. can gain 27,000 jobs.¹¹ By producing 100% of its fuel domestically, the U.S. could decrease the annual trade deficit by over \$53 billion and create 1.43 million jobs in the biofuels and supporting services industries.

The Positive Economic Impact of the U.S. Ethanol Industry

The U.S. ethanol industry is an example of a growing renewable fuel industry. In 1980, less than 25 million gallons of ethanol were produced in the United States.¹² Today, more than 1.6 billion gallons of ethanol are produced annually.¹³ Although much of the ethanol produced in the United States is sold as industrial alcohol, ethanol is increasingly being added to gasoline to raise octane levels.



Each year, petroleum imports increase, creating a rise in the trade deficit. This in turn contributes to the overall debt of the nation. If these trends continue, they could destabilize the economy. Sources: 1996 Economic Report of the President, the Energy Information Administration 1995 Annual Energy Review, and the U.S. Treasury Department.



The production of renewable fuels stimulates the growth of domestic industries. This leads to more jobs, increased tax revenues, and higher farm income. Source: Renewable Fuels Association.

Every year, the ethanol industry has the following economic impacts in the U.S.:¹⁴

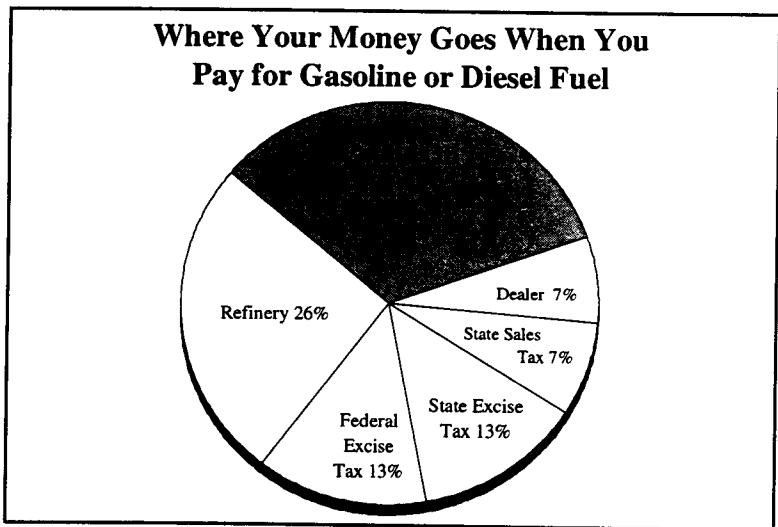
- The addition of \$51 billion to the entire U.S. economy.
- An increase in farm income by \$2.2 billion or nearly 3%.
- 5,800 jobs and an estimated 50,000 indirect service jobs.
- The generation of \$555 million in federal taxes.
- A \$1.3 billion reduction in the trade deficit.

It is interesting to note that the ethanol industry's contribution to reducing the trade deficit is only slightly less than the number of gallons of ethanol produced annually. The ethanol industry creates jobs, decreases the national trade deficit, generates tax revenues, and stimulates the economy. The economic success of the domestic ethanol industry indicates the future economic benefits of using vegetable oil and other renewable fuels.

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Putting It All Together

Consider this analogy. You have a bowl with ten dollars in it. Each time you go to the park in your car, you have to buy a dollars worth of fuel. After ten trips to the park you have an empty bowl. When you buy fossil fuel, over 30% of the money you spend goes overseas.¹⁵ The fuel you buy contributes to the trade deficit. Now you have less money and your economy also has less money. The fuel you buy also goes through the engine and out the tailpipe. The economy has been weakened and the environment has been polluted.



Now, assume that you had paid for a renewable fuel at the gas station. You still have an empty bowl, and you still used ten dollars worth of fuel. But by putting 100% of your ten dollars into a renewable fuel, you expanded many parts of the economy. The money that would have gone overseas instead paid for the farmers who grew the fuel crop, the truck drivers who

More than one third of the money spent at the pump on fossil fuel goes overseas. By buying renewable fuels, we can funnel this money back into the domestic economy. Source: California Energy Commission, Jan. 1998.

transported the crop, the machines to process the crop into fuel, the people to run the machines, and the people to market the fuel. Those people paid taxes. You do not get the ten dollars back in the bowl, but by using a renewable fuel, you will create growth in your economy. A renewable fuels economy will result in a higher quality of social services, lower unemployment, and increased national security. Once you can grow your own fuel and energy, defending fossil fuel is like defending one can of preserved apples when you have your own apple orchard.

CHAPTER 3

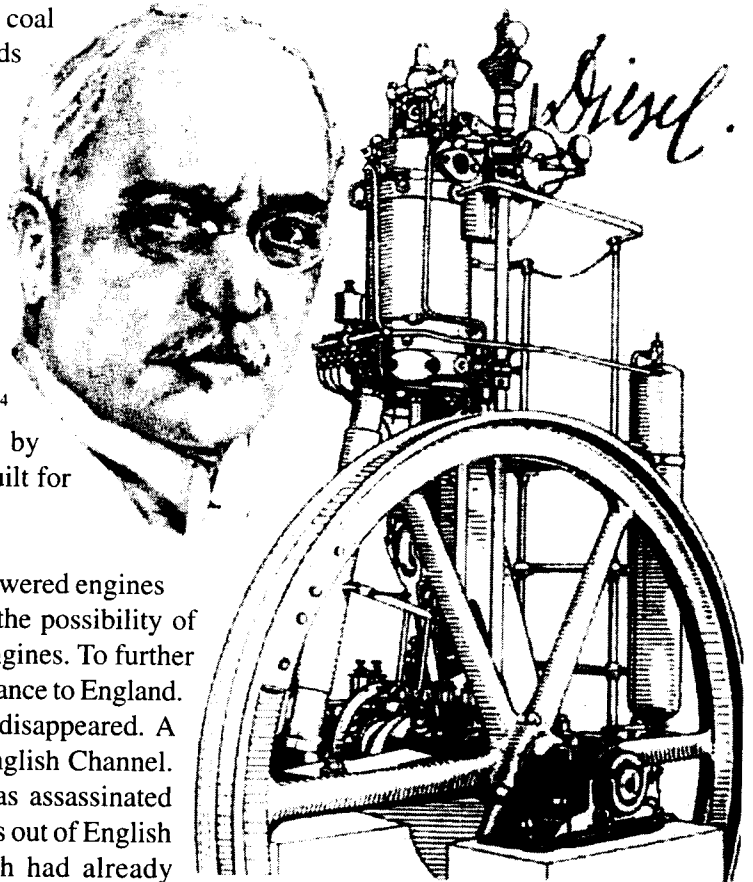
DIESEL ENGINES

Dr. Rudolf Diesel first developed the Diesel engine in 1895 with the full intention of running it on a variety of fuels, including vegetable oil. Diesel showed his engine at the World Exhibition in Paris in 1900 using peanut oil as fuel. In 1911 he said, "the Diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it."¹ In 1912 Diesel said, "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as petroleum and the coal tar products of the present time."² Dr. Diesel's words are more true today than ever before.

When Rudolf Diesel showed his engine at the World Exhibition in Paris in 1900, he said two words which astonished the gathered engineers, inventors, and scientists: peanut oil. The patented Diesel engine ran "on almost any hydrocarbon from gasoline to peanut oil."³ The first Diesel engines and fuel systems built in the United States and Europe were so strong that some of them still work.⁴ These early Diesel engines were easily powered by straight vegetable oil as their fuel systems were built for heavy fuels.

Dr. Diesel died before his vision of vegetable oil powered engines became a reality. In 1913, Diesel was discussing the possibility of converting the English submarine fleet to Diesel engines. To further these discussions, he took a boat from his home in France to England. After dinner on the boat one evening, Dr. Diesel disappeared. A few days later, his body was found adrift in the English Channel. The English newspapers suggested that Diesel was assassinated by French operatives working to keep Diesel engines out of English submarines.⁵ It is not surprising that the French had already converted their submarine fleet to Diesel engines in 1905.

Since Rudolf Diesel's time, the Diesel engine has been modified to run on the cheapest fuel available, petroleum. After Diesel's death, the petroleum industry capitalized on the Diesel engine by labeling one of the byproducts of gasoline distillation "diesel fuel."⁶ Thus, cheap, dirty "diesel fuel" became the fuel of the Diesel engine and vegetable oil was all but forgotten as a fuel source. During the last three quarters of a century, many variations of Rudolf Diesel's original engine have been produced. Most of these engines are designed to run on less viscous fuels than the vegetable oil which powered the original Diesel.⁷



**Dr. Rudolf Diesel (1858-1913)
and the first Diesel engine.**

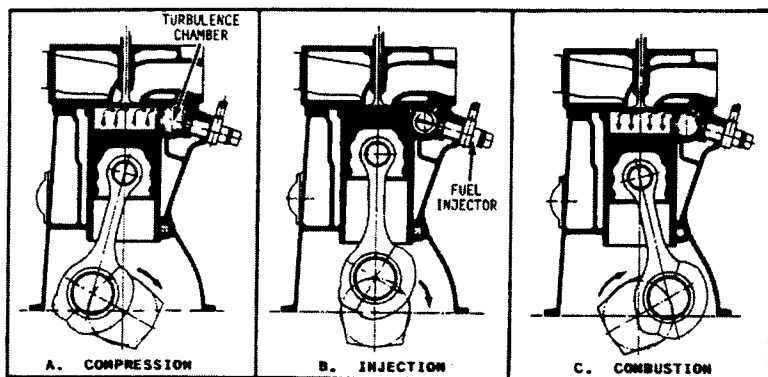
In the 1970s, scientists discovered that the viscosity of vegetable oil could be decreased through a simple chemical process. The process yields a vegetable oil-based fuel that works as well as diesel fuel in modern Diesel engines. This fuel is called *biodiesel*. We will discuss biodiesel and other vegetable oil fuels later in this chapter and in subsequent chapters.

HOW THE DIESEL ENGINE WORKS

The Diesel engine works on the principle of *compression ignition*. Inside the Diesel engine, fuel is injected into a chamber of pressurized air. The pressurized air ignites the fuel. The Diesel engine is different from the *spark ignition* engine which uses spark plugs to ignite gasoline. The Diesel engine contains no spark plugs, no ignition coil, no distributor, and no carburetor. Most Diesel engines contain *glow plugs*. Glow plugs are small electric heaters that help ignite the fuel so that the engine can start. Diesel engines are generally more reliable than gasoline engines because they do not have electrical ignition components.

The virtue of the Diesel engine can also be its downside. Since a Diesel engine uses compression to ignite its fuel, the engine must have a fuel which only ignites under very high pressure. Compared to the 7-11 carbon long hydrocarbon chains which make up gasoline, diesel fuel hydrocarbons are 12-18 carbons long.⁸ Due to the thick nature of diesel fuel, some Diesel engines emit partially burned fuel in the form of soot. The black soot common to older Diesels can be eliminated by using biodiesel or by making a Diesel engine burn fuel more efficiently.

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The Diesel combustion cycle on an indirect injection engine. A. Air is compressed in the combustion chamber, or the turbulence chamber. B. Fuel is injected into the chamber. C. The air/fuel mixture explodes, pushing the piston down.

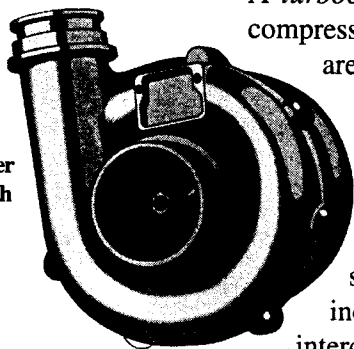
Source: U.S. Navy.

pressure. Compared to the 7-11 carbon long hydrocarbon chains which make up gasoline, diesel fuel hydrocarbons are 12-18 carbons long.⁸ Due to the thick nature of diesel fuel, some Diesel engines emit partially burned fuel in the form of soot. The black soot common to older Diesels can be eliminated by using biodiesel or by making a Diesel engine burn fuel more efficiently.

Turbochargers and Intercoolers

The addition of modern components can make Diesel engines burn fuel as cleanly as gasoline engines. Modern Diesels often come with turbochargers and intercoolers. A *turbocharger* is a device which uses otherwise wasted exhaust pressure to compress air going into the combustion chamber. The *combustion chamber* is the area inside each cylinder where air and fuel mix and explode. Forcing more air into the combustion chamber insures a more complete burn of the fuel.

A turbocharger has a fan which is spun by the pressure of exhaust gases.



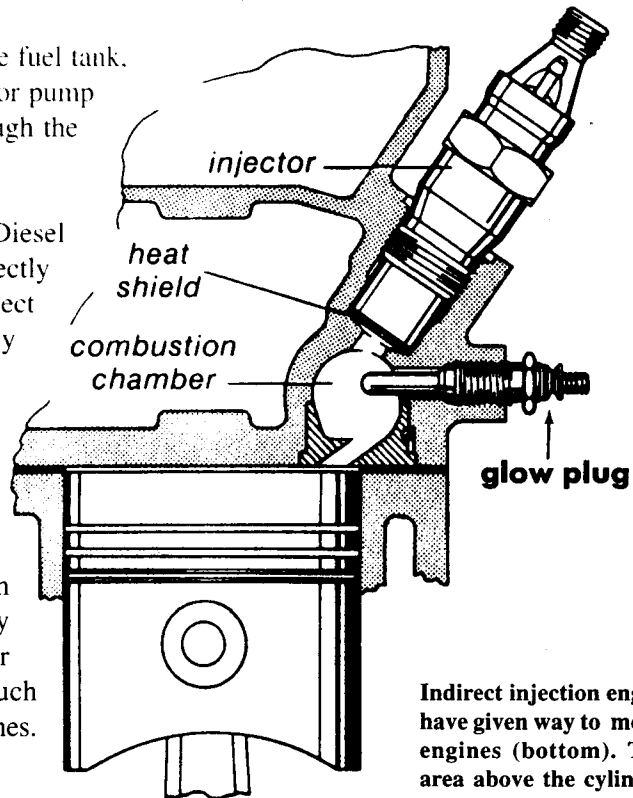
An *intercooler* is a network of thin metal fins which cools air coming out of a turbocharger. As a turbocharger is spun by exhaust gases, it becomes hot and heats the air going into the engine. Since hot air takes up more space, the turbocharger has to work harder to force air into the engine. To increase the efficiency of the turbocharger, air can be routed through an intercooler. The intercooler cools the turbocharged air with the cool air coming toward the vehicle or by circulating water through its fins. Cooling air brings oxygen molecules closer together and makes air more dense. Dense air takes up the same amount of space, but has more oxygen in it. The more oxygen that is forced into a combustion chamber, the more complete the combustion will be. The addition of an intercooler and a turbocharger to the Diesel engine greatly improves fuel combustion.

The Fuel System

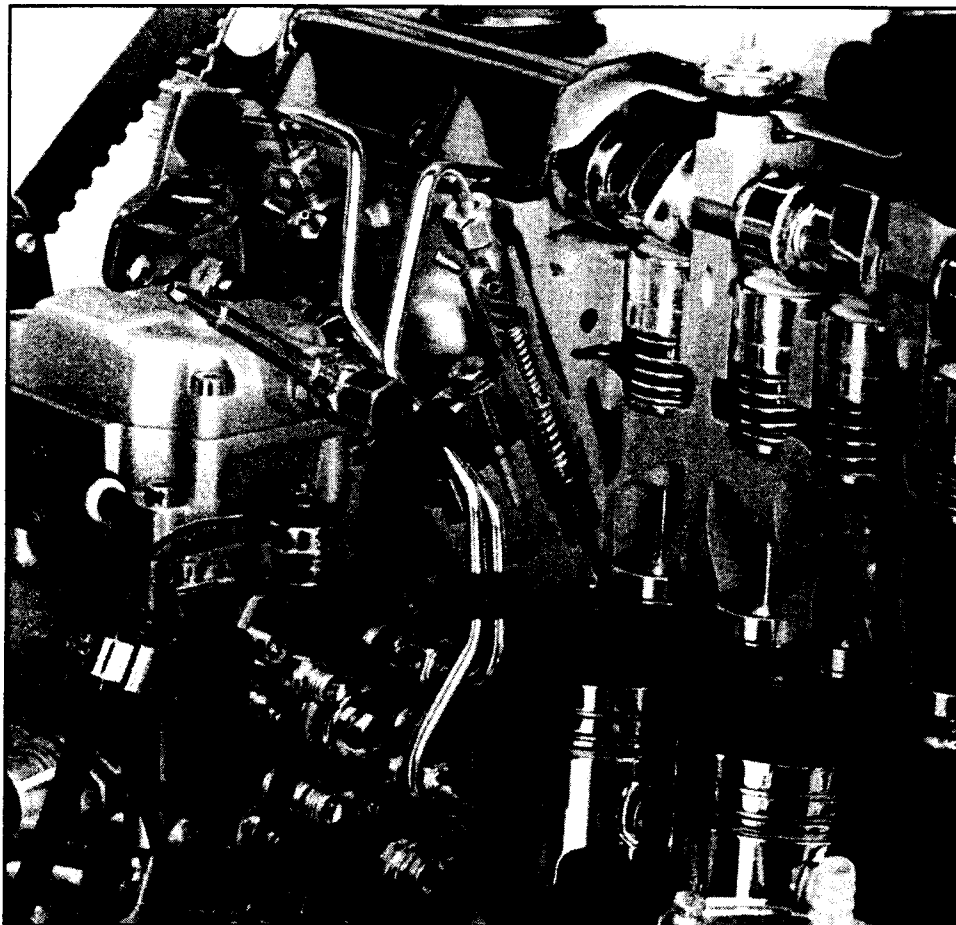
The basic parts of the Diesel fuel system are the fuel tank, the injector pump, and the injectors. The injector pump pulls fuel from the fuel tank and forces it through the injectors into the combustion chamber.

There are two ways to inject the fuel into a Diesel engine. The first method is to inject the fuel directly into the cylinder, and the second method is to inject the fuel into a *prechamber* where it partially combusts before entering the cylinder. These methods are called *direct injection* and *indirect injection*.

Most older Diesel engines are indirect injection. Most new Diesels are direct injection or turbo direct injection (TDI). The older indirect injection engines are tough, extremely durable, and very reliable. They will take a lot of abuse. The newer TDI engines are quieter, cleaner, and have much better pickup than the older indirect injection engines.

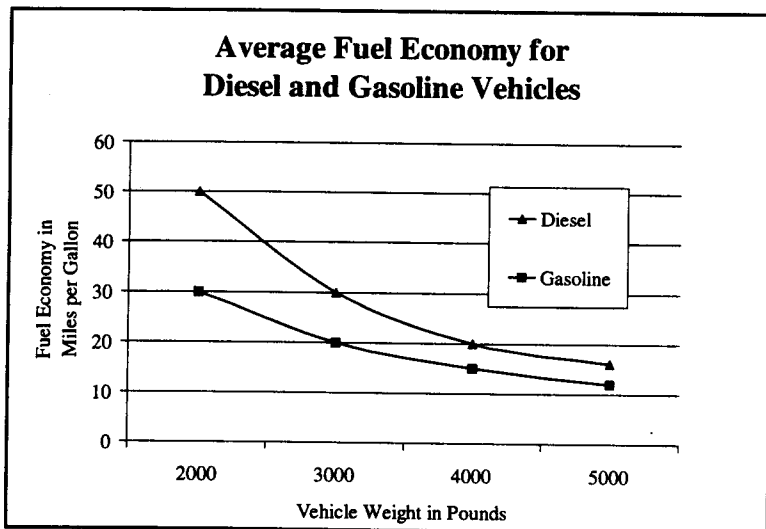


Indirect injection engines (top) have given way to modern TDI engines (bottom). The small area above the cylinder in the indirect injection engine is referred to as a prechamber, a turbulence chamber, or a combustion chamber. Air is compressed into the prechamber and then fuel is injected into the prechamber. The fuel ignites the air, causing an explosion. In the TDI engine, there is no prechamber above each cylinder. (See the photo of the interior of the TDI engine on the left). In a TDI engine, the injector injects fuel directly into the cylinder. The compressed air inside the cylinder explodes, forcing the piston down. The combustion chamber in a TDI engine is simply the upper section of a cylinder. In order to inject fuel directly into the cylinder, injector pumps on TDI engines operate at even higher pressures than injector pumps on indirect injection engines. The design of the TDI engine allows it to attain acceleration, power, and low noise levels previously unattainable by Diesel engines. Photo courtesy of Volkswagen of America, Inc.



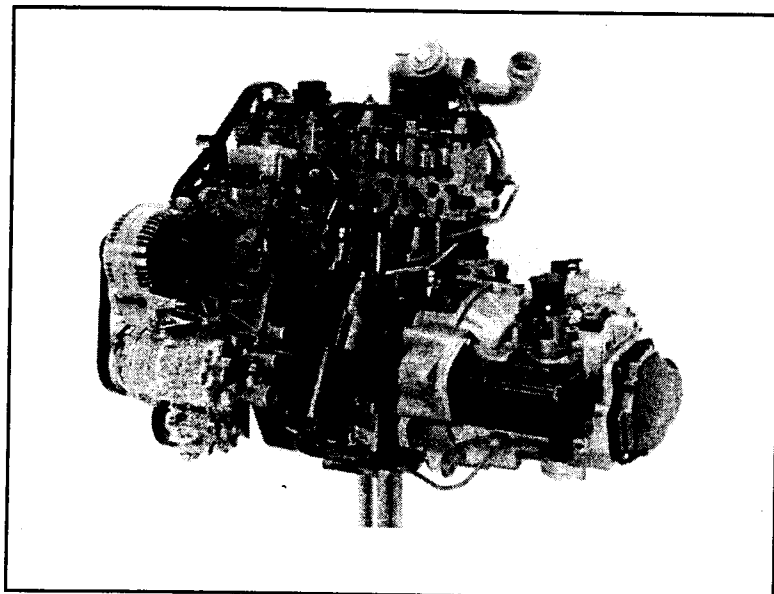
TYPES OF DIESEL VEHICLES

There are as many types of Diesel vehicles as there are gasoline vehicles. A Diesel vehicle can be so well built that it will last a lifetime. Dodge says that the Cummins engine in its new trucks "can go an average of 300,000 miles before its first overhaul."⁹ Many Diesel cars and trucks go 200,000-300,000 miles (320,000-480,000 kilometers) before they need engine rebuilds. Diesel vehicles are typically 10-20% more fuel efficient than their gasoline counterparts.¹⁰



The efficiency of Diesel engines is most noticeable in light vehicles. Passenger vehicles with Diesel engines are almost twice as efficient as the same models with gasoline engines. Source: *Crown's Diesel Repair Manual*.

Cross section of the popular Volkswagen 1.9 liter TDI engine, which is available in the VW Golf in Europe and in the Golf, Jetta, and new Beetle in the U.S. Photo courtesy of Volkswagen of America, Inc.



Diesel engines are generally more reliable than gasoline engines for heavy duty applications. That is why Diesel vehicles make up the backbone of the transport industry. The same Diesel technology that transports goods around the world has been applied to the many Diesel passenger and light duty vehicles that are available. With proper care, passenger and light duty Diesels can be reliable, clean, and economical to operate.

The production of Diesel vehicles in the United States increased in the early 1980s. After the oil shocks of the 1970s, drivers wanted "alternatively" fueled vehicles. Automakers responded by putting vehicles with Diesel engines on the market. Within a few years, consumers realized that diesel fuel was not a true alternative to gasoline. During the mid-1980s, demand for Diesels fell sharply and so did production.

Meanwhile, the rest of the world continued to use and develop Diesel automobiles. As a result, used Diesel vehicles of just about any age are available in Europe, Australia, Asia, Japan, and Africa. It was not until the late 1990s that Diesels again became available in the United States. With the advent of TDI engines, Volkswagen and Mercedes Benz are offering Diesel cars in the U.S. that are quiet, clean, and very efficient. Dodge trucks with Cummins Diesel engines and Ford trucks with Ford "Powerstroke" Diesel engines are also now available to U.S. drivers.

As you search for a Diesel vehicle that will suit your needs, remember that as long as it has a Diesel engine, you can power it with vegetable oil.

Choosing a Diesel Vehicle

Diesels range from luxurious Mercedes' to Dodge trucks with powerful Cummins engines. When shopping for a Diesel vehicle, keep in mind what you intend to do with it, your budget, if you will maintain the vehicle yourself or have it professionally serviced, and how long you want it to last. Someone wanting to do a high school or college experiment will probably want an inexpensive 1980s model Volkswagen. A person looking for dependable, comfortable transport might look for a newer Mercedes. If you live on a farm or an isolated community, you might look for a Toyota or Dodge pickup truck.

The Japanese and German 4-cylinder Diesel engines are reliable and efficient. If you live in the United States, we recommend a Volkswagen/Audi Diesel. Parts for Volkswagen and Audi Diesels are inexpensive and easy to find. Although Toyota Diesels are not common in the United States, Toyota Diesels are well-built, long lasting, and are common in most countries. Both Volkswagen and Toyota made or currently make vans, pickup trucks, passenger cars, and station wagons with Diesel engines.

When shopping for a Diesel vehicle, keep in mind what you intend to do with it, your budget, if you will maintain the vehicle yourself or have it professionally serviced, and how long you want it to last.

Dodge trucks with Cummins engines are powerful work vehicles. Chevrolet/GMC Diesels have had a history of problems including engine block cracking and other complete failures. Ford Diesels tend to be difficult to work on, expensive to fix, and less reliable than most heavy duty Diesels. It is best to choose a Diesel vehicle which is common in your area. Parts and service for common vehicles are usually easy to find and inexpensive. For a list of Diesel vehicles available in the U.S., see the Diesel Vehicle Chart in Appendix 1.

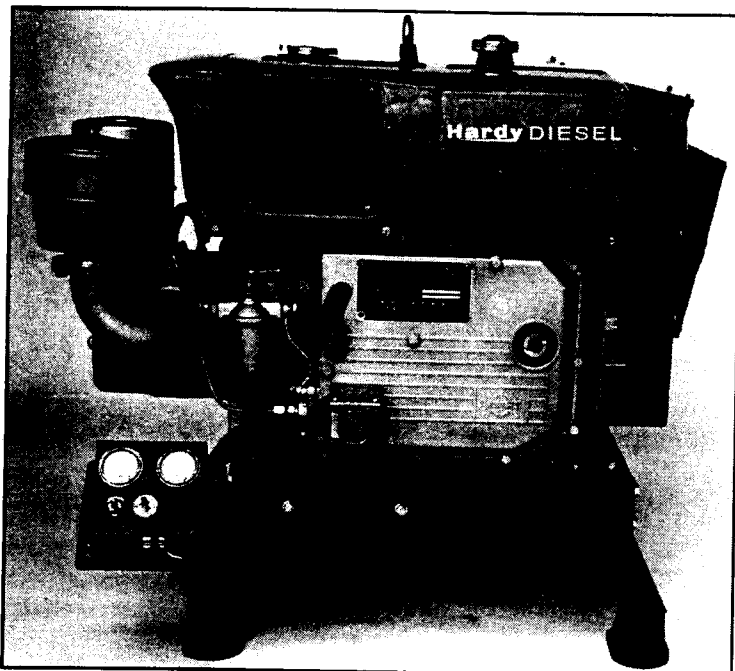
The Volkswagen Jetta with the 1.9 liter turbo direct injection Diesel engine gets 50 miles per gallon on the highway.



Diesel Engines in Generators, Boats, and Tractors

Diesel engines are used in many industrial and agricultural applications. Diesel engines can be as small as those used on some model aircraft and as large as those used to generate power for whole towns. Other uses for Diesel engines include

water pumps, lawn maintenance equipment, bilge pumps, boat motors, passenger airplane engines, forklifts, earth-moving equipment, mining equipment, and cranes. Every one of these Diesel engines can run on biodiesel.

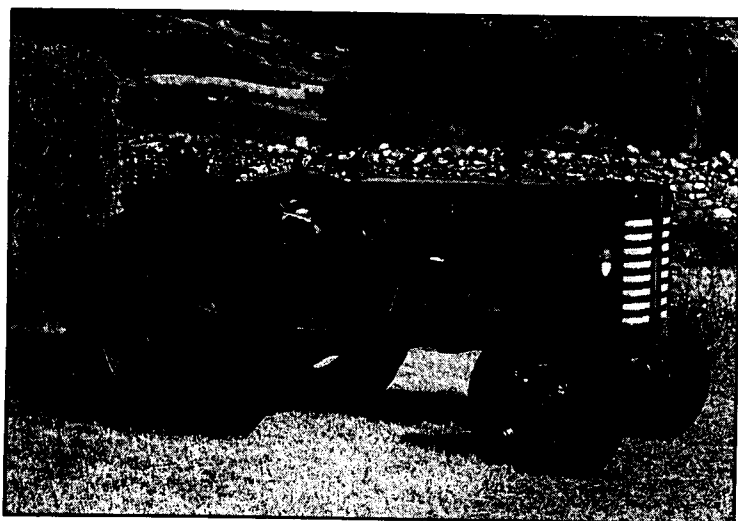


Diesel generators provide reliable electrical power for many rural communities. The use of a generator can increase the reliability of an alternative energy system which primarily uses solar, wind, or water power. Photo courtesy of China Diesel, Inc.

Many people who do not have access to traditional electrical power sources use Diesel generators. Such a generator can be used in conjunction with alternative power systems including solar panels, wind turbines, and micro-hydro systems, or the generator can be used by itself. Diesel generators can provide AC or DC power. Diesel generators are reliable, require low maintenance, and consume very little fuel. But Diesel generators can create severe localized pollution when they use petroleum diesel fuel.

All Diesel generators including Kubota, Yanmar, China Diesel, Duetz, Onan and military surplus generators will run on biodiesel.

Diesel tractors are very common. John Deere, Massey Ferguson, and many other Diesel tractors have been around for years. Chinese Diesel tractors are becoming more popular. When cared for properly, a Diesel tractor will last a lifetime. Any Diesel tractor can run on biodiesel.



Diesel tractors have been used in agriculture since the 1920s. Agricultural equipment in the U.S. and elsewhere relies almost exclusively on Diesel engines.

One of the most common uses for Diesel engines is on boats. Power boats and sailboats often have Diesel engines, Diesel generators, and Diesel bilge pumps. Some boats even have Diesel stoves, ovens, heaters, and lanterns. The use of Diesel engines on boats is due to the low risk of spontaneous combustion of diesel fuel. Although diesel fuel fires can occur under the right conditions, diesel fuel is much less likely to catch fire than gasoline. Biodiesel fuel is even less likely to catch fire than diesel fuel. Straight vegetable is even safer than biodiesel.

FUELING DIESEL ENGINES WITH VEGETABLE OIL

There are three do-it-yourself (DIY) ways to use vegetable oil in a Diesel engine. Each method has advantages and disadvantages. This section gives a brief overview of the three DIY methods for using vegetable oil in a Diesel engine. Each of these methods is described in further detail in Section Two: Do-It-Yourself Experiments.

Biodiesel

Biodiesel is a fuel made from 80-90% vegetable oil, 10-20% alcohol, and 0.35-1.5% catalyst. It is a stable fuel, performs reliably in all Diesel engines, cuts emissions, is mixable with petroleum diesel fuel, is easy to make, safe to handle, and will work with all diesel fuel storage and pumping systems. No engine modifications are needed to use biodiesel in a Diesel engine. Biodiesel can be poured straight into the fuel tank of any Diesel vehicle.

No engine modifications are needed to use biodiesel in a Diesel engine. Biodiesel can be poured straight into the fuel tank of any Diesel vehicle.

Vegetable Oil/Kerosene Mix

Diesel engines can run on a mixture of vegetable oil and kerosene. This method involves “cutting” vegetable oil with kerosene. This method requires careful attention to mixing proportions, does not produce reliable results, and can be damaging to a Diesel engine if not done carefully. This method also requires that an extra fuel tank be installed in the vehicle. The engine must be started and cooled down on petroleum diesel fuel. The vegetable oil and kerosene mix should be considered experimental and potentially harmful to the Diesel engine.

Straight Vegetable Oil

A Diesel engine can run on straight vegetable oil as long as the engine is started on diesel fuel and the vegetable oil is heated. Either used cooking oil or new vegetable oil can be used as fuel. This method involves installing a vegetable oil tank and modifying the heater hoses of the Diesel engine. Once the tank is installed and the heater hoses have been modified, the Diesel engine is started on diesel or biodiesel fuel and then switched to hot, straight vegetable oil. When the engine is running, the engine coolant is used to heat the vegetable oil so that it has a similar viscosity to diesel fuel. When it is time to turn the engine off, it is cooled down on diesel or biodiesel fuel. With attention to detail, this system is reliable.



Any Diesel engine can be fueled with vegetable oil. This fuel tank is being filled with used cooking oil from a bakery.

Vegetable Oil Fuel Comparison Chart

The following chart shows the differences between the three methods for fueling a Diesel engine with vegetable oil. Biodiesel is a good substitute or additive fuel for diesel fuel, vegetable oil and kerosene mix is useful as an emergency fuel, and straight vegetable oil is a good fuel if the vehicle is modified. There is a way to make fuel from vegetable oil for every application where Diesel engines are used.

COMPARISON OF VEGETABLE OIL FUELS FOR DIESEL ENGINES			
FUEL PROPERTY	BIODIESEL	VEG./KERO. MIX	VEGETABLE OIL
Works in all Diesel engines	yes	yes	yes
Can be made from used cooking oil	yes	yes	yes
Can be made from new vegetable oil	yes	yes	yes
Requires vehicle modification	no	yes	yes
Requires added chemicals to produce	yes	yes	no
Requires startup tank of biodiesel or diesel fuel	no	yes	yes
Good startup fuel	yes	no	no
Requires heating for operation at any temperature	no	no	yes
Can be reliably mixed in any proportion with diesel fuel	yes	no	no
Biodegradable and non-toxic	yes	no	yes
Safe to handle and store	yes	no	yes
Reliably cuts emissions in all Diesel engines	yes	no	yes
Considered an alternative fuel under EPACT*	yes	no	yes
EPACT allows a 20% mix with 80% diesel fuel**	yes	no	no
Simple way to run vehicle in an emergency	no	yes	no
Stable fuel at room temperature	yes	no	no
Better lubricity than diesel fuel	yes	yes	yes
Can be used as lubrication additive to diesel fuel	yes	no	no
Gels in cold weather	yes	yes	yes
Covered by many engine warranties	yes	no	no
Engine life, power, torque, and fuel consumption are relatively unaffected	yes	yes	yes
Can clog fuel injectors if used improperly	no	yes	yes
Tested and documented by U.S. universities	yes	no	yes
Can be used in some lanterns and stoves	yes	no	yes
Possible substitute for home heating oil in furnaces	yes	no	no

*Under EPACT regulations, any biologically derived fuel is considered an alternative fuel.

**Recent EPACT legislation states that each biodiesel fleet vehicle must use a minimum of 450 gallons of biodiesel per year to meet alternative fuel requirements.

DIESEL ENGINES IN COLD WEATHER

Some Diesel vehicles experience difficulties while operating in cold weather. You can tell if a Diesel is experiencing cold weather problems if the engine will not start but: the engine turns over normally, the glow plugs are working properly, and the ambient temperature is below 20° F (-7° C). If these three conditions are true, then gelled fuel has likely clogged the fuel system. Petroleum diesel fuel will begin to *cloud* at 20° F (-7° C).¹¹ The *cloud point* is the point at which fuel appears cloudy because wax crystals form in the fuel.

In 1996, the American Society for Testing and Materials (ASTM) recommended that biodiesel have a cloud point of at least 38° F (3° C).¹² Biodiesel will actually cloud at temperatures between 60° and 25° F (16° and -4° C).¹³ The more free fatty acids that are in the biodiesel, the higher the cloud point will be. This means that biodiesel made from used cooking oil or animal fat will cloud at higher temperatures than biodiesel made from new canola oil.

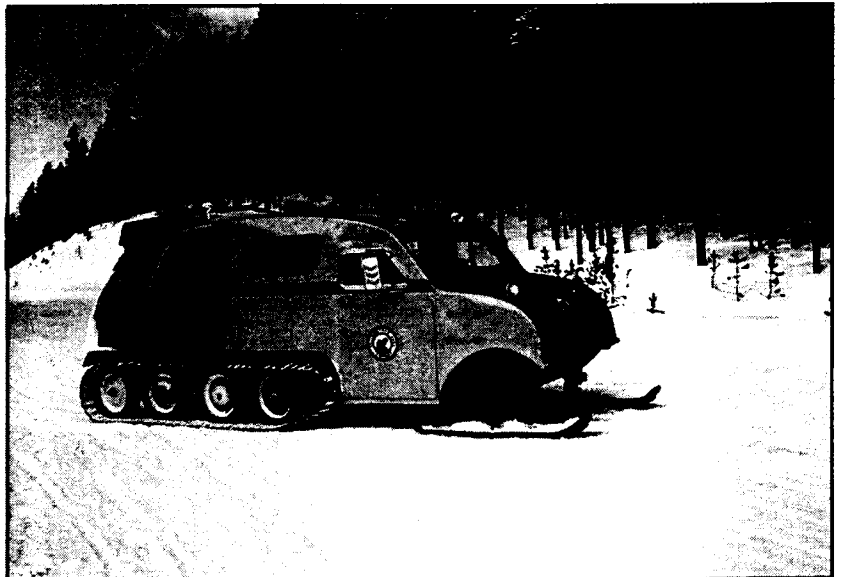
When fuel clouds, it can clog the fuel filter and disable the vehicle. When the temperature reaches the fuel's *pour point*, the fuel will cease to move through fuel lines. When the temperature reaches the fuel's *gel point*, the fuel will become the consistency of petroleum jelly.

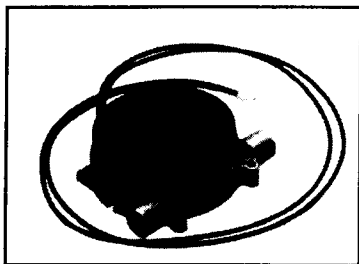
There are two types of diesel fuel, diesel #1 and diesel #2. Diesel #1 is similar to or the same as kerosene. Diesel #2 is more common. Diesel #1 can be used down to -20° F (-29° C).¹⁴ Diesel #2 can be used down to -10° F (-23° C).¹⁵

The use of a *winterizing agent*, *anti-gel formula*, or *flow-improver additive* can lower the cloud point of biodiesel and petroleum diesel fuel in cold weather. Since biodiesel is chemically similar to diesel fuel, diesel winterizing agents can also be used with biodiesel. The effects of winterizing agents on fuel cloud points vary widely and are unpredictable. Always use winterizing agents according to the directions. If no directions are supplied, add 7 fluid ounces of winterizing agent with each tank of fuel. We have found the best results using Amsoil Diesel Fuel Additive.

*When fuel clouds, it can clog the fuel filter and disable the vehicle...
When the temperature reaches the fuel's gel point, the fuel will become the consistency of petroleum jelly.*

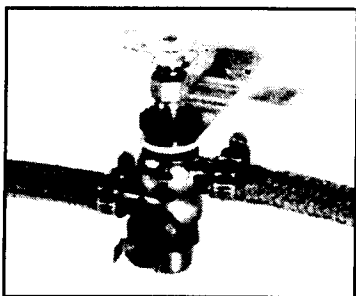
While diesel fuel and biodiesel might not be the best suited fuels for cold weather use, there are a number of ways to ensure reliable Diesel engine operation in subzero temperatures.





The Racor brand electric fuel heater (top) is designed for Diesels operating in below freezing temperatures.

The electric Dieseltherm heater (bottom) is small and well-suited for passenger Diesel vehicles. Both brands of fuel heaters install directly into the fuel line before the fuel filter. Bottom photo courtesy of Dieseltherm.



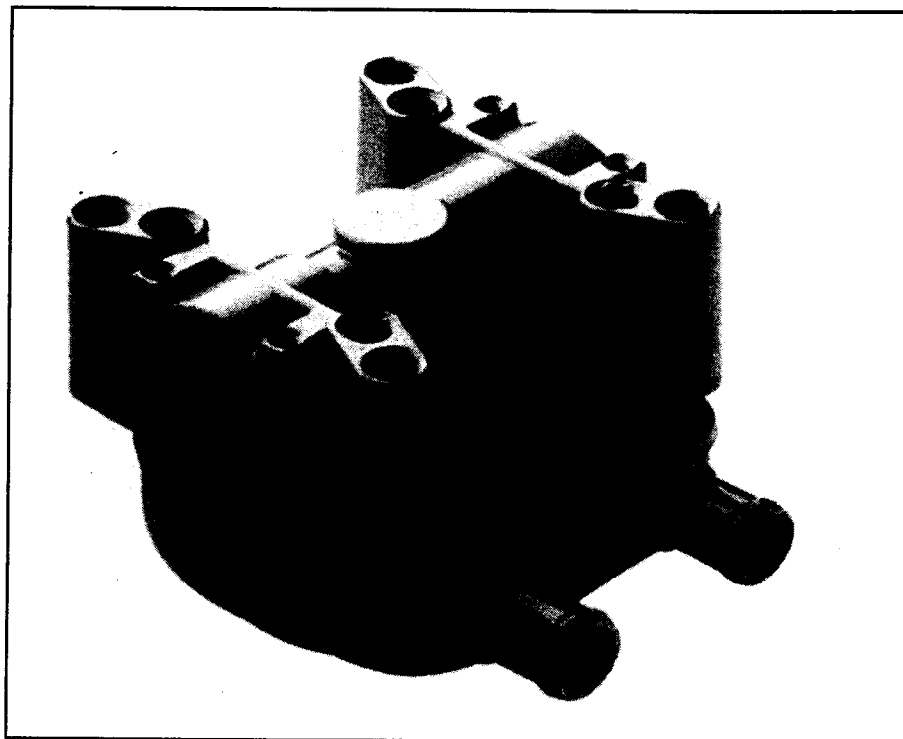
Coolant operated fuel heaters such as this one from Racor (right) are usually made for large Diesel vehicles and heavy duty machinery. Coolant operated heaters are advantageous because they heat fuel to higher temperatures and they do not use electricity. To use a coolant operated fuel heater on a passenger Diesel vehicle, you may need to use hose adapters to adapt the fittings on the coolant operated heater to the hoses in your car.

Heating Devices for Diesels

The addition of a fuel heating accessory can ensure the reliable operation of a Diesel vehicle in cold weather. Following is a list of simple fuel heating devices:

1. An engine block heater is a very simple electrical element that installs directly into an engine block drain plug. An engine block heater plugs into a household electrical outlet when the vehicle is stationary. Engine block heaters are installed to ensure that engine oil does not gel and they help when starting a Diesel in cold weather.
2. A fuel tank heater is a stainless steel pipe that goes inside the fuel tank and keeps the fuel in the tank warm when the vehicle is operating.
3. An electric fuel heating element attaches to the fuel line directly before the fuel filter housing. One such product we recommend is the Dieseltherm. The Dieseltherm uses electricity from the engine battery to heat the fuel.
4. A coolant-operated fuel heater uses engine coolant to heat the fuel. These heaters are available from Racor and Advanced Maintenance Technology.
5. A fuel line heater is a fuel line with an electric element inside of it. The fuel line heater will replace the regular fuel line from the tank to the fuel filter. Electric fuel line heaters are available from Racor.

In some Diesel vehicles, fuel can cloud inside the fuel tank and clog the *fuel tank filter*. Diesel vehicles such the 1980s General Motors Diesels and some Volkswagen Diesels are equipped with a sock filter located inside the fuel tank. If you own a Diesel that experiences clogging of the fuel tank filter, you should contact the manufacturer of your Diesel vehicle and ask if they make a cold weather kit for the fuel tank. You need not mention that you are running your vehicle on biodiesel fuel made from waste McDonald's grease.



BUGS AND BACTERIA

When operating a Diesel in a warm climate, the fuel system may become covered with what appears to be green slime. This slime can clog the fuel system and disable the vehicle. The slime is not algae, as algae need light to grow. The greenish to black slime that is found in Diesel fuel systems in warm, humid climates is a bacteria.¹⁶ The bacteria attack petroleum diesel fuel and biodiesel fuel which is in a fuel tank or in a storage tank. The precautions and treatment for bacteria are the same whether you are using biodiesel or petroleum diesel fuel.

Checking for Bacteria

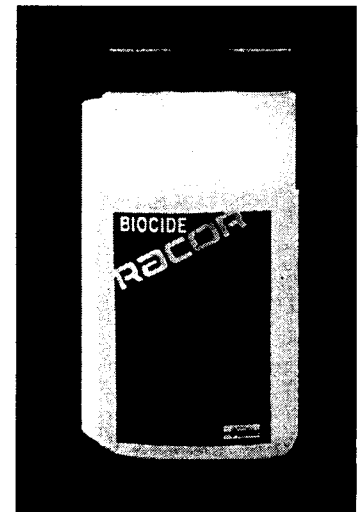
If you are having trouble starting a Diesel engine and the fuel, starter, glow plug, and air systems are operational, there may be bacteria in your fuel system. To determine if there is bacteria in the fuel system, remove the filler cap from the fuel tank. Run your finger along the inside edge of the filler pipe. If bacteria have invaded the fuel system, there will be green sludge or slime on your finger. If the filler cap appears normal, it does not rule out the possibility that there are bacteria in your fuel system.

Find a clean wooden rod or a dowel. Carefully and slowly insert this rod into the filler pipe on your Diesel vehicle. If the rod meets resistance, stop pushing or you may damage something. When you pull the rod out, thoroughly inspect it for any signs of green, slimy bacteria. If there is slime on the rod, replace the fuel filter in the engine compartment and pour some liquid *biocide* into the fuel tank. Biocide is a liquid poison which kills the microorganisms living in your fuel tank. You can buy biocide at automotive parts stores, diesel fuel or home heating oil distributors, Diesel service shops, and boat marinas. We recommend Racor Diesel Biocide.

Follow the directions on the bottle of biocide. If there are no directions, pour 2 ounces of biocide into the fuel tank and fill the tank with fuel. Use the biocide with the next 3 tanks of fuel. After that, use the biocide every other time you fill your tank until the slime goes away. If a Diesel is going to sit for longer than two weeks, fill the fuel tank to the top with fuel and put two ounces of biocide or *biostat* in the fuel tank. Biostats inhibit the growth of bacteria. In warm, humid areas, biostats are often added to fuel as a precaution against the possibility of bacteria growth.

In addition to using a biocide or biostat, biodiesel and diesel fuel should be stored in as cool and dark a place as possible. Fuel tanks and storage tanks should be kept as full as possible to avoid excessive exposure to oxygen.

If a Diesel engine has been sitting without being started in a warm, humid climate, it is possible for bacteria to fully clog fuel lines and even the injector pump. To remove the bacteria, disconnect all fuel lines, flush them with compressed air, flush the fuel lines with diesel fuel, change the fuel filter, drain and fill the fuel tank, and add a couple of ounces of biocide. Although such a case is uncommon, it can happen if a vehicle or generator has been sitting for 6 months or longer.



Biocide can be found anywhere Diesel vehicles are serviced. Wear chemical resistant gloves when pouring biocide into a fuel tank.

THE FUTURE OF THE DIESEL ENGINE

Ford, DaimlerChrysler, Navistar and other automobile and engine manufacturers have participated in the joint research and development of a new breed of advanced Diesel engines. Due to their ultra low emissions and super efficiency, automakers are calling the new engines "green Diesels." These recently developed Diesel engines require no new manufacturing facilities, achieve pollution levels below those of current gasoline engines, and double fuel efficiency. The cost of producing these new Diesel engines is comparable to the cost of producing normal gasoline engines.¹⁷



The Volkswagen Lupo is available in Europe with a super efficient Diesel engine.

Super Efficient Diesels

In April 1999, Volkswagen of Germany released its 80 mile per gallon Lupo car. The Lupo has an aluminum body with a twelve year rustproof warranty, a small Diesel engine, and a computer controlled manual transmission. The Lupo has similar acceleration and power to other cars in its class while maintaining emissions levels well below new EU emissions standards.¹⁸ In addition, the Lupo is warranted to use biodiesel fuel. Like the many Diesel vehicles that will follow its example, the Lupo is efficient, clean, and quiet.

In conjunction with the Department of Energy, Ford has developed a "green Diesel" family car called the P2000. The P2000 has a similar chassis to the Ford Taurus. However, the P2000 Diesel gets 63 miles per gallon and weighs only 2,000 pounds (908 kilograms).¹⁹ The P2000 has a super efficient direct injection Diesel engine which is similar to the TDI Diesel engine in the Volkswagen Lupo. Ford claims it will market the P2000 within the next several years.

Hybrid Vehicles

Hybrid vehicles operate on the principle that two engines are better than one. One of the engines is an electric motor and the other one is either a Diesel or gasoline engine. By combining the best features of the two engines, a Diesel electric hybrid vehicle doubles fuel efficiency with no net loss of power, style, or comfort. Many of the new hybrid vehicles have Diesel engines coupled to their electric motors.

Ford's concept hybrid vehicle, the Synergy 2010, contains a 1 liter direct injection Diesel engine and an electric motor. The Synergy 2010 incorporates super efficiency, ultra low emissions, solar panels, and a 40% increase in aerodynamic efficiency over the most aerodynamic vehicle in Ford's current line of cars.²⁰

Since early 1999, a number of Diesel electric hybrid UPS delivery trucks have been operating in several cities across the United States.²¹ The trucks were designed by Lockheed Martin and built by Navistar. Unlike lightweight passenger hybrids vehicles, Navistar *HEVs*, or hybrid electric vehicles, are full-sized, heavy duty trucks. The Navistar *HEVs* double fuel efficiency while maintaining emissions levels below Ultra-Low Emissions Vehicle (ULEV) standards.²²

C H A P T E R 4

B I O D I E S E L F U E L

Biodiesel has many advantages over petroleum diesel fuel. Biodiesel fuel is reliable, renewable, and its use can strengthen the economy by creating jobs. Engines running on biodiesel have logged millions of road miles. From over 20,000 miles (32,000 kilometers) of first hand experience with biodiesel, we can personally testify that biodiesel works as well as petroleum diesel fuel.

OVERVIEW OF BIODIESEL

A Transportation Industry Fuel

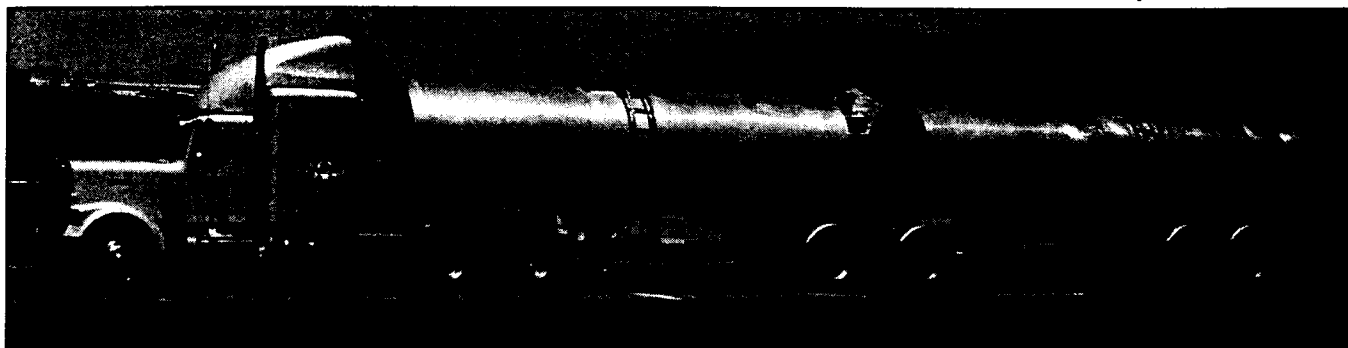
Biodiesel is an ideal fuel for the transportation industry because it can be used in any Diesel engine. Everything from the food at the grocery store to the book that you are currently reading is transported on Diesel trucks. Most farming equipment has Diesel engines. Diesel mining equipment extracts the metals that are used to make electronics. Diesel trucks, trains, and boats bring computers, stereos, food, fuel, televisions, and cars from factories to stores. From planting seeds to mining copper, Diesel engines are used to make and transport the items we depend on. Every one of these Diesel engines can run on biodiesel.

Biodiesel fuel is reliable, renewable, and its use can strengthen the economy by creating jobs.

A Lubricity Additive

Between 0.4-5% biodiesel mixed with petroleum diesel fuel increases the fuel *lubricity*.¹ Lubricity describes how a fuel lubricates the fuel system and engine. Diesel fuel was once lubricated primarily with sulfur. When fuel containing sulfur is burned, it produces sulfur dioxide (SO₂), the primary component of acid rain.² When the legal limit of sulfur in diesel fuel was decreased in the United States, many Diesel engines experienced fuel system problems.³ Biodiesel can be used to restore the lubricity of diesel fuel.

Large Diesel trucks like this fuel truck can run on biodiesel. In the future, these trucks may deliver biodiesel instead of petroleum to fuel pumps across the country.

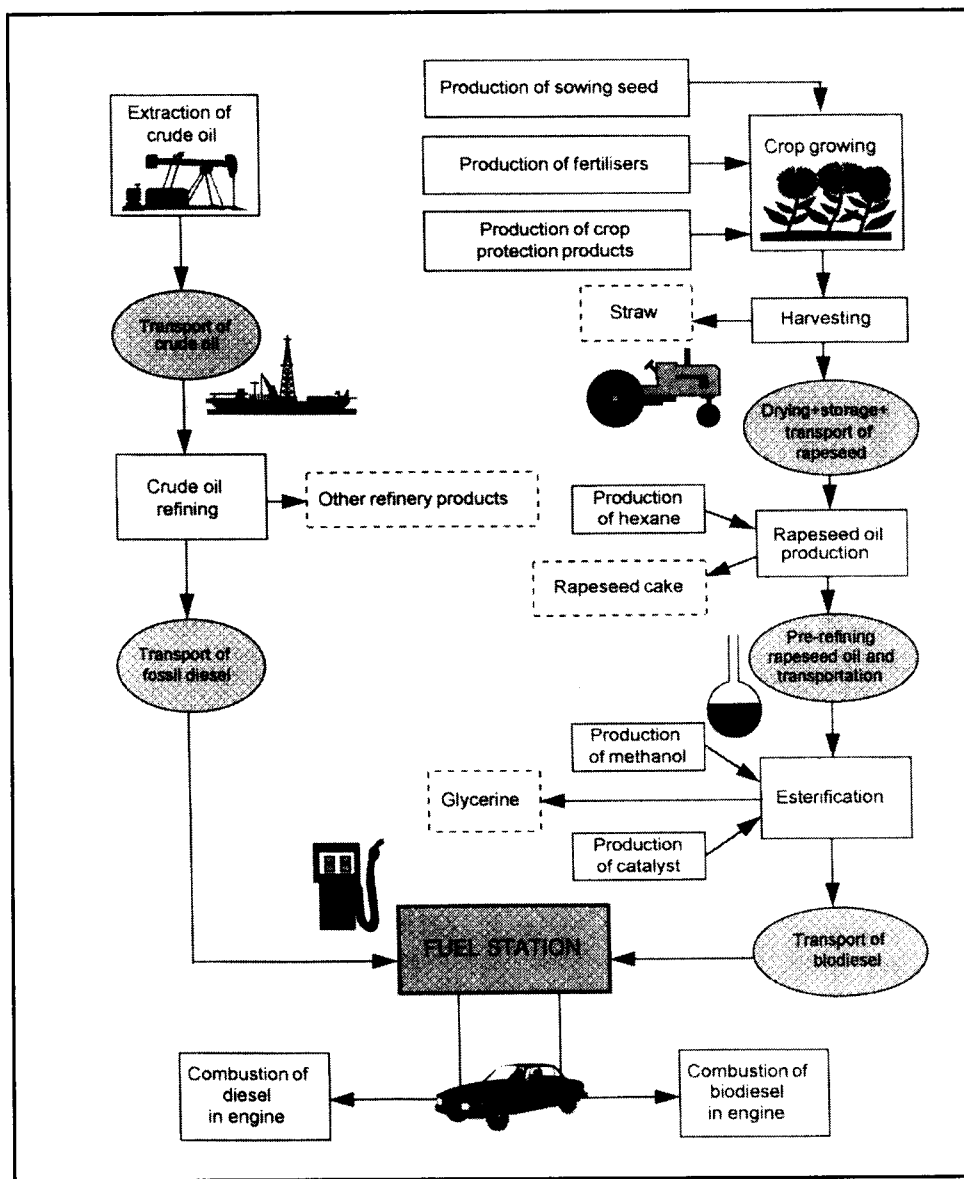


Energy Balance Ratio

Biodiesel has a favorable *energy balance ratio*. An energy balance ratio is a comparison of the energy stored in a fuel to the energy required to grow, process, and distribute that fuel. The energy balance ratio of biodiesel is at least 2.5 to 1.⁴ For every one unit of energy put into the fertilizer, pesticides, fuel, feedstock, extraction, refining, processing, and transporting of biodiesel, there are at least 2.5 units of energy contained in the biodiesel. Biodiesel has a positive energy balance ratio because it is an efficient carrier of solar energy.

To obtain an accurate energy balance ratio for biodiesel, the quantities of energy consumed in each step of the biodiesel manufacturing process are added together. The total energy needed to produce a gallon of biodiesel is then compared to the energy contained in the gallon of biodiesel. Although the biodiesel manufacturing process has many steps, biodiesel's energy balance ratio is higher than most fossil fuels and agriculturally-derived fuels.

Source: British Association for Bio Fuels and Oils.



Blends with Petroleum Diesel

Biodiesel can be blended in any ratio with petroleum diesel fuel. A blend of 20% biodiesel and 80% diesel fuel is called B20. B20 is becoming a popular alternative fuel for U.S. *fleets*. A fleet is a group of vehicles operated from a central location, like buses or delivery trucks. B20 is appealing fleets because it reduces emissions considerably, is reasonably priced, and requires no engine modifications.

Biodegradability and Toxicity

Biodiesel is biodegradable and non-toxic. 100% biodiesel is as biodegradable as sugar and less toxic than table salt.⁵ Studies have shown biodiesel to biodegrade up to four times faster than petroleum diesel fuel, with up to 98% biodegradation in 3 weeks.⁶ The reduced emissions, pleasant odor, biodegradability, and safety of biodiesel make it well-suited for use in marine environments and sensitive areas such as national parks and forests.

Transportation and Storage Safety

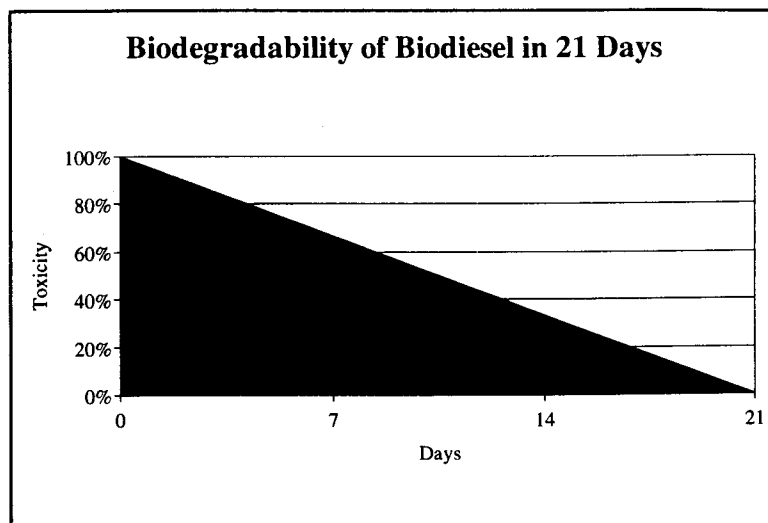
Biodiesel will not spontaneously explode or ignite under normal circumstances because it has a high *flashpoint*, or ignition temperature. Biodiesel must be at least 300° F (150° C) before it will ignite.⁷ Comparatively, petroleum diesel fuel has a flashpoint of 125° F (52° C).⁸ Since biodiesel is not explosive under normal circumstances, it can be transported with shipping services such as Yellow Freight and UPS. When biodiesel is transported, it must have a Materials Safety and Data Sheet (MSDS). For an example of a MSDS, see Appendix 2.

Energy Content, Fuel Consumption, Power, and Torque

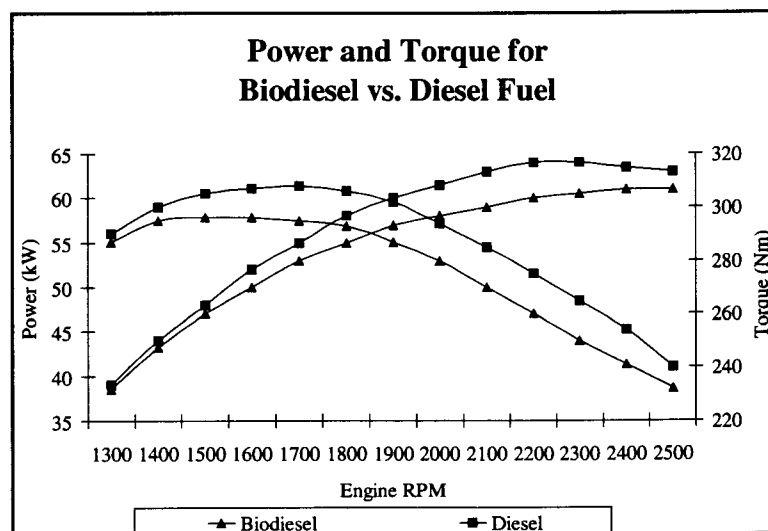
Biodiesel contains approximately 12% less energy than diesel fuel. Biodiesel contains approximately 37 megajoules of energy per kilogram whereas diesel fuel contains approximately 42 megajoules per kilogram.⁹ The reduction of energy in biodiesel is partially offset by a 7% average increase in the combustion efficiency of biodiesel.¹⁰ On average, biodiesel use results in a 5% decrease in torque, power, and fuel efficiency.¹¹ However, the performance of most vehicles using biodiesel is not noticeably affected.

Other Aspects of Biodiesel:

- Biodiesel can be stored anywhere that petroleum diesel fuel is stored.
- Because of its lubricating properties, biodiesel use can increase the life of Diesel engines in which it is used.¹²
- Biodiesel's exhaust is free of lead, sulfur dioxide, halogens, and has reduced particulates, unburned hydrocarbons, carbon monoxide, and carbon dioxide.¹³
- Biodiesel replaces the exhaust odor typical of petroleum diesel with the pleasant smell of french fries or donuts.
- Biodiesel can be made cheaply from used cooking oil, an abundant waste product.



Biodiesel is less toxic than table salt and is fully biodegradable. Source: Körbitz Consulting.

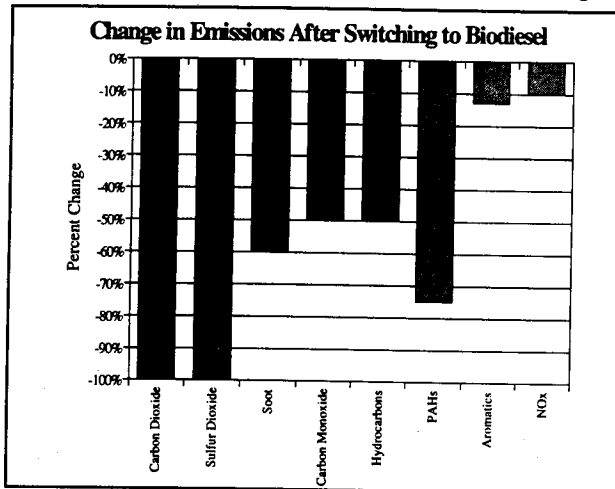


Although biodiesel contains slightly less energy per kilogram than diesel fuel, biodiesel produces similar power and torque to diesel fuel at any engine speed. In most cases, there is no noticeable difference in performance between biodiesel and diesel fuel. Source: University of Idaho.

BIODIESEL EMISSIONS

Biodiesel emissions are substantially lower than petroleum diesel emissions. Biodiesel tailpipe emissions are similar to gasoline emissions. However, compared to gasoline, biodiesel produces no sulfur dioxide, no net carbon dioxide, up to 20 times less carbon monoxide, and more free oxygen.¹⁴ Biodiesel has the following emissions characteristics when compared to petroleum diesel fuel:¹⁵

- Reduction of net carbon dioxide (CO₂) emissions by 100%.
- Reduction of sulfur dioxide (SO₂) emissions by 100%.
- Reduction of soot emissions by 40-60%.
- Reduction of carbon monoxide (CO) emissions by 10-50%.
- Reduction of hydrocarbon (HC) emissions by 10-50%.
- Reduction of all polycyclic aromatic hydrocarbons (PAHs) and specifically the reduction of the following carcinogenic PAHs:
 - Reduction of phenanthren by 97%.
 - Reduction of benzofloraanthen by 56%.
 - Reduction of benzapyren by 71%.
 - Reduction of Aldehydes and Aromatic Compounds by 13%.
- Reduction or increase of nitrous oxide (NO_x) emissions by 5-10% depending on the age of the vehicle and the tuning of the engine.



Biodiesel reduces most of the emissions of a Diesel engine. These figures represent the maximum percent change in emissions experienced with biodiesel. Source: Körbitz Consulting.

There are two ways to reduce NO_x emissions in an older Diesel engine: reduce the combustion temperature or install a catalytic converter. Reducing combustion temperature can be done by retarding engine timing one to three degrees.¹⁸ The addition of a catalytic converter to an older Diesel vehicle will reduce all emissions, including NO_x. The combination of retarding engine timing and adding a catalytic converter will bring the level of NO_x emissions from most biodiesel powered vehicles below levels experienced while using petroleum diesel fuel.¹⁹ These services can be performed by any licensed Diesel mechanic.

Carbon Dioxide Emissions

The use of biodiesel does not increase atmospheric carbon dioxide. A recent European *life-cycle analysis* of biodiesel made from rapeseed oil studied every aspect of manufacturing biodiesel, from planting the seed to transporting the fuel to a service station. The researchers found that “for each kilogram of biodiesel fuel burned in a diesel engine, up to three kilograms of carbon dioxide are consumed, not produced, during the life-cycle of biodiesel fuel.”²⁰

Nitrous Oxide Emissions

The use of biodiesel does not decrease nitrous oxide emissions. NO_x emissions are created when nitrogen is burned, or oxidized. Since the Earth’s atmosphere is 80% nitrogen, any internal combustion engine running on any fuel produces NO_x emissions.¹⁶ Regardless of the fuel used, the amount of nitrous oxides produced by an engine is directly related to the age and design of the engine. While an old, poorly tuned Diesel engine can produce as much as 12 grams of NO_x per brake horsepower hour, new Diesel engines produce as little as 1.4 grams of NO_x per brake horsepower hour, less NO_x emissions than many gasoline engines.¹⁷

ENGINE WARRANTIES AND BIODIESEL

Biodiesel will run in any Diesel engine but not all manufacturers of Diesel engines will honor an engine warranty of a new vehicle or generator that has been using biodiesel. If you buy a new Diesel vehicle in the United States and are concerned about the warranty, we recommend that you buy biodiesel from a commercial supplier who will back an engine warranty even if the engine manufacturer does not warrant the engine for biodiesel use. For an example warranty letter from a commercial biodiesel supplier, see Appendix 3. The use of experimental or homemade biodiesel can confuse engine warranty issues. If a part malfunctions while an engine is operating on homemade fuel, the burden of proof that the fuel was made to specifications will be on the operator. Unless the experimental fuel was tested at a laboratory, there is no way to prove that the fuel met specifications set forth by the engine manufacturer.

Rubber and Biodiesel

Engine manufacturers are hesitant to warrant biodiesel use because biodiesel has a tendency to deteriorate rubber fuel system parts. The alcohol in biodiesel deteriorates rubber. If an engine will be using 100% biodiesel for over 100,000 miles (160,000 kilometers), it is wise to replace rubber fuel hoses and seals with Viton® or another brand of fluoroelastomer hoses and seals. All synthetic hoses and seals resistant to oxygenated fuels, methanol, and ethanol are suitable for use with biodiesel. Synthetic hoses are common on European made Diesel vehicles. Deterioration of rubber fuel hoses can occur in new and old vehicles using biodiesel. B20 does not cause deterioration of rubber fuel parts as rapidly as 100% biodiesel.²¹

The following rubber parts may need to be replaced with synthetic equivalents: the rubber filler hose which goes from the filler opening to the fuel tank, the rubber fuel lines which run from the fuel tank to the fuel filter, and the fuel line which runs from the fuel filter to the injection pump. In some Diesels, it may be necessary to use a fuel filter which does not use rubber seals. On certain vehicles, like Ford Diesels, there are rubber parts in the fuel injectors and injection pump which are also susceptible to deterioration.

Many European Diesels come with warranties which cover the use of biodiesel because most Diesels that are sold in Europe come with synthetic hoses, seals, and gaskets in the fuel system. Viton® brand hoses and fuel system parts are also standard on Detroit Diesel engines sold in the United States.

Warranty Specifications

Each engine manufacturer sets specific fuel requirements and parameters for their engines. As long as the fuel used in the engine can be proven to meet or exceed those requirements, the engine warranty is valid. According to the Cummins Diesel Service Bulletin, Cummins will “assume no warranty responsibility for repairs or increased costs of operation with ‘Bio-Diesel’ fuels.”²² See Appendix 4 for the full list of acceptable fuel properties for Cummins engines. Commercially made biodiesel would meet or exceed all of the properties set forth by Cummins for normal diesel fuel. Thus, when a Cummins engine is running on commercially made biodiesel, the warranty is valid. Even so, Cummins will not cover repairs specifically caused by biodiesel.



It is occasionally necessary to replace rubber fuel lines with synthetic equivalents after switching to biodiesel. When replacing fuel system components, use hoses that are resistant to oxygenated fuels such as the Viton® brand of fluoroelastomer hoses.



Most biodiesel manufacturers have engine testing facilities to ensure that their fuel performs properly.

Homemade biodiesel would probably meet the Cummins limits for an "Emergency Fuel." Even a new Cummins engine running on an emergency fuel carries a valid warranty. However, if there is a problem which can be attributed directly to using an emergency fuel, Cummins will not pay to repair it. Of course, any engine failure that is not fuel-related and is a result of a manufacturer's defect will be covered by a warranty regardless of the type of fuel used. Non-fuel related warranty issues are not affected by the use of biodiesel.

ECONOMICS OF BIODIESEL

By using inexpensive sources of vegetable oil, biodiesel manufacturers can cut costs while maintaining healthy profit margins. Biodiesel made from waste cooking oil, animal tallow, and vegetable oil from crops grown on fallow land can cost the same as or less than petroleum diesel fuel. Even in its infancy, the biodiesel industry will create jobs, increase farm income, and stimulate economic growth while simultaneously lessening the national trade deficit.



The fast food fryers of the world are an excellent source of cheap vegetable oil for biodiesel.

Used Cooking Oil

Every year, fast food restaurants in the United States produce over 3 billion gallons (11.3 billion liters) of used cooking oil.²³ While some restaurants are paid for their used cooking oil, others pay to have their cooking oil taken away. Some of the used cooking oil will be mixed into pet food, makeup, livestock feed, or fertilizer. Many gallons of used cooking oil are dumped into sewers and landfills, causing damage and costing municipalities millions of dollars in cleanup fees. Companies and individuals can easily make cheap biodiesel from waste cooking oil.

Using Animal Fat

Cooking oil is not the only source of waste fat for making biodiesel. Biodiesel can also be made from beef tallow, poultry fat, fish oil, and all other forms of animal fat. There are over 1 billion pounds (454 million kilograms) of beef fat produced in the state of Nebraska alone each year.²⁴ In total, the U.S. produces the equivalent of 1 billion gallons (3.8 billion liters) of animal fat per year.²⁵

Samples of biodiesel made from used cooking oil, animal fat, and new vegetable oil.



Government Price Controls

Biodiesel from new vegetable oil is expensive because vegetable oil is expensive. A gallon of vegetable oil costs at least \$4 in a supermarket. Unlike the price of fossil fuel, the price of vegetable oil is not kept artificially low. In fact, the opposite is true. The U.S. government pays farmers not to grow crops in order to keep the prices of certain farm products, like vegetable oil, from dropping. *Farm commodity programs* were designed to ensure that farmers do not “overproduce” crops and thereby bring food prices down.²⁶



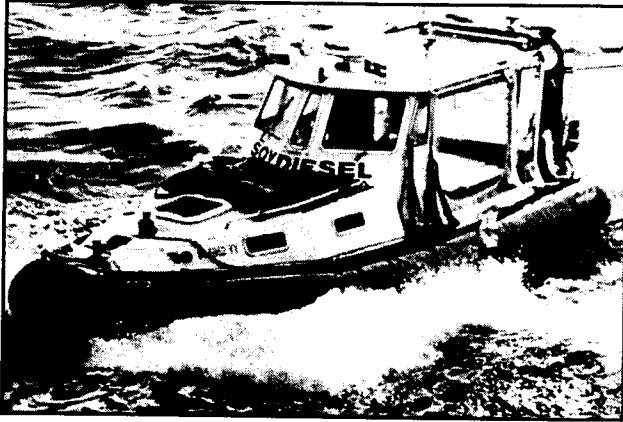
Farmers are paid not to grow certain crops in order to stabilize prices of products like vegetable oil. However, farmers could earn billions of dollars by growing crops for biodiesel on land that is not currently used for food production.

Using Fallow Cropland

Each year approximately 60 million acres (24 million hectares) of U.S. cropland are left fallow due to government programs.²⁷ Biodiesel will have a broader economic impact if vegetable oil crops are grown on these fallow lands. One study of North Dakota farmland compared the economic benefits of leaving an acre fallow with the economic benefits of planting the acre with sunflowers. The study found that leaving the acre fallow would give the farm \$15.31 income annually whereas growing sunflowers for oil would yield \$57.27, an increase of \$41.96.²⁸ Researchers at the University of North Dakota estimated that when the money from increased farm yields was spent and re-spent throughout the economy, it would result in an increase of \$131 per acre in gross business volume, or a multiplier effect of 2.25.²⁹

If we apply these figures to 60 million acres of fallow cropland, growing sunflowers would increase farm income by approximately \$2.5 billion a year. Due to the multiplier effect, the total increase in gross business volume from growing sunflowers on fallow land would be \$7.8 billion annually. It is unlikely that all of the 60 million fallow acres in the U.S. would be planted with sunflowers and that per acre yields would be identical across the country. However, this example demonstrates the billions of dollars in potential economic growth that the biodiesel industry has to offer the United States.

If the demand for vegetable oil increases, the government will have to work with farmers to allow more land to be cultivated. Meanwhile, biodiesel made from used restaurant cooking oil is inexpensive and widely available.



The Sunrider circled the globe on 100% biodiesel in 1996. Photo courtesy of DOE/NREL.

INTERNATIONAL STATUS OF BIODIESEL

There has been an increase in biodiesel research since the mid-1980s both in the United States and abroad. Several universities including the University of Idaho, the University of Missouri, and the University of Graz have extensively researched and tested biodiesel. There are over 1,000 biodiesel fueling stations in Germany. In Italy, biodiesel is sold as home heating oil and as a lubricity additive for diesel fuel.³⁰

Demonstrations

Demonstrations of biodiesel have taken place in at least 34 U.S. states by universities, government agencies, private industries, mass transit programs, and individuals.³¹ Over 100 cities have conducted demonstrations or test projects using biodiesel. More than 1,000 buses have been fueled with biodiesel.³² Biodiesel demonstrations create public interest and demand for biodiesel fuel. Some of the recent biodiesel tests and demonstrations in the United States include:

- The "Sunrider" boat circumnavigated the globe on 100% biodiesel in 1996.
- The "Bean Buses" of Lincoln, Nebraska run on 25% soybean biodiesel.
- Marine use of biodiesel has been promoted in Maryland's Chesapeake Bay.
- Biodiesel was used in Chicago's buses during the 1996 Democratic Convention.
- Fort McCoy Military Base ran 4 trucks on 20% biodiesel for over 50,000 miles.
- The Veggie Van traveled 10,000 miles (16,000 kilometers) across the U.S. on biodiesel made from used restaurant fryer oil in a portable fuel processor.
- In 1999, the Deer Valley School District in Phoenix, Arizona began to fuel a fleet of over 100 school buses with 20% biodiesel.

School buses in Arizona and other states are switching to biodiesel.





The Veggie Van crossed the United States on fuel made from used vegetable oil from fast food restaurants. On average, the Veggie Van gets 25 miles per gallon. Since 1 acre of soybeans yields about 52 gallons of vegetable oil, the Veggie Van gets 1,300 miles per acre.

Production

Biodiesel has been researched in at least 28 countries around the world. There are currently over 85 biodiesel production plants in 21 countries, including:³³

- 45 biodiesel plants in Western Europe including 11 plants in Italy.
- 29 biodiesel plants in Eastern Europe including 16 plants in the Czech Republic.
- 7 biodiesel plants in the United States.
- 2 biodiesel plants in Japan.
- 1 biodiesel plant in Nicaragua.
- 1 biodiesel plant in Malaysia.

Most of these plants incorporate waste frying oils into their production. Biodiesel is competitively priced in most of the European Community countries because it is not taxed as much as fossil fuels. For example, biodiesel can be purchased in Germany for the same price or slightly less than diesel fuel.

Legislation

As of 1997, legislation for tax exemption of biodiesel had been passed in Austria, France, Germany, Italy, Ireland, Norway, Sweden, Poland, Slovakia, and the Czech Republic.³⁴ A large percentage of set-aside land for non-food crops in Europe has been earmarked for biodiesel crops.³⁵ In France, all diesel fuel sold is blended with 5% biodiesel, known there as "diester."³⁶ In Canada, the Alternative Fuels Act requires that 50% of all new government vehicles purchased must be able to run on alternative fuels and the requirement will rise to 75% by the year 2004.³⁷



The CytoCulture "Bio-Fuel Test Vehicle" has driven 40,000 miles on biodiesel. CytoCulture distributes biodiesel in the San Francisco Area.



The Bean Buses in Lincoln, Nebraska run on biodiesel made from soybean oil. Photo courtesy of DOE/NREL.

U.S. BIODIESEL LEGISLATION

In 1992, the United States passed a law called the Energy Policy Act (EPACT). The goal of EPACT is to displace 10% of U.S. petroleum use by the year 2000 and to displace 30% of U.S. petroleum use by the year 2010.³⁸ By passing EPACT, the United States set very high goals for itself while setting an example for the rest of the world. EPACT sparked a new interest in alternative fueled and powered vehicles in the United States. EPACT resulted in government subsidies for research into electric vehicles, ethanol, methanol, and biodiesel as well as other alternative energy technologies.

EPACT Mandates

Many U.S. fleet vehicle purchases are governed by EPACT law. EPACT requires more alternative fuel vehicle (AFV) purchases each year. EPACT mandates AFV purchases for:³⁹

- Any Federal or State fleet - including police cars, U.S. postal trucks, school buses, etc.
- Any Alternative Fuel Provider fleet – meaning any fleet of vehicles which actually deliver alternative fuels.
- Anyone who owns, operates, leases, or otherwise controls 50 or more light-duty vehicles within the United States provided that 20 or more of those vehicles operate primarily within an area with a 1980 population of 250,000 or more and those 20 vehicles are centrally fueled or capable of being centrally fueled.

**PERCENTAGE OF NEW VEHICLES PURCHASED EACH YEAR
REQUIRED BY EPACT TO BE AFVs**

YEAR	FEDERAL FLEET	STATE FLEET	ALTERNATIVE FUEL PROVIDER FLEET	MUNICIPAL AND PRIVATE*
1998	50%	15%	50%	
1999	75%	25%	70%	
2000	75%	50%	90%	
2001	75%	75%	90%	
2002	75%	75%	90%	20%
2003	75%	75%	90%	40%
2004	75%	75%	90%	60%
2005	75%	75%	90%	70%
2006	75%	75%	90%	70%

*Percentages listed for municipal and private fleets are tentative at the time of writing. The DOE is scheduled to finalize the ruling on municipal and private fleets on January 1, 2000.

EPACT gives a broad definition for “alternative fuels.” Under EPACT, propane, natural gas, coal-derived liquid fuels, hydrogen, biofuels, electric cars, and other non-petroleum fuels are classified as alternative fuels.⁴⁰ Propane, natural gas, and coal are fossil fuels. While the use of these fuels might displace oil bought from the Middle East, it does little to displace our dependence on limited natural resources.

Electric cars are more efficient than gasoline or Diesel cars and they can be recharged with renewable electricity such as solar power.⁴¹ *Biofuels*, or agriculturally-derived fuels, such as 100% biodiesel and straight vegetable oil, offer an easy and inexpensive way to meet EPACT regulations because they allow the use of existing vehicles.

Under EPACT, propane, natural gas, coal-derived liquid fuels, hydrogen, biofuels, electric cars, and other non-petroleum fuels are classified as alternative fuels.

In October 1998, the U.S. government passed legislation that alters EPACT by classifying a blend of 20% biodiesel fuel with 80% diesel fuel (B20) as an alternative fuel.⁴² Although 100% biodiesel was already considered an alternative fuel, now any blend of biodiesel with diesel from 100% biodiesel with no diesel fuel down to 20% biodiesel with 80% diesel fuel is considered an alternative fuel under EPACT. To meet their EPACT requirements, fleets must purchase a minimum of 450 gallons (1700 liters) of biodiesel per vehicle per year.⁴³ Fleets can meet up to 50% of their EPACT requirements with biodiesel.

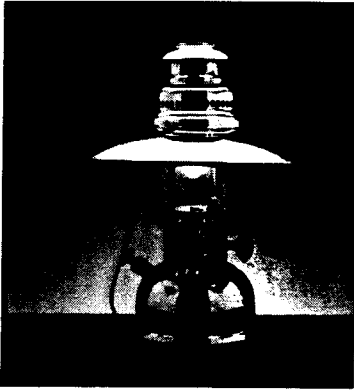
Biodiesel vs. Compressed Natural Gas

Compressed Natural Gas (CNG) is the number one alternative fuel choice of U.S. fleet managers.⁴⁴ CNG is cleaner burning than petroleum liquid fuel but it still emits nitrous oxides and carbon dioxide. CNG is not renewable and world supplies of cheap natural gas will be depleted by as early as 2040. CNG is a good transition fuel to use while renewable fuels gain acceptance. Many vehicles are being converted to run on CNG and fueling stations are appearing in major cities.

Biodiesel is the number two alternative fuel choice of U.S. fleet managers, according to a National Biodiesel Board survey, because it is so easy to switch existing Diesel vehicles to biodiesel fuel.⁴⁵ Researchers at the University of Georgia compared the costs of CNG, diesel, and biodiesel in a fleet of 300 buses. Looking at fuel costs over the 30 year life span of the buses, they found the baseline use of diesel fuel to cost 24.7 cents per mile (cpm). Compressed natural gas usage costs varied from 37.5 to 42 cpm. The cost of biodiesel blended with diesel ranged from 27.9 to 47.5 cpm, depending on the blend and the price of biodiesel used.⁴⁶

Biodiesel and CNG cost about the same on a per mile basis. But unlike CNG, biodiesel can be poured directly into the fuel tank of any existing Diesel vehicle.

Biodiesel and CNG cost about the same on a per mile basis. But unlike CNG, biodiesel can be poured directly into the fuel tank of any existing Diesel vehicle. CNG conversions are expensive, require a lot of down time, and reduce the range of the vehicles. Biodiesel has none of those disadvantages. As natural gas becomes more expensive and biodiesel becomes cheaper, more fleets will switch to biodiesel.



Biodiesel can be used in certain lanterns, heaters, and stoves in place of kerosene or home heating oil. Photo courtesy of BriteLyt.

OTHER USES FOR BIODIESEL

Biodiesel can be used for a myriad of applications other than engine fuel. Following is a list of alternative uses for biodiesel:

- Biodiesel can be used in diesel-fueled heaters, lanterns, and stoves. It can be substituted for kerosene in many camping lanterns and stoves.⁴⁷
- Biodiesel can be used as a substitute for model aircraft fuel in model aircraft engines with glow plugs.⁴⁸
- Biodiesel can be used as a substitute for home heating oil in some home heaters.⁴⁹
- Biodiesel can be used as a solvent for non-automotive paint, spray paint, and other adhesive chemicals.⁵⁰
- Biodiesel is an excellent parts cleaner for coked or greasy engine components.⁵¹ Parts left in a bucket of biodiesel overnight are usually clean by morning.
- Biodiesel can be used as an all-purpose machinery lubricant.⁵²
- Biodiesel can be used to fire pottery in some kilns.⁵³
- Biodiesel can be used to clean up petroleum oil spills on land or in water.⁵⁴
- Biodiesel can be used as a non-toxic crop adjuvant.⁵⁵

Aside from its value as a Diesel engine fuel, biodiesel can be used as a non-toxic alternative to petroleum in other applications.

C H A P T E R 5

G R O W Y O U R F U E L

Vegetable oils contain energy which came directly from the sun. Vegetable oil crops such as peanuts, sunflowers, and soybeans concentrate solar energy in their oils. Whereas fossil oil was made over a period of hundreds of millions of years, it takes as little as a few months to grow vegetable oil from seeds. Vegetable oil is a practical Diesel engine fuel in many locations. For example, numerous islands produce electricity with Diesel generators. These islands import diesel fuel which costs several dollars a gallon while they export coconut and palm oils for a few cents a gallon. By using locally grown vegetable oil for fuel, islands and countless other communities around the world can benefit from reduced fuel costs as well as lower localized emissions.

TEN COMMON OIL-PRODUCING CROPS

There are over 350 species of *oleaginous*, or oil-producing plants and thousands of sub-species. This chapter concentrates on ten plants which are commonly found in different regions of the world. The following table gives average annual oil yield in pounds of vegetable oil per acre and kilograms of vegetable oil per hectare for ten common oilseed crops. Many plant species produce more oil in tropical climates and conditions. Some species can be harvested more than once a year. For a more extensive chart of oil-producing crops, see Appendix 5.

PRODUCTION AVERAGES FOR TEN COMMON OIL CROPS			
Plant	Latin Name	lb. oil/acre	kg. oil/hectare
oil palm	<i>Elaeis guineensis</i>	4,585	5,000
coconut	<i>Cocos nucifera</i>	2,070	2,260
jatropha	<i>Jatropha curcas</i>	1,460	1,590
rapeseed	<i>Brassica napus</i>	915	1,000
peanut	<i>Arachis hypogaea</i>	815	890
sunflower	<i>Helianthus annuus</i>	720	800
safflower	<i>Carthamus tinctorius</i>	605	655
soybean	<i>Glycine max</i>	345	375
hemp	<i>Cannabis sativa</i>	280	305
corn	<i>Zea mays</i>	135	145

Figures are international averages. Harvests vary with region and sub-species.



Both the oil palm tree and the coconut tree grow in tropical and subtropical climates and produce large amounts of vegetable oil. Tests have shown that both coconut and palm oils are excellent fuels for Diesel engines.

African oil palm is slightly hardier than the coconut and is often grown in subtropical regions as an ornamental tree.¹

Coconut

The coconut tree is one of the ten most useful trees in the world. The coconut tree grows to a height of 10-90 feet (3-30 meters). The coconut may have originated in South America but it can now be found in all tropical regions of the world. Among the hundreds of items made from different parts of the coconut tree are margarine, lamp oil, hydraulic oil, ice cream, alcohol, vinegar, lubricant, filters, plastics, bowls, clothing, rope, boat rigging, animal feed, and rubber. Different species of the coconut tree will live in high pH soils, low pH soils, sand, latrine runoff, on inclines, and in other adverse conditions. The coconut tree begins to produce fruit in 5-9 years and is in full production by 13 years, soil conditions permitting. Coconut trees live for between 30-90 years depending on the variety and local conditions. Coconut trees



Oil Palm

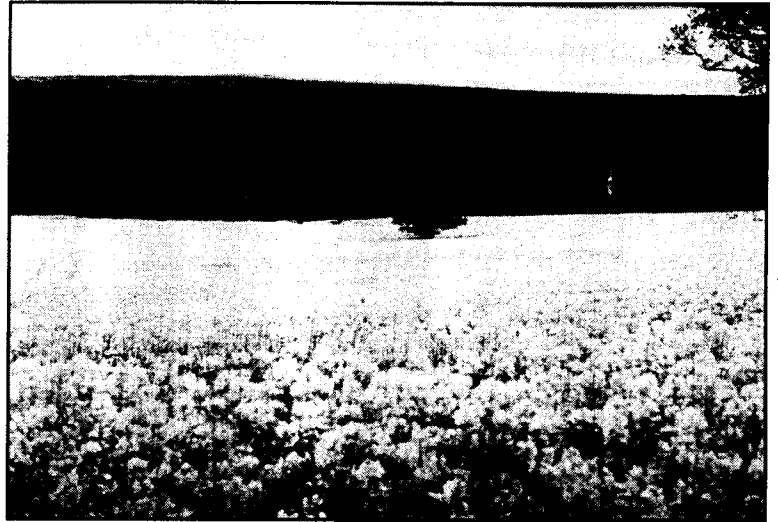
The African palm, or oil palm, is the highest oil-producing tree on earth. One hectare of oil palm can yield up to 5 metric tons of oil per year. The African palm produces two types of oil, palm oil and palm kernel oil. Palm oil is extracted from the fleshy outside, or *mesocarp*, of the fruit. This oil is used to make soaps, candles, margarine, and cooking oils. Palm kernel oil is extracted from the inner kernel of the fruit. Palm kernel oil is similar to coconut oil and is solid at room temperature. It is used to make mayonnaise, cooking oil, ice cream, and baked goods. The pressed cake is used as an animal feed. The African palm grows to a height of 24-60 feet (8-20 meters). The tree is found along the African coast from Libya to Angola and has spread to regions of the Indian Ocean, including Zanzibar and Malagasy. The

provide food for millions of people around the world. Extraction of coconut oil is one of the oldest seed-crushing industries. Coconut oil is the third most produced oil in the world, after peanuts and soybeans. To make coconut oil, the meat, or *copra*, of the coconut is peeled from the husk, dried in the sun or in dryers, and pressed. The white copra contains between 60-75% oil.²

Jatropha

Jatropha is a versatile crop which is native to the Americas. The Portuguese used jatropha oil for lantern fuel and spread jatropha seed around the world. Today, jatropha is common in Brazil, Fiji, Honduras, India, Jamaica, Panama, Puerto

Rico, El Salvador, Mexico, and in much of Africa. *Jatropha* is used to make soap, food, medicine, and poison. Unlike the other oil-producing crops we discuss, the *Jatropha* plant is a bush which lives for up to 40 years. It is grown in many places as a hedge to divide properties, fence animals, and reverse soil erosion. *Jatropha* produces seed year-round if irrigated. It is especially resistant to drought and can be planted in desert climates. *Jatropha* grows from a seed or cutting and quickly establishes itself. In addition to its other positive characteristics, an acre (2.47 hectares) of irrigated *Jatropha* can produce over 500 gallons (1,900 liters) of oil per year. *Jatropha* has numerous medicinal characteristics and is rumored by the Jamaicans and other traditional peoples to contain a cure for cancer.³



Rapeseed/Canola

The yellow flowering oil crop called canola in the United States is known as rapeseed in Europe. Rapeseed is grown in colder regions such as Germany, Canada, and Russia. Although inedible to humans, the meal from the rape plant is a good animal feed. Most of the biodiesel in Europe is made from rapeseed oil. Yields of oil of rapeseed range from 100-200 gallons (380-760 liters) per acre and are among the highest of any conventional oil crop.⁴ The majority of the biodiesel research to date has been done on Rapeseed Methyl Ester (RME) and Rapeseed Ethyl Ester (REE).

Rapeseed has one of the highest yields of oil per acre of any conventional oilseed crop.

Peanut

Peanuts are native to South America and grow well in warm climates and sandy soil. The peanut plant has a slightly lower oil yield per acre than rape/canola and a slightly higher average yield than soybeans.⁵ The Diesel engine was shown being powered by peanut oil at the 1900 World Exhibition in Paris. One University of Georgia tractor runs on 100% peanut oil, while two University of Georgia buses operate 8 hours a day on a 30% mixture of peanut oil and diesel fuel.⁶ Peanut oil can be made on a farm using a sheller and a press.

Sunflowers produce a large amount of oil per acre and are native to North America.

Sunflower

Sunflowers are an aesthetically pleasing oil crop. They grow between 15 inches and 8 feet (0.7-3.5 meters) tall and prefer warm temperatures and rich soil. Sunflower crops yield slightly less oil per acre than do rapeseed/canola crops. Sunflower oil is the second most important edible oil in the world and is used for cooking, margarine, salad dressings, lubrication, soaps, and lighting. Sunflower is the only major oil crop native to western North America.⁷



Safflower

The safflower is a thistle-like plant which grows to a height of approximately 4 feet (1.3 meters). Safflower grows well in the same regions as cotton and barley and usually bears a yellow or orange flower. The safflower plant was grown prehistorically in India, Egypt, and Persia. Today, India is the largest grower of safflower. Safflower is grown exclusively for its oil which is high in essential unsaturated fatty acids. The oil is light in color and is used in salad and cooking oils, margarine, liqueurs, candles, paints, linoleum, and varnishes. The flowers can be used to make yellow and red dyes. The safflower crop is grown and processed using the same machinery that is used for small grains. It has a growing season of 150-200 days.⁸

The soybean is the most commonly grown crop in the United States. Most of the used cooking oil in the U.S. is soybean oil. Photo courtesy of DOE/NREL.



Soybean

The soybean, or soya, plant has been cultivated in East Asia for the past 5,000 years. There are more than 2,500 known species of soybean cultivated in the world. The soybean is the most commonly grown crop in the United States. The soybean is a high protein bean of approximately 20% oil and 80% meal by weight.⁹ Most of the biodiesel made in the United States is made from either virgin soybean oil or used cooking soybean oil. Soybeans are not the best suited crop for oil production. Nevertheless, the soybean is a well-researched, hardy species that yields a protein suitable for both human and animal consumption.

Hemp

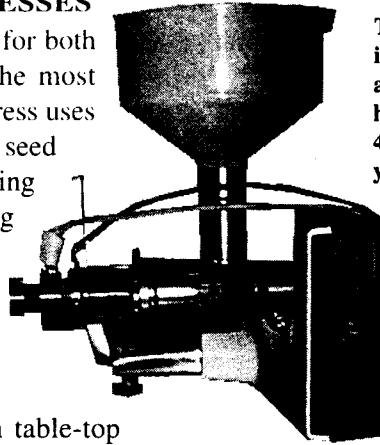
The hemp plant grows to 15 feet (5 meters) in height and bears a hard, nutty seed. For 5,000 years, hemp has been grown and processed in Russia, China, and other parts of Asia where it has been used as a source of fiber and food. Some countries are experimenting with growing hemp for paper and textile fiber. The seed of the hemp plant contains approximately 30% oil.¹⁰ While the hemp seed contains a higher percentage of oil than the soybean, the average annual per acre yield of hemp oil is lower than that of soybean oil. Due to the many varieties of hemp, annual per acre oil yields vary.

Corn

Also known as maize, corn is a native grain crop of the Americas. Corn has been cultivated for more than 5,000 years from sea level to over 9,000 feet (3,000 meters), and from Chile to southern parts of Canada. Corn grows to 6-9 feet (2-3 meters) in height. Corn is used for 75% of the world's starch and is the third most important grain in the world after wheat and rice. This hardy crop is resistant to depredation by birds and produces the largest amount of grain per hour of labor. Since only 7-8% of the grain is oil, corn oil is a bonus byproduct. Processed corn oil is used extensively in the United States as a fast food frying oil.¹¹ Among its many uses, corn starch is used to make ethanol, a renewable alcohol fuel. A corn crop can produce both ethanol and vegetable oil fuels.

SMALL AND LARGE SCALE OIL PRESSES

There are two types of oil presses which are useful for both small and large scale vegetable oil processing. The most common type of oil press is the *screw press*. This press uses a large diameter screw inside a metal housing. The oil seed is fed into the top of the press and falls into the churning screw. As the seed is churned into a mash by the turning threads of the screw, the oil is squeezed from the meal, or cake. The protein cake from the oilseed oozes from the side of the press and the vegetable oil dribbles from the bottom of the press.¹²



The Electrolux model screw press is a table top press that doubles as a grain grinder. This press runs on household current and can process 4-8 kilograms of seed per hour, yielding 0.25-2 liters of vegetable oil. Photo courtesy of TäbyPressen of Sweden.

Screw presses are available in sizes ranging from table-top models to industrial models which can produce 2,000 pounds (4,400 kilograms) of oil per day. Screw presses are available in electrical powered and Diesel powered models. Screw presses tend to be slow and they sometimes produce oil with bits of meal still in it. A *ram press* is a more efficient oil press design. This press uses a hydraulic piston inside of a cylinder to crush the oilseed.¹³ Ram presses can be powered by hand, by an electric motor, or by a Diesel engine.

Oil Settling

After a vegetable oil is pressed, it is often left to settle for a few days in a horizontal settling tank. The vegetable gums and pieces of meal cake will settle to the bottom of the tank. If the vegetable oil is to be used as a fuel, it should be pumped through a series of filters. First, it should be passed through a 150 micron mesh screen, then through a 70 micron mesh screen, then through a 25 micron filter, and then through a 10-15 micron fuel filter.



Carl Bielenberg of the Better World Workshop demonstrates his ram press to a women's cooperative engaged in sesame seed cultivation in Gambia. Photo courtesy of Better World Workshop.

Diesel Powered Presses

Most of the mid to large sized oil presses can be powered with Diesel engines. When used in conjunction with a Diesel engine which has been modified to burn straight vegetable oil, these presses can produce their own fuel. In addition to producing their own fuel, Diesel powered presses can provide fuel for entire communities or villages. Diesel powered generators, mills, and pumps can run on the vegetable oil produced from a local resource such as jatropha oil. The combination of a Diesel powered press and a Diesel generator can offer many people who live in rural or isolated areas an inexpensive, sustainable system of generating electricity.



The Bielenberg ram press can process 10-15 kilograms of seed per hour, yielding 3-4 liters of vegetable oil. This oil press is well-suited to rural communities because it can be operated by hand. Photo courtesy of Better World Workshop.

HOW MUCH CAN WE GROW?

One of the most commonly asked and controversial questions about biodiesel and vegetable oil is how much can we grow?

U.S. Potential

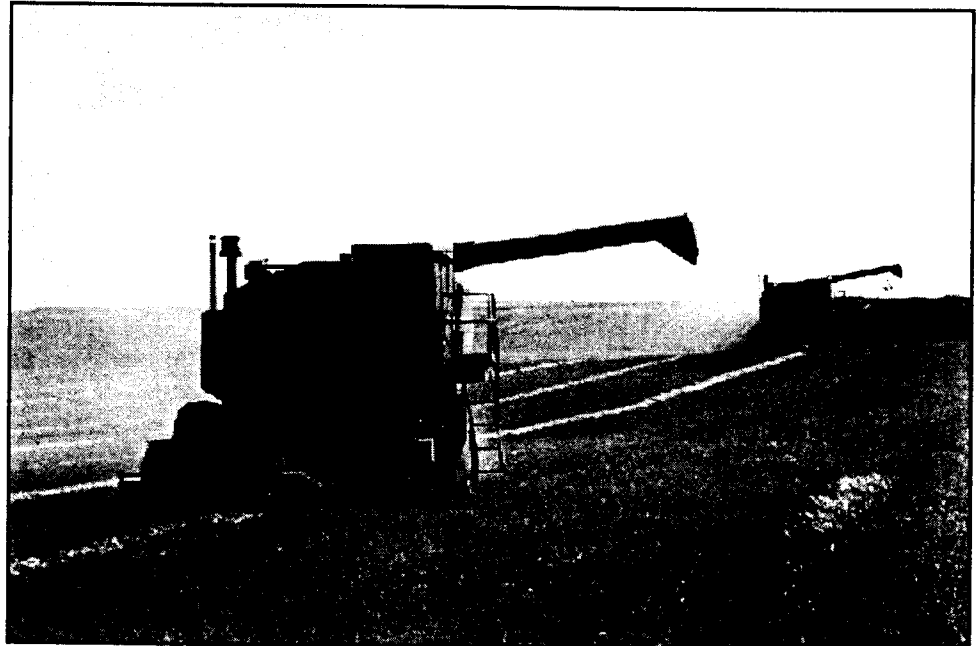
The United States is the largest single consumer of fossil fuels in the world. Each year, the U.S. consumes 125 billion gallons (475 billion liters) of gasoline and 60 billion gallons (228 billion liters) of diesel fuel.¹⁴

The United States generates over 3 billion gallons (11.3 billion liters) of used frying oil annually. This equates to 5% of U.S. diesel fuel use. Using this fryer oil as a fuel stock offers a way to “jump-start” the biodiesel industry.

Each year approximately 60 million acres (24 million hectares) of U.S. cropland are left fallow. By growing rapeseed, which produces 100 gallons of oil per acre, the U.S. could feasibly grow 6 billion gallons (23 billion liters) of vegetable oil on fallow cropland. This equates to approximately 10% of U.S. annual diesel fuel usage.

By using used cooking oil and fallow cropland, the U.S. could boost biodiesel to 15% of its annual diesel fuel usage without displacing any current food production. Europeans have been using high efficiency farming techniques to double the vegetable oil production from an acre of land. Some European rapeseed yields are up to 5,000 pounds of seed per acre, compared to only 2,000 pounds per acre in the United States.¹⁵ Such high efficiency farming could double the potential fuel grown on fallow cropland in the United States. According to researchers at the University of Idaho, as much as 24% of U.S. diesel fuel could be produced from high production rapeseed grown on fallow croplands.¹⁶ This figure is encouraging, but the quantity of vegetable oil that the United States could grow from rapeseed is dwarfed by the potential quantity of fuel that could come from oil-producing algae.

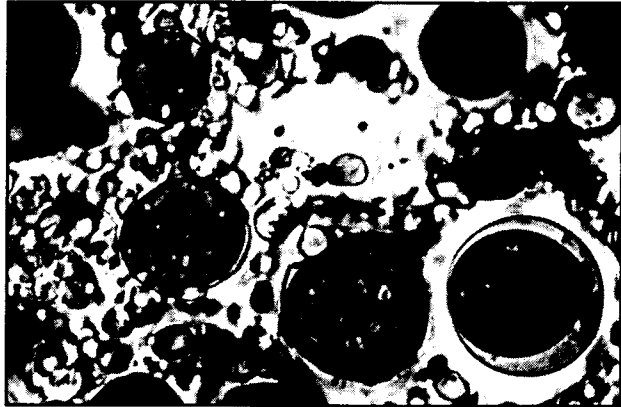
Researchers at the University of Idaho estimate that the U.S. could “grow” up to 24% of its diesel fuel without displacing any food crops.



FUEL FROM ALGAE

Algae are the most efficient biological producer of oil on the planet.¹⁷ Algae may soon be one of Earth's most important renewable fuel crops. According to research funded by the DOE, algae could produce more than enough oil to fulfill U.S. diesel fuel needs.¹⁸

Scientists at the National Renewable Energy Laboratory (NREL) have cultivated and cataloged 300 strains of algae which eat carbon dioxide and produce oil. In a \$25 million program funded by the DOE called the *Aquatic Species Program: Biodiesel from Algae*, NREL researchers established a number of algae testing ponds including a pond facility in the desert near Roswell, New Mexico.

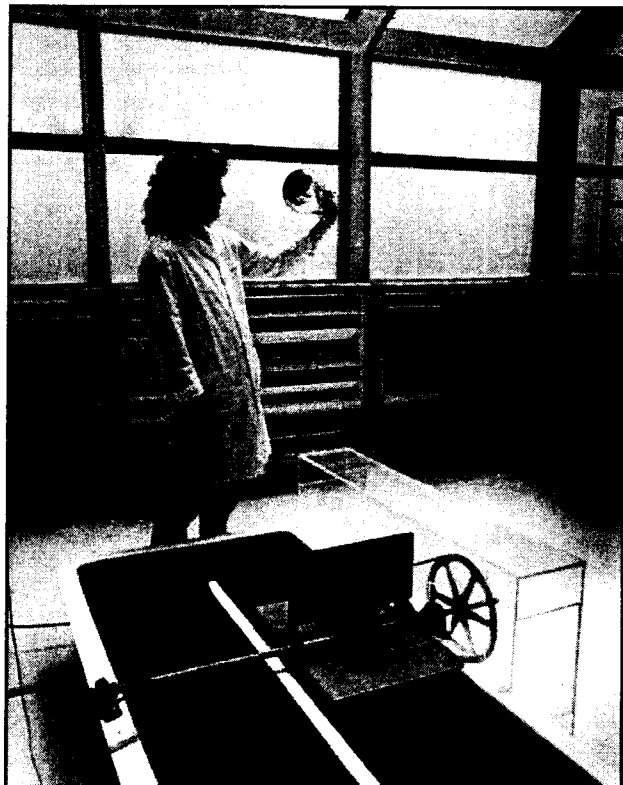


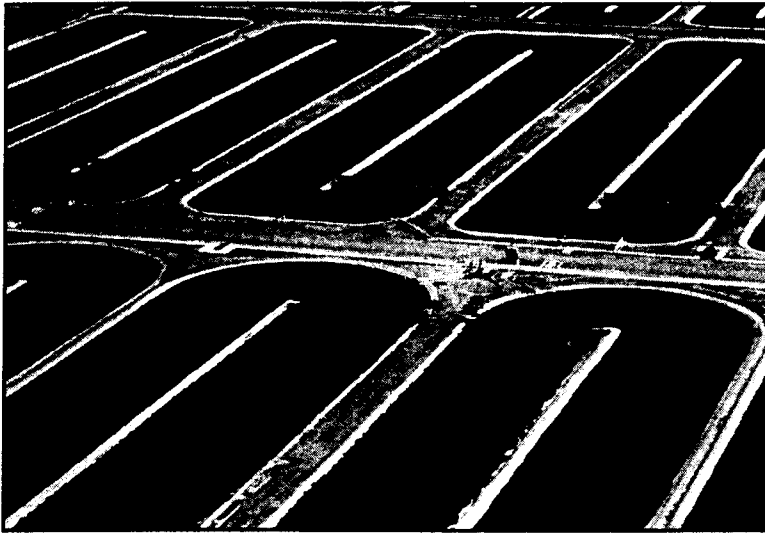
Top: Algae could provide enough oil to meet all of the diesel fuel needs of the U.S.

The quantity of oil that can be produced by algae is astonishing. At the Roswell site, diatom algae productivity reached 50 grams of algae per square meter per day. Each pond was 1,000 square meters in size. There was a possible daily yield of 50,000 grams of algae from each pond. 50,000 grams is equivalent to 50 kilograms or 110 pounds. Diatom algae are approximately 50% oil by weight. This is a possible yield of 25 kilograms of oil per day per 1,000 square meters. Per year, this equates to 9,125 kilograms or 20,075 pounds of oil per pond. Rounding up for convenience, we will assume that oil weighs 10 pounds per gallon (1.2 kilograms per liter). That means that in one pond in one year, 2,007 gallons (7,600 liters) of algal oil could be produced. Comparatively, only 50 gallons (190 liters) of oil can be produced with high-yield canola plants in 1,000 square meters of space. Even at 10% efficient oil extraction, one pond of algae would yield 200 gallons (760 liters) of algal oil per year, an increase in production over canola by a factor of 4.

Bottom: A researcher inspects a flask of algae paste. Notice the simple construction of the algae pond and paddle wheel. Photos courtesy of DOE/NREL.

The NREL researchers concluded that on 490,000 acres (200,000 hectares) of land in the U.S., 1 quadrillion BTUs, or 1 *quad*, of algal oil could be produced. One quadrillion BTUs (1,000,000,000,000,000) is approximately equal to ten billion gallons (10,000,000,000) or 3.8 billion liters of oil. According to the researchers, "algal biodiesel could easily supply several 'quads' of fuel."¹⁹ This fuel could be grown on less than 1 million acres (400,000 hectares), or 1/60th of the currently fallow cropland in the United States. The NREL researchers estimate that once an economy of scale production is reached with algae, algal biodiesel could be produced for approximately \$1.65 per gallon.²⁰





Algae cultivation can be a large scale operation such as this spirulina algae farm in southern California.

How Algae Grow

Algae could supply the fuel needs of our planet with little land and water because algae reproduce more rapidly than any other form of plant life. Algae reproduce by cellular division. They divide and divide and divide until they fill whatever space they are in or exhaust their nutrients.

Algae grow with little more than sunlight and water. Algae will grow faster if levels of carbon dioxide and nutrients are increased in algae ponds. According to NREL, algae consume more carbon dioxide than other plants. To keep the algae in their experimentation ponds alive, NREL researchers bubbled bottled carbon

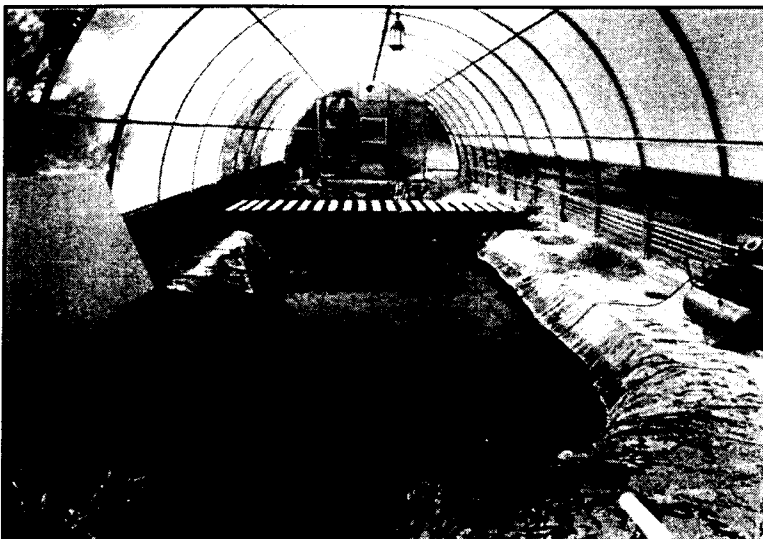
dioxide into the algae ponds. Algae ponds could use carbon dioxide emissions from power plants as a source of nutrients.

Conditions for Algae Production

The strains of diatom algae that NREL scientists experimented with grew in saline water in very hot, dry climates. The southwestern United States has many locations suitable for algae production. Earthrise Farms and Amway are the two largest producers of nutritional spirulina algae in the continental United States. Their pond farms are located in the southern California desert where daytime temperatures reach 120° F (50° C).

Algae grow in a wide variety of climates and conditions. This simple polytunnel contains a small pond which produces both spirulina algae and fish. Photo courtesy of Ecogenics, Inc.

Since oil-producing algae can grow in saline water, there is no competition for water between algae agriculture and food agriculture. In addition, the areas targeted for the highest production per acre of algae are desert climates which are largely unused and unsuitable for traditional food crop cultivation. Algae can also be grown in wastewater treatment facilities.²¹



Algae cultivation is not limited to hot, dry climates and algae can also grow in fresh water. Algae are capable of growing in and adapting to numerous climates and growing environments. There are algae cultivation ponds across the United States in such places as Pennsylvania, Tennessee, Florida, and Oregon.

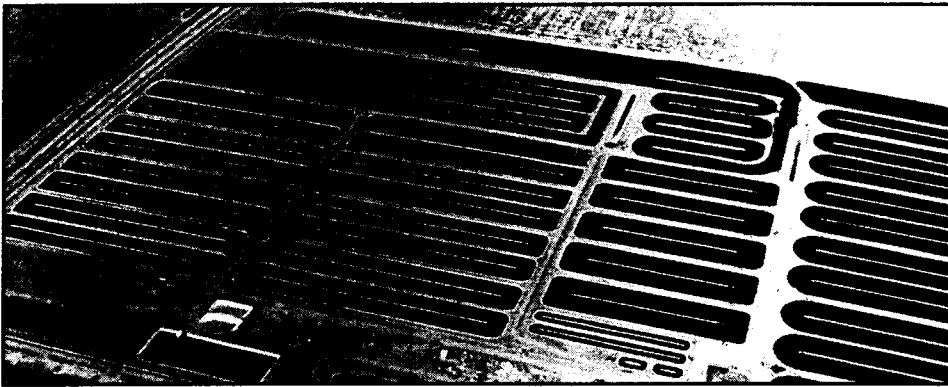
Processing Algae into Fuel

Several processes for algal oil extraction have been developed. The simplest process, called *physical extraction*, uses a filter or a chemical to separate the algae from the water in which they grow.²² The filter or chemical forces the algae to clump together, resulting in algae paste.

The paste is then spun in a large three-phase centrifuge to extract more moisture. The last step of the process is to use a solvent which is used in soybean oil extraction to extract the oil from the protein and carbohydrate parts of the algae. *Thermochemical liquification* is another method of algal oil extraction. This process converts algae into oil by using high heat and pressure.²³ Algal oil extraction methods have achieved oil yields of 30-40%.²⁴

The Future of Algal Oil

Due to the simplicity of algae cultivation and processing, algal oil-based biodiesel will soon become reality. In the words of the scientists who wrote the closing report for the DOE on their research with algae, "...this report, should not be seen as an ending, but as a beginning. When the time is right, we fully expect to see renewed interest in algae as a source of fuels and other chemicals."²⁵ The time for interest and research into algal fuel is now.



Aerial view of the world's largest algae farm. This farm encompasses 108 acres of spirulina algae ponds. Facilities such as this one may one day "grow" much of the world's fuel. Photo courtesy of Earthrise Farms.

SECTION TWO

DO-IT-YOURSELF EXPERIMENTS

C H A P T E R 6

H O W T O M A K E B I O D I E S E L

This chapter will familiarize you with the chemical process of making biodiesel. The process will work for making biodiesel in any quantity. In the next chapter we give instructions for constructing a small scale biodiesel processor.

Homemade biodiesel can fuel any Diesel engine, but it is up to the biodiesel maker to determine whether it is safe to use the biodiesel in a Diesel engine. We have traveled thousands of miles on homemade biodiesel fuel. Nevertheless, it is best to test experimental fuel in an inexpensive engine like a Diesel model aircraft engine which can be purchased from a hobby store.

TRANSESTERIFICATION

The process of making biodiesel from vegetable oil is called *transesterification* (trans-ester-ification). Transesterification is the transformation of one type of an *ester* into another type of ester. An ester is a hydrocarbon chain that will bond with another molecule.

A vegetable oil molecule is made up of three esters attached to a molecule of glycerin. To imagine a vegetable oil molecule, picture an octopus with only three legs.

A vegetable oil molecule is made up of three esters attached to a molecule of glycerin. To imagine a vegetable oil molecule, picture an octopus with only three legs. The head of the octopus is the glycerin. The three legs are the esters. Vegetable oil is called a *triglyceride*. Tri refers to the three esters and glyceride refers to glycerin. Vegetable oil is also called *glycerol esters*.

About 20% of a vegetable oil molecule is glycerin. Glycerin is also called glycerine, glycerol, and glyceride. Glycerin makes vegetable oil thick and sticky. During transesterification, glycerin is removed from vegetable oil to make the oil thinner, or to reduce its viscosity.

The Alcohol

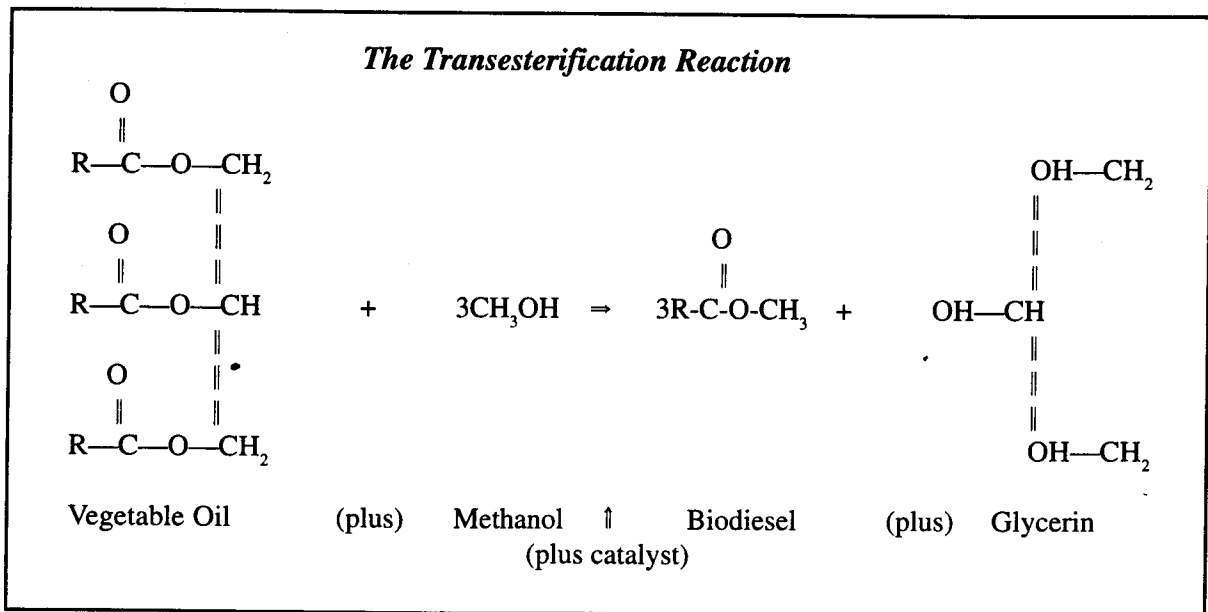
To make biodiesel, the esters in vegetable oil are separated from the glycerin. The esters are the basis for biodiesel fuel. During the transesterification process, the glycerin component of vegetable oil is replaced with an alcohol. Either ethanol alcohol or methanol alcohol can be used. Ethanol is an alcohol made from grains. Methanol is an alcohol that can be made from coal, natural gas, or wood. We prefer methanol to ethanol because it produces a more stable biodiesel reaction. However, methanol is an aggressive alcohol which dissolves rubber, can be fatal if swallowed, and requires extreme caution when handled.

Methyl esters refers to biodiesel that is made from methanol and vegetable oil esters. *Ethyl esters* refers to biodiesel that is made from ethanol and vegetable oil esters. *Alkyl esters* is a more general term which refers to any combination of alcohol and vegetable oil esters. Regardless of which alcohol or type of vegetable oil is used, the biodiesel reaction always involves breaking each triglyceride molecule into three esters and one glycerin molecule. Each of the three esters attaches to some alcohol. From one triglyceride molecule we get three alkyl ester molecules.

The Catalyst

In order to break triglycerides, or “crack” vegetable oil, a *catalyst* is added to the vegetable oil. A catalyst is a substance that initiates a reaction between other substances. The possible catalysts for the biodiesel reaction are sodium hydroxide (NaOH) and potassium hydroxide (KOH). Sodium hydroxide is a white substance commonly called lye or caustic soda. Potassium hydroxide can be used if sodium hydroxide is not available. Both come in powdered, granular, or pelletized form. Both are dangerous chemicals and should be handled with extreme care. Sodium hydroxide and potassium hydroxide can damage skin, eyes, and lungs and can be fatal if swallowed.

The catalyst for the biodiesel reaction will break the triglycerides and release the esters. Once the esters are free, they will combine with the alcohol. The catalyst will combine with the glycerin, which will fall to the bottom of the biodiesel reaction container. The biodiesel reaction produces alkyl esters and glycerin soap.



The pH Scale

The pH scale is a way of measuring the strength of acids and bases. The pH scale is numbered 0 through 14. 7 is neutral, or equal to pure water. Numbers below 7 on the pH scale show that a liquid is acidic. Numbers above 7 on the pH scale show that a liquid is basic. The lower the pH number, the stronger an acid a liquid is. The higher the pH number, the stronger a base a liquid is.

The rule of thumb with pH is that opposites attract and react. For example, the biodiesel reaction occurs between an acid and two bases. Vegetable oil is an acid. The alcohol and the catalyst are both bases. The amount of catalyst used in the biodiesel reaction will depend on the pH of the vegetable oil. The success of the biodiesel reaction depends on your ability to measure the pH, or the acidity, of vegetable oil.

Free Fatty Acids

Fats and oils are sometimes called *fatty acids* because they are acidic. Used vegetable oil is more acidic than new vegetable oil because it has been heated or fried. When vegetable oil is heated in the presence of hydrogen, it becomes *hydrogenated*.

Free fatty acids result from frying vegetable oil.

These fatty acids float amongst the triglycerides, “free” to attach themselves to anything basic. Free fatty acids increase the gelling temperature of vegetable oil. That is why hydrogenated vegetable oil is solid at room temperature. When making biodiesel, it is important to eliminate free fatty acids.

To eliminate the free fatty acids in used cooking oil, more catalyst is used in the biodiesel reaction. This is called *neutralizing* the free fatty acids. Neutralize means to take back to neutral. How much catalyst is used depends on how acidic the oil is.

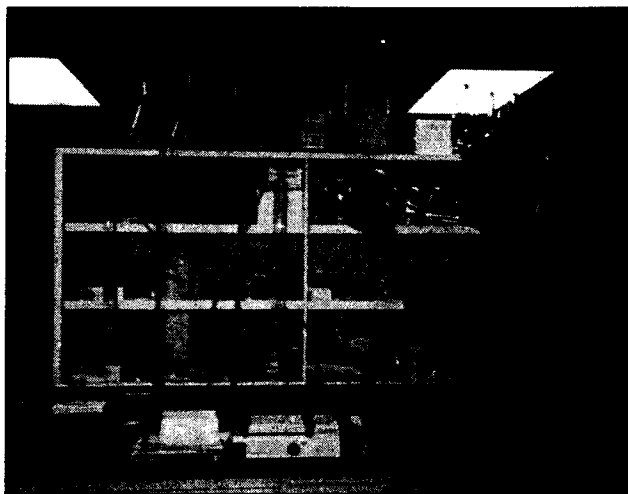
SUPPLIES FOR A BIODIESEL BLENDER REACTION

It is best to start with a small reaction when learning how to make biodiesel. This section lists the supplies needed to make a small batch of biodiesel in a blender. In the next chapter we give instructions for constructing a small scale biodiesel processor. A small scale biodiesel processor is essentially a “big blender.” The steps for making biodiesel in a small scale processor are the same as the steps for making biodiesel in a blender. The only difference is that in a small scale biodiesel processor, the vegetable oil, alcohol, and catalyst are mixed together for 1 hour instead of 15 minutes.

A Work Space

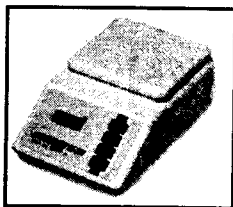
The best place to make a blender of biodiesel is in a chemistry lab. If a lab is unavailable, a clean garage or workshop is the next best place to make biodiesel. Have a hose or other means of performing an emergency eye wash available in case a reactant splashes. Also, be prepared to wash any body part which comes in contact with methanol or lye. The work space should be clean and free from unnecessary objects. There should be nothing on the ground to trip on. Have some vinegar on hand to neutralize any methanol or lye that may spill.

The amount of catalyst used in the biodiesel reaction will depend on the pH of the vegetable oil. The success of the biodiesel reaction depends on your ability to measure the pH, or the acidity, of vegetable oil.



A lab is the best place to make a blender of biodiesel.

This digital scale is sensitive to 0.01 grams.



Scale

Use a scale sensitive to at least 1 gram. Triple beam balance scales, digital scales, and small pocket scales can all be used. Edmund Scientific sells a number of good scales including a pocket-sized scale sensitive to 0.01 grams for \$10. You can find Edmund Scientific in the Resource Guide.



Litmus Paper or pH Meter

Litmus paper measures pH. Litmus paper comes as little strips of paper with different color bars on them. When litmus paper is dipped into a liquid, it changes color. The colors of the paper are matched to a color chart which tells the pH of the liquid. Litmus paper is available at pharmacies and can be ordered through chemical supply companies. Litmus paper is usually inexpensive. A more expensive tool for measuring pH is a digital pH meter, which is available through Edmund Scientific or a laboratory supply company.

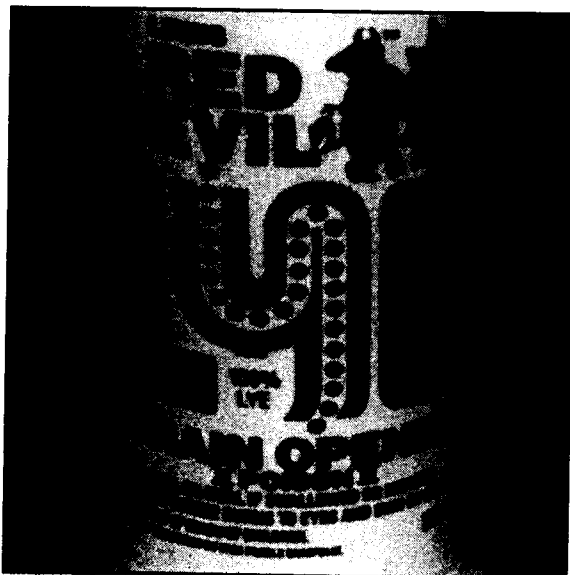
Blender

Buy a blender with a glass container. Make sure the blender is not used for food after it has been used to make biodiesel.

A digital pH meter is expensive but gives an exact measurement.

Safety Wear

The alcohol and the catalyst used to make biodiesel are both strong bases. To avoid contact with these chemicals, wear gloves, goggles, and protective clothing when handling the chemicals and performing the reaction. Goggles, chemical resistant gloves, surgical gloves, and plastic aprons can be purchased at a hardware store. Goggles should go all the way around the eyes in case something splashes from the side or from below. During the biodiesel reaction, wear long pants, shoes, and a long sleeved shirt. Hair should be tied back. Remove all dangling jewelry.



Lewis Red Devil Lye can be found in most grocery stores and hardware stores in the U.S.

Lye or KOH

Sodium hydroxide, or lye, is usually stocked in a good lab. Lye is also called caustic soda. Buy only 100% pure, undiluted lye. It can be in either flake or granule form, but not in liquid form. Lye is available at hardware stores and grocery stores. Lewis Red Devil Lye Drain Opener is the most common brand in the U.S. In Australia, look for Record Caustic Soda. In Canada, look for Gillette's. A 12 ounce (340 gram) container of lye costs about \$3. This is enough to make between 12 and 25 gallons (45-95 liters) of biodiesel. Both sodium hydroxide and potassium hydroxide (KOH) are available through chemical distributors and companies that sell soap-making supplies.

Only buy lye in a container with a tight, unbroken seal. Shake the container before you buy it to make sure the lye has not formed clumps. At your lab or workshop, put the container in a ziplock bag and keep it in a cool, dry place. Lye will quickly absorb moisture from the air and become useless. Keep lye out of the reach of children.

Methanol or Ethanol

Methanol is also known as methyl alcohol. Methanol is as clear as water and more flammable than gasoline. Methanol must be put in a container which is made to carry fuel. Plastic, red fuel containers are suitable. Label methanol clearly. If methanol is swallowed, it can be fatal.

Methanol is sold at racetracks as a motor racing fuel for between \$1.50 and \$2.50 a gallon. One gallon of methanol is enough to make 5 gallons of biodiesel. Racetracks are listed in the phone book under automotive racing, racetracks, or fuel. Methanol is also sold at model and hobby shops as fuel for model cars and planes. Only buy a container which says "100% methanol." Do not buy anything which contains isopropyl alcohol, methylated spirits, or mineral spirits.

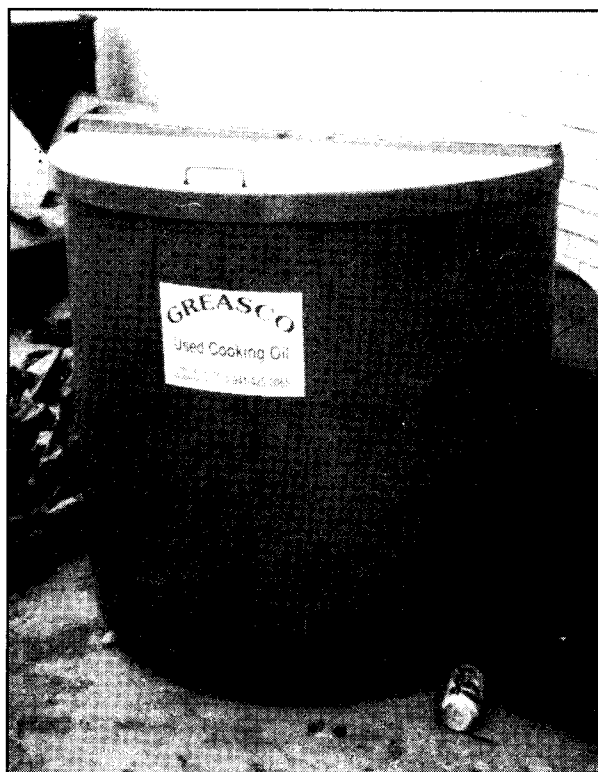
Finding methanol can be tricky. Sometimes it is necessary to call all of the automotive and racing stores in an area. A person who has a race car will usually have a drum of methanol from which they will sell smaller quantities.

Methanol is preferable to ethanol for the biodiesel reaction because methanol produces a more reliable biodiesel reaction. Methanol is also less affected by water in the vegetable oil than ethanol and therefore tends to react with greater predictability. At the time of writing, methanol is easier to obtain than ethanol in the United States. Nevertheless, biodiesel can be successfully made with ethanol. Ethanol is less toxic than methanol and is always produced from a renewable resource. Both methanol and ethanol are sold by chemical distributors, which can be found in a phone book under chemicals. Some manufacturers and distributors of ethanol and methanol are listed in the Resource Guide.

A container of used cooking oil can be found behind most restaurants.

Used Cooking Oil

Used cooking oil is usually put into a container behind a restaurant where it will be picked up by a grease collection truck. However, restaurant workers can usually be persuaded to put the used cooking oil directly into 5 gallon (19 liter) plastic jugs or buckets. Approach the manager of a restaurant during the morning before lunch. Explain your "science project" and tell the manager you are looking for a restaurant to "sponsor" you by giving you some of their used cooking oil. Ask them when they empty their fryers and ask if you can return at that time to put some used cooking oil into your containers. If that is not possible, ask if you can leave your containers and have the restaurant workers fill the containers at their convenience. They can call you when it is time to pick up the containers, or you can arrange a time in advance. It is possible to scoop out used cooking oil from the container behind the restaurant, but that is a messy procedure. It is better to obtain the oil directly from the fryer if possible.





Conical restaurant fryer filters are excellent for removing food particles from used cooking oil. The filter on the right is new. The filter on the left has filtered 5 gallons of used cooking oil.

If possible, establish a routine with the restaurant workers so that they filter the oil before you pick it up. Most modern fryers have a built-in filter. If the restaurant cannot filter the oil, it is best to get the oil still warm. However, do not get oil which exceeds 120° F (50° C). Pick up the warm oil and take it to your work space. Pour the oil through some pantyhose, a tightly woven mesh screen, or a restaurant fryer filter. Restaurant fryer filters are large, conical filters which can be purchased at a restaurant supply store. Pour the used cooking oil through the filters a few times to remove any food particles from the oil.

Other Supplies

Paper towels
 small pump (condiment pump, fountain pump, or hand pump) or a ladle
 Marker
 Masking tape
 One 20 ml beaker
 Two 500 ml beakers
 Three 1500 ml beakers
 small dish or container for measuring lye (such as a petri dish)
 graduated eyedropper with 1 milliliter graduations
 1500 ml glass container with a stopcock (optional)

Chemicals

1 liter of new or used vegetable oil
 1 bottle of unopened isopropyl alcohol (rubbing alcohol)
 200 ml of methanol (CH₃OH)
 1 container of unopened lye (NaOH)
 1 liter of distilled water

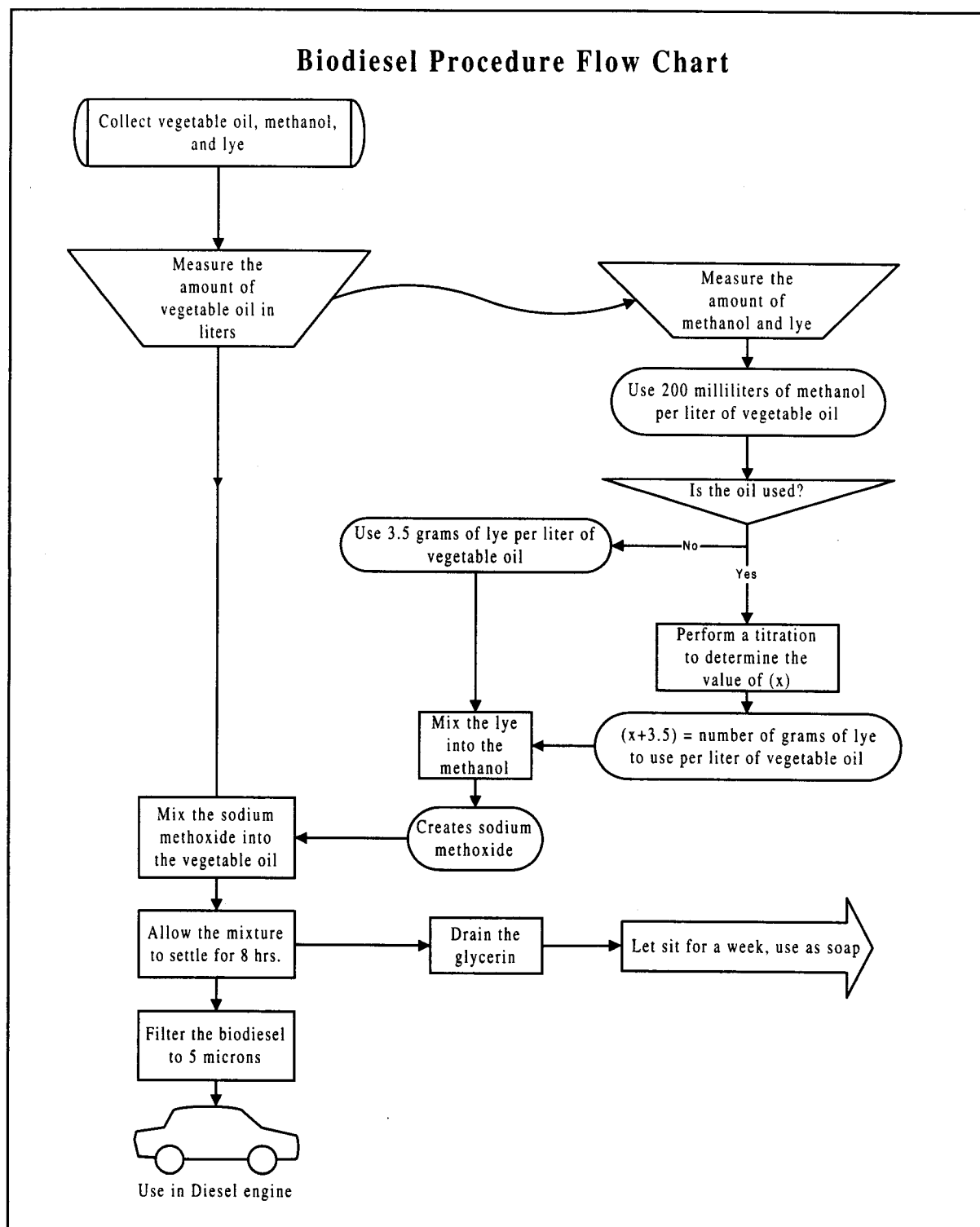
TRANSESTERIFICATION PROCEDURE

This section gives the procedure for making biodiesel in a blender. The same process and proportions are used when making biodiesel on a larger scale. See Appendix 6 for large biodiesel formulas.

The amount of methanol used in the biodiesel reaction is 20% of the volume of the vegetable oil. This equals 200 milliliters of methanol per liter of vegetable oil. The amount of lye used in the biodiesel reaction is 0.35% of the volume of the vegetable oil plus extra if you are using used cooking oil.¹ This equals 3.5 grams of lye per liter of vegetable oil plus extra lye to neutralize the free fatty acids in used cooking oil. To find out how much extra lye is needed when you are using used cooking oil, you must perform a titration.

The procedure for making biodiesel in a blender is as follows:

1. Determine the amount of catalyst needed for the batch of oil.
2. Measure the quantity of methanol, lye, and vegetable oil.
3. Dissolve the lye into the methanol by mixing for up to 5 minutes.
4. Mix the sodium methoxide with the vegetable oil for 15 minutes in a blender.
5. Allow the glycerin to settle to the bottom of the blender.
6. After 8 hours, separate the biodiesel from the glycerin.
7. Clean the work area and store the leftover chemicals.



Pre-Procedure Check

Read the entire lab procedure from start to finish before you perform any steps. Check to make sure that you have everything on the lab equipment and chemicals lists. Make sure that your work space is clean and free of obstructions. Make sure there is a hose or shower nearby and that there is nothing to trip on. Put your gloves and your goggles on.

STEP 1. DETERMINE THE QUANTITY OF CATALYST

A *titration* is a method of determining how much catalyst is needed to neutralize the free fatty acids in used vegetable oil. A titration is a reaction between the catalyst and the vegetable oil. Isopropyl alcohol is used in the titration instead of methanol because isopropyl alcohol will not react with vegetable oil. Later in this chapter, we give an alternative method for determining the amount of catalyst to use in a biodiesel reaction. Be careful when doing the titration procedure, it is easy to make a mistake.

To perform a titration, dissolve 1 gram of lye into 1 liter of distilled water and dissolve 1 milliliter of vegetable oil into 10 milliliters of isopropyl alcohol. Then, drop the diluted lye into the diluted vegetable oil, one milliliter at a time. After each milliliter, measure the pH of the diluted vegetable oil. When the pH rises significantly, the free fatty acids will be neutralized.

For instance, the diluted vegetable oil might have an initial pH reading of 5. After one milliliter of lye/water is added, the pH might still be close to 5. After two milliliters of lye/water are added, the pH might suddenly rise to 8 or 9. The increase in pH means that the free fatty acids have been neutralized.

The final pH should be between 8 and 9. When the pH has increased to between 8 and 9, count the number of milliliters of lye/water which were added to the diluted vegetable oil. The number of milliliters will equal the number of extra grams of lye to use per liter of vegetable oil in the biodiesel reaction. The lye used for the titration must be the same lye used for the batch of biodiesel.

Titration

Skip the titration if you are using new vegetable oil. The steps for the titration are as follows:

1. Measure 1 gram of lye onto a petri dish on a scale.
2. Measure 1 liter of distilled water into a 1500 ml beaker.
3. Pour the 1 gram of lye into the 1 liter of water.
4. Label this beaker with a piece of masking tape and a marker "lye/water solution, do not drink."
5. Measure 10 ml of isopropyl alcohol into a 20 ml beaker.
6. Dissolve 1 ml of used vegetable oil into the isopropyl alcohol.
7. Label this 20 ml beaker "oil/alcohol solution."
8. Use a graduated eyedropper to drop 1 milliliter of the lye/water solution into the oil/alcohol solution.
9. After 1 milliliter of lye/water solution is added, check the pH of the diluted vegetable oil. Do this by inserting the strip of litmus paper into the oil/alcohol container. Compare the litmus strip's color with the color chart. Or use a pH meter to get an immediate reading.
10. Repeat steps 8 and 9, counting the milliliters of lye/water solution you add, until the oil/alcohol reaches a pH of between 8 and 9. The pH increase will usually occur suddenly. You will usually add no more than 3 milliliters of lye/water solution.

11. Use the following equation:
- the number of milliliters of the lye/water solution dropped into the oil/ alcohol mixture = (x).
 - $(x + 3.5) = L$.
 - L = the number of grams of lye necessary to neutralize and react one liter of used vegetable oil.
 - L will usually be between 4.5 and 6.5, but it can be higher if the oil has been used for a long time.

STEP 2. MEASURE THE REACTANTS

Measure the reactants in separate containers.

For new vegetable oil measure:

1 liter of new oil into a 1500 ml beaker
 200 ml of methanol into a 500 ml beaker
 3.5 grams of lye onto a petri dish on a gram scale

For used vegetable oil measure:

1 liter of filtered used oil into a 1500 ml beaker
 200 ml of methanol into a 500 ml beaker
 L grams of lye onto a petri dish on a gram scale

STEP 3. DISSOLVE THE LYE INTO THE METHANOL

The third step is to combine the methanol with the lye to create sodium methoxide, an extremely strong base. Once the lye is dissolved in the methanol, the sodium methoxide must be mixed with the vegetable oil right away.

1. Make sure the blender is properly put together and that it is sealed down on the base tightly. To make sure the blender is sealed, fill it with water and blend on low speed for a few seconds. If there are no leaks, pour the water out and continue.
2. Carefully pour the methanol into the opened blender. Make sure not to spill any on yourself or on your work space. If any methanol spills, clean the spill with a wet paper towel and some vinegar.
3. Carefully pour the lye into the blender.
4. Put the top securely on the blender. Blend on the lowest setting for thirty seconds or until all of the lye is dissolved in the methanol. There is now sodium methoxide in the blender. Be careful.

STEP 4. MIX THE REACTANTS

1. Carefully open the blender and put the top to the side. Keep your face away from the top of the blender.
2. Carefully pour the vegetable oil into the blender.
3. Put the top back on the blender. Blend on the medium or high setting for 15 minutes. If the blender motor or the container get excessively hot, turn the blender off.

STEP 5. ALLOW THE GLYCERIN TO SETTLE

Settling takes about 8 hours. Since about 75% of the separation occurs within the first hour after the reaction, you will be able to see immediate progress. Within 8 hours, the glycerin will fall to the bottom of the blender. The layer of liquid on top of the glycerin is methyl esters, or biodiesel. There will be a visible difference between the top and bottom layers. The top layer will be a lighter color than the bottom layer. There may be anywhere from 5-20% glycerin settled on the bottom of the blender.

With a Stopcock Container

1. If you have a 1500 ml container with a stopcock, set it where it can sit for 8 hours. It should have space enough to open the stopcock and drain the contents into another container.
2. Make sure the stopcock does not leak by partially filling the container with water and opening and closing the valve. If there are no leaks, make sure the valve is closed and the container is dry.
3. Pour the contents of the blender into the container.
4. Wait at least 8 hours.

With the Blender

1. If you do not have a container with a stopcock, unplug the blender and leave it. You can label it "biodiesel reaction in progress, do not drink."
2. Wait at least 8 hours.

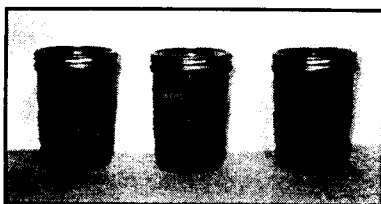
STEP 6. SEPARATE THE GLYCERIN AND THE BIODIESEL***With a Stopcock Container***

If you have a container with a stopcock, put a 500 ml beaker or similar container under the stopcock and open the valve slowly. Drain the glycerin and shut the valve when the glycerin has completely drained. It is alright if you get a small quantity of biodiesel in the glycerin. The remaining liquid in the stopcock container is biodiesel.

With the Blender

If you let your biodiesel settle in the blender, do not just pour the biodiesel out. If you do this, you will pour the glycerin as well, and the biodiesel and glycerin will mix. To pump the biodiesel out of the blender, use either a small electric pump or a hand pump. A small water circulation pump from a fountain will work. If you do not have a small circulation pump, get an industrial-sized condiment hand pump from a cafeteria. Make sure the condiment pump is clean. Pump the biodiesel into a 1500 ml beaker. You can also use a ladle to scoop off the biodiesel, but don't stir up or scoop out any of the glycerin which has settled to the bottom of the blender.

The difference between the biodiesel and the glycerin will be obvious after 8 hours. The jar on the left contains only biodiesel. The jar in the middle contains a layer of biodiesel and a layer of glycerin. The jar on the right contains only glycerin.

**STEP 7. CLEANUP**

1. Put leftover methanol in a clearly labeled bottle.
2. Store leftover lye in a cool, dry place.
3. Put leftover used oil in a dark container and store it in a cool, dry place.
4. Expose the glycerin to air and sunlight for 1 week and then use it as soap.
5. Clean all of the equipment. Do not use the blender for food again.

GLYCERIN

The glycerin produced during small scale biodiesel production can be used as a degreasing soap without any further processing. The glycerin can also be composted or put on the ground where it will quickly be consumed by natural bacteria and microbes. The glycerin is biodegradable, non-toxic, contains no PCBs, and it will not harm animal or plant life. Most of the alcohol in the glycerin will evaporate if the glycerin is left in the sun for a week. Fragrances and other soap agents can be added to the glycerin. Recipes for glycerin soap are given in Appendix 7.

Pure glycerin is used to make hundreds of products and can be very expensive. However, the glycerin produced during transesterification contains many impurities. Most of the catalyst and some unreacted alcohol in the biodiesel reaction fall into the glycerin. The glycerin can also contain food particles, water, and other impurities which were in the vegetable oil.

To remove all of the alcohol from the glycerin, the glycerin must be heated in an open container in a well ventilated area. If methanol was used in the biodiesel reaction, the glycerin must be heated beyond the boiling point of methanol, which is 148° F (65° C). If ethanol was used in the biodiesel reaction, the glycerin must be heated beyond the boiling point of ethanol, which is 175° F (79° C). To remove all of the water from the glycerin, the glycerin must be brought to a boil for at least 10 minutes. When heated, the glycerin will become liquid. In an industrial scale biodiesel facility, the alcohol can be recovered from the glycerin by distillation. The glycerin can then be purified and sold.

USING KOH INSTEAD OF NAOH

Potassium hydroxide (KOH) works as well as or better than lye in the biodiesel reaction. KOH is slightly less toxic than lye. The byproduct of biodiesel made with KOH is glycerin which contains potassium. This byproduct can be used as a component in potassium phosphate fertilizer. Whereas lye is only 0.35% of the volume of the vegetable oil in the biodiesel reaction, KOH should be at least 0.90% of the volume of the vegetable oil.² For example, instead of using 3.5 grams of lye per liter of vegetable oil, you would use 9 grams of KOH per liter of vegetable oil.

The titration is performed the same way when using KOH, but every place that it calls for lye, KOH is used instead. In the titration, 1 gram of KOH is put into 1 liter of distilled water. For every milliliter of KOH/water solution that is dropped into the oil/alcohol, 1 gram of KOH is added to the reaction. The reaction formula for KOH is $(x + 9) = K$. K is the number of grams of KOH to use with one liter of used vegetable oil. K will usually be between 10 and 13 grams. At times, K will be as high as 20 grams per liter. Double check the titration if you think you need more than 15 grams of KOH per liter of oil just to make sure.

USING ETHANOL INSTEAD OF METHANOL

Whereas we use 20% methanol by volume of the vegetable oil to perform the biodiesel reaction, it is necessary to use 30% ethanol.³ The ethanol used to make biodiesel must be *anhydrous*, or without water, since water will disrupt the biodiesel reaction. The ethanol should also be 200 proof, 100% pure ethanol. We do not recommend using ethanol that has been denatured with gasoline.

TRIAL AND ERROR MINI BATCHES

The purpose of making a mini batch of biodiesel is to ensure that you have calculated the correct amount of catalyst to use per liter of vegetable oil. A mini batch of biodiesel will indicate whether or not a large biodiesel reaction will succeed using the amount of catalyst you calculated. A mini batch of biodiesel should always be made before any large biodiesel reaction.

Mini batches of biodiesel can also be used in place of a titration. To determine the amount of catalyst needed for a sample of used vegetable oil, make a series of trial and error mini batches of biodiesel with slightly different amounts of catalyst. The mini batch which succeeds in producing two distinct layers will indicate how much catalyst to use per liter of used vegetable oil in a large biodiesel reaction. The mini batch must be made using the same vegetable oil, alcohol, and catalyst that will be used in the large reaction.

A mini batch of biodiesel is usually 100 milliliters or 500 milliliters of vegetable oil. The mini batch reaction can be done in a blender, in a jar which you shake by hand, or in a container on top of a magnetic stirrer. A scale sensitive to 0.01 grams is needed when using lye. A scale sensitive to 0.1 grams can be used with KOH. Either new or used vegetable oil can be used in the mini batch reaction.

The procedure for trial and error mini batches is as follows:

1. Dissolve 0.35 grams of lye into 20 milliliters of methanol.
2. Add 100 milliliters of vegetable oil to the mixture.
3. Mix vigorously for 5-15 minutes.
4. Allow to settle for 30 minutes-2 hours. Did two separate layers occur? If yes, use 3.5 grams of lye per liter of vegetable oil. If no, go to step 5.
5. Dissolve 0.45 grams of lye into 20 milliliters of methanol.
6. Add 100 milliliters of vegetable oil to the mixture.
7. Mix vigorously for 5-15 minutes.
8. Allow to settle for 30 minutes-2 hours. Did two separate layers occur? If yes, use 4.5 grams of lye per liter of vegetable oil. If no, try again using 0.55 grams of lye.

In the next step, you add 0.55 grams of lye to the methanol and continue the process. Each time the layers do not separate, increase the amount of catalyst used by 0.1 grams. The layers will usually separate using between 0.35 and 0.65 grams of lye. When using KOH and methanol, begin by mixing 0.9 grams of KOH into 20 milliliters of methanol and adding 100 milliliters of vegetable oil. Then try 1 gram of KOH, 1.1 grams of KOH, and so on. When using ethanol instead of methanol, use 30 milliliters of ethanol with 100 milliliters of vegetable oil.

WATER WASH

The purpose of washing biodiesel with water is to remove any unreacted alcohol, catalyst, and glycerin which may be left in the biodiesel after the reaction. In a complete biodiesel reaction, a water wash is unnecessary because 99.9% of the catalyst and glycerin settle at the bottom of the reaction container and are removed with the glycerin layer.

The concentration of unreacted alcohol in unwashed biodiesel is typically 50,000-100,000 parts per million (5-10%).⁴ The advantage of leaving the unreacted alcohol in the biodiesel is that the alcohol acts like a fuel additive by increasing the energy contained in the biodiesel. Vehicles with synthetic fuel hoses will not be negatively affected by unreacted alcohol in biodiesel. The disadvantages of leaving unreacted alcohol in biodiesel are that the alcohol will increase wear on rubber fuel hoses in some vehicles, the alcohol will decrease the flashpoint of the biodiesel, and biodiesel which contains more than 0.2% alcohol does not meet ASTM standards. Washing biodiesel with water is an effective way to reduce alcohol levels to below 2,000 parts per million (0.2%).

Washing biodiesel with water will also remove any soap from the biodiesel. If too much catalyst was used in the biodiesel reaction and the reaction produces a biodiesel layer, a glycerin layer, and an additional milky layer, there is probably soap in the biodiesel. If the milky layer is 10% or more of the total mixture, the biodiesel should be washed.

We recommend washing biodiesel with water only if your vehicle has rubber fuel hoses, if your biodiesel reaction produced a significant milky layer, or if you are making biodiesel to meet ASTM specifications. In most cases, a water wash is an unnecessary procedure. The water wash adds a tremendous amount of time to the biodiesel process. In addition, washing biodiesel with water removes alcohol which boosts the energy contained in the biodiesel. For these reasons, we do not wash our biodiesel. Our vehicles have never experienced any problems as a result of using unwashed biodiesel.

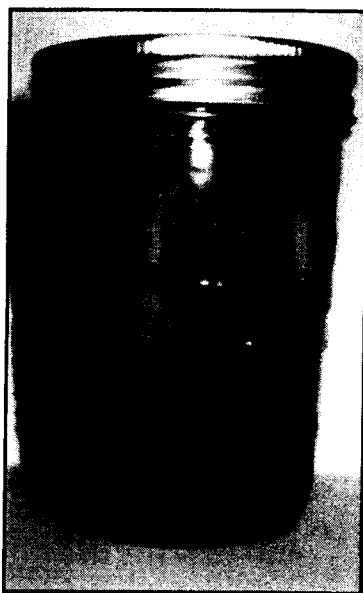
If you decide to perform a water wash, follow these steps:

1. After the glycerin settles to the bottom of the container, measure the pH of the biodiesel layer. The pH of unwashed biodiesel will be about 9.
2. Drain the glycerin from the container.
3. Using a shower head or lawn sprinkler, slowly sprinkle water into the biodiesel container until there is an equal amount of water and biodiesel in the container. To decrease the settling time of the water wash, 10 milliliters of acetic or tannic acid can be added to each liter of water before the water is sprinkled into the biodiesel. Adding acid is optional and not necessary for an effective water wash.
4. Agitate the biodiesel and water gently for 5 minutes. The biodiesel and water will form a white, milky mixture.
5. Allow the water to settle out of the biodiesel. This will take several days.
6. Once the mixture has settled, the biodiesel will be floating on top of the water. There will also be a murky middle layer. First drain the water. The water layer contains a very diluted amount of alcohol but it is not toxic. It can be drained onto the ground or into any wastewater drain. Drain the murky middle layer into a separate container. The murky middle layer will eventually settle into biodiesel and water.
7. Measure the pH of the biodiesel. The biodiesel should have a pH close to 7.
8. Although washing the biodiesel one time is almost always sufficient, the biodiesel can be washed up to 3 times to purify it further.

TESTING BIODIESEL

Gas chromatography and other ASTM tests which determine the quality of biodiesel are very expensive. It can cost between \$600 and \$1,000 to have one gallon of biodiesel tested by a laboratory. However, you can perform a number of simple tests to determine the characteristics of biodiesel.

The layers of biodiesel and glycerin in this jar indicate the biodiesel reaction was successful.



Visual Inspection

A visual inspection of the reaction layers will indicate if the biodiesel reaction was successful. A successful reaction results in two distinct layers. The top layer will usually be 80-90% of the product. The top layer will be lighter in color than the bottom layer. This top layer is the biodiesel, or esters. The bottom layer will usually be 10-20% of the product. The bottom layer will be significantly darker than the top layer. The bottom layer is a thick mixture of glycerin, catalyst, and alcohol. If used cooking oil was used to make the biodiesel, the bottom layer may also contain some food particles.

If there is a significant milky middle layer (10% or more), the reaction has produced soap. This is a result of water in the vegetable oil or the addition of too much catalyst. The biodiesel from such a reaction is usable, but it should be washed with water before being put into an engine.

If the reaction was unsuccessful, the mixture will be a homogenous gel or soap.

Cloud Point and Gel Point

To determine the cold weather characteristics of biodiesel, test a sample of the biodiesel in a refrigerator or freezer. Take the biodiesel out of the freezer every 15 minutes, measure the temperature, and look for signs of clouding. When crystals begin to form in the biodiesel, it has reached the cloud point. When the biodiesel turns into a gel, it has reached the gel point.

Specific Gravity

Specific gravity is a measurement of the density of a liquid. Testing the specific gravity of biodiesel will provide more information about how the fuel will perform in a Diesel engine than any other single test. Specific gravity is tested to see how dense the fuel is. The density of the fuel is related to the viscosity of the fuel.

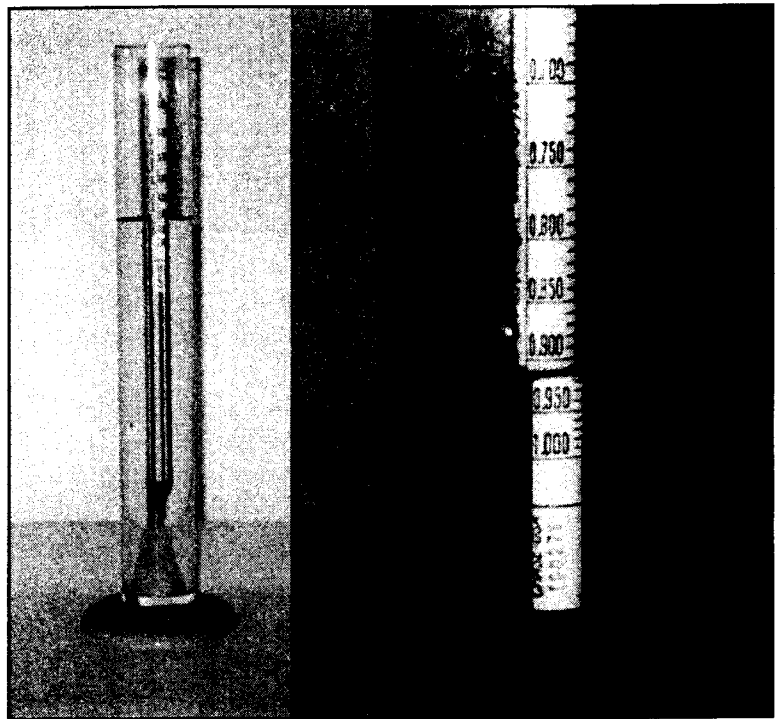
Diesel #2 fuel has a specific gravity of approximately 0.830 at 60° F (15° C) and a Kinematic viscosity of approximately 2.2 at 104° F (40° C).⁵ In contrast, rapeseed oil has a specific gravity of approximately 0.920 at 60° F (15° C) and a Kinematic viscosity of 50 at 104° F (40° C).⁶ Hence, a small increase in specific gravity can indicate a large increase in viscosity.

According to the 1999 ASTM standards for biodiesel, biodiesel should have a specific gravity of no more than 0.900 at 60° F (15° C) and a Kinematic viscosity of no more than 6 at 104° F (40° C). If biodiesel fuel has a specific gravity of more than 0.900 at 60° F, it is probably the result of an incomplete reaction and should not be used to fuel a Diesel engine. If fuel with a specific gravity of more than 0.900 is used in an unmodified Diesel engine, the fuel can increase engine wear, injector coking, emissions, and could cause damage to the engine.

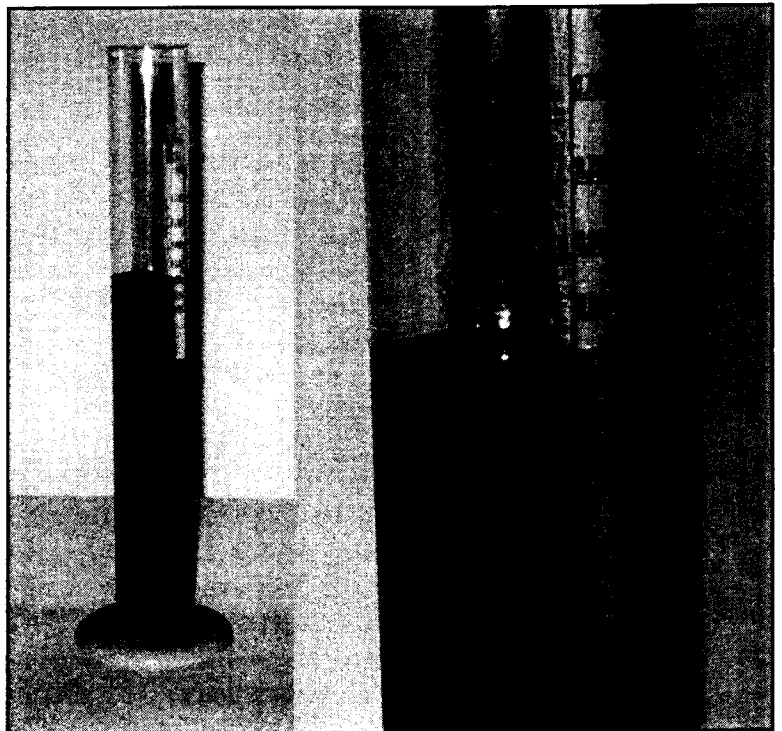
A device called a *hydrometer* is used to measure the specific gravity of biodiesel. A hydrometer is a graduated glass tube which has been filled with air and fitted with a weight. The hydrometer is dropped into a cylinder which is filled with biodiesel. The hydrometer floats in the biodiesel inside the cylinder and the specific gravity is read at the point where the hydrometer meets the surface of the biodiesel. Hydrometer readings are supposed to be taken at 60° F (15° C), but we have taken accurate readings at up to 85° F (30° C). There is a special hydrometer and plastic cylinder for testing biodiesel listed in the Resource Guide.

The specific gravity of biodiesel should be between 0.860 and 0.900.⁷ The specific gravity of biodiesel is usually 0.880. The specific gravity of vegetable oil is usually 0.920 or higher. If it is not possible to test the specific gravity of biodiesel at 60° F (15° C), then it is a good idea to compare the specific gravities of the biodiesel and the vegetable oil used to make the biodiesel at the same temperature. The specific gravity of the biodiesel should always be significantly lower than the specific gravity of the vegetable oil that was used to make the biodiesel.

A Diesel engine will run on biodiesel as long as the biodiesel is significantly less viscous than vegetable oil, it is passed through a fuel filter before being poured into the fuel tank, and it does not have water in it. A successful batch of homemade biodiesel will be significantly less viscous than vegetable oil and it will contain less than 0.25% or 2,500 parts per million of water. In Appendix 6, we give pre-calculated quantities for making large amounts of biodiesel.



A hydrometer is used to measure the specific gravity of vegetable oil (top) and biodiesel (bottom). Vegetable oil will always have a specific gravity above 0.900 and biodiesel will always have a specific gravity below 0.900. Even though these measurements were taken at 80° F (27° C), the readings showed the specific gravity of the biodiesel to be significantly less than that of the vegetable oil. Biodiesel will usually have a specific gravity of 0.880.



C H A P T E R 7

HOW TO BUILD A BIODIESEL PROCESSOR

This chapter builds on the information you learned in Chapter 6. Constructing a small scale biodiesel processor involves specialized skills and knowledge. If you are unfamiliar with the terms and concepts presented in this chapter, it is best to work with someone who is. Many of the parts used to build a small scale biodiesel processor can be purchased from United States Plastic Corporation. You can find U.S. Plastic Corp. in the Resource Guide and order their free catalog.

COMMERCIAL BIODIESEL FACILITIES

A commercial biodiesel facility can produce a large volume of high quality biodiesel. Commercially produced biodiesel must meet strict quality standards set by the American Society for Testing and Materials or the equivalent organization in other countries. These standards allow Diesel engine manufacturers to issue warranties which cover the use of commercially produced and tested biodiesel. See Appendix 8 for the ASTM standards for biodiesel fuel.

A commercial biodiesel facility will be profitable as long as it can secure a large, constant source of inexpensive vegetable oil and as long as the retail price of its biodiesel is competitive with the price of petroleum diesel. For example, on the Hawaiian island of Maui, used vegetable oil was once thrown away at a landfill. Now, a commercial biodiesel facility located at the landfill produces high quality biodiesel from the used vegetable oil. The biodiesel produced at this facility is competitively priced with petroleum diesel.

SMALL SCALE BIODIESEL PROCESSORS

A small scale biodiesel processor can be inexpensive to build and can produce high quality biodiesel fuel. All of the processes performed by an industrial facility can be replicated on a small scale. Much of the biodiesel testing performed at universities in the U.S. and abroad has been done with biodiesel made in dual tank processors like the one we discuss in this chapter. A small scale biodiesel processor can be made from recycled materials. The two types of biodiesel processors which are described in this chapter are based on working small scale facilities. The experience we gained from building our own small scale biodiesel processor, "The Green Grease Machine," is also integrated into this chapter.

The first small scale biodiesel processor described in this chapter will cost between \$50 and \$500 to build. The second small scale processor described in this chapter will cost between \$500-\$2000 to build. Either processor will make biodiesel with 2 hours of labor: 30 minutes of preparation, 1 hour of mixing, and 30 minutes to clean up. After the 1 hour of mixing, the biodiesel mixture will need to settle for at least 8 hours and not more than 20 hours. The per gallon cost of making biodiesel from used cooking oil in a small scale processor will be between 50 cents and \$1.¹

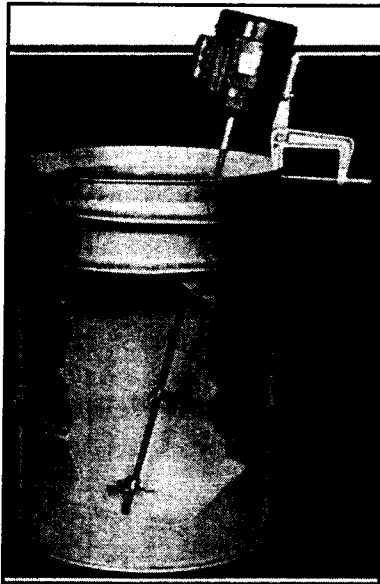


The "Green Grease Machine" is a portable biodiesel processor mounted on a trailer. The processor consists of a Diesel generator, a pump, a filter, a mixer, and a steam kettle.

A SINGLE TANK BIODIESEL PROCESSOR

A single tank biodiesel processor should have four basic parts:

1. A biodiesel mixing tank.
2. A motorized chemical mixer.
3. A heater.
4. Piping and ball valves.



Chemical mixers and metal and plastic containers such as these are available from plastics companies, container companies, and drum companies. Although a container with a flat bottom can be used as a biodiesel processor, it is preferable to use a container with a conical bottom. See the Resource Guide for more information. Photos reprinted from the United States Plastic Corporation Catalog.



1. The Mixing Tank

A biodiesel processor is a large mixer in which vegetable oil and sodium methoxide are rapidly mixed together. The faster and more vigorously the reactants are mixed, the better the reaction will be. Typical sizes of mixing tanks are 5 gallon (19 liter), 10 gallon (38 liter), 15 gallon (57 liter), 25 gallon (95 liter), 55 gallon (210 liter), and 80 gallon (304 liter) containers. The best material for a mixing tank is stainless steel. Inexpensive stainless steel containers can be found at restaurant supply stores and military auctions. A used *steam kettle* makes a good biodiesel mixing tank. A steam kettle is a large stainless steel cooking pot surrounded by a water or steam heating jacket. The second best material for a mixing tank is polyethylene. Polyethylene *chem-mix tanks* are specifically designed for mixing chemicals and are available through U.S. Plastic Corp. Steel 55 gallon drums are the third best containers. Steel drums should be free of chemical residue and rust. Aluminum pots are good for making 5, 10, or 15 gallon batches of biodiesel.

The mixing tank should have a conical bottom. A conical bottom allows the glycerin to be drained easily and accurately. A ball valve will be attached to the bottom of the cone. After the biodiesel reactants have settled, you will place a bucket under the cone and slowly open the faucet. Thick glycerin will drain into the bucket. You will shut the tap just when the glycerin runs out and the biodiesel begins to drain out. The shape of the conical bottom allows the glycerin to drain completely and not mix with the biodiesel. Polyethylene chem-mix tanks come with conical bottoms. Alternatively, you can make a conical bottom by welding some sheet metal to the bottom of a steel 55 gallon drum.

2. The Chemical Mixer

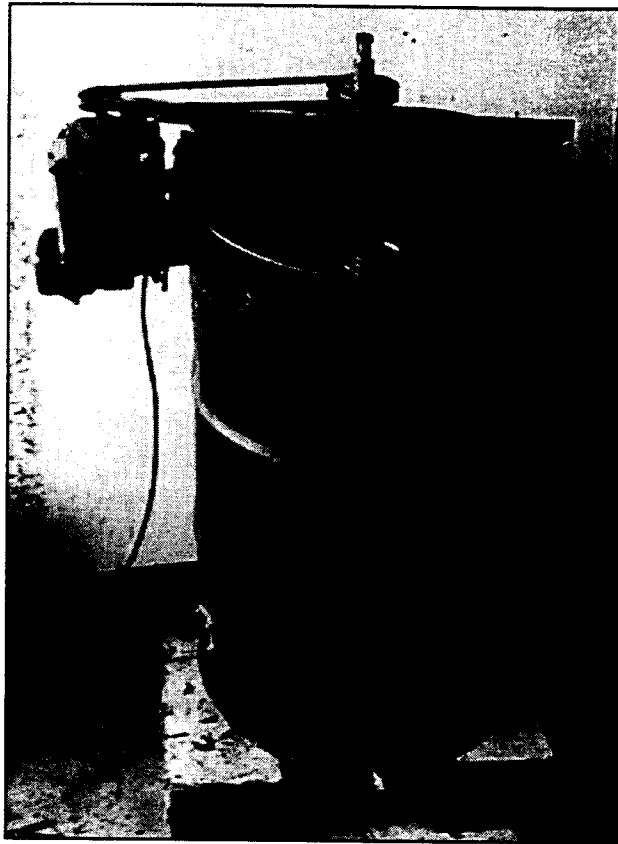
The best type of mixing device is a *chemical mixer*. A chemical mixer consists of an electric motor with a long shaft and a propeller. Pre-made chemical mixers are available for between \$120-\$300 from U.S. Plastic Corp. Most chemical mixers will mount on the side of a 55 gallon drum or chem-mix tank. If you do not want to buy a chemical mixer, you can make one by following the directions in the upcoming section.

3. The Heater

When the temperature is below 70° F (20° C), or when the vegetable oil is solid or lumpy, it will be necessary to heat the reactants before, during, and possibly after the mixing. The ideal temperature to attain is 120° F (50° C). A fish tank heater will heat 10-30 gallons (40-120 liters) of reactants. For larger batches of biodiesel, a water heater element can be mounted into a steel mixing tank. Make sure that you follow manufacturer's directions and safety precautions when adding any electrical device to a system. Be careful when heating vegetable oil in a plastic container. Polyethylene cannot withstand temperatures above 140° F (60° C).

4. Piping and Ball Valves

Short sections of steel piping up to 5 inches (13 cm) in length are acceptable, but long sections will rust. Both polyester and vinyl tubing will work for a short while before they degrade. Poly-Vinyl-Chloride (PVC) piping is used for household plumbing and is a good choice for small scale biodiesel processors. A type of PVC piping which is rated for higher temperatures and is slightly more resistant to chemicals is CPVC. Copper offers good chemical resistance and is easy to work with. Use brass valves with copper or steel pipe. Clear polyethylene piping is high quality, highly resistant to chemicals, but expensive. Stainless steel is the best piping, but it is very expensive. We recommend starting with PVC or CPVC piping. You can later upgrade the piping to copper, polyethylene, or stainless steel.



Tim Gerrits of Kelseyville, CA built this single tank biodiesel processor using a steel olive oil drum. Although this processor does not have a conical bottom, it only cost about \$50 to build. Notice the use of recycled parts.



The brass ball valve on the right is the drain and the heater on the left is used to heat the vegetable oil when it is solid or lumpy. Photos courtesy of Tim Gerrits.

BUILDING A SINGLE TANK BIODIESEL PROCESSOR

The simplest way to make a small biodiesel processor is to use a steel 55 gallon drum and a chemical mixer. A single tank biodiesel processor uses the same container for mixing and settling. No extra containers, pumps, piping, or mixers are needed. The single tank processor can be made from common salvaged and recycled parts. This processor can cost as little as \$50 and as much as \$500 to build, depending on how many new parts are bought. The parts listed here are based on standard measurements. We include the metric conversion for each of the sizes.

Parts List

The following parts can be used to build a single tank biodiesel processor using a steel 55 gallon drum:

1. A steel 55 gallon (210 liter) drum.
2. A $\frac{1}{2}$ or $\frac{3}{4}$ horse power electric motor.
3. Two pulleys which will produce a minimum of 250 revolutions per minute (rpm) and a maximum of 750 rpm at the mixer blade.
4. A belt to wrap around both pulleys.
5. A $\frac{1}{2}$ inch (12.7 mm) rolled steel rod.
6. A propellor made from two 3 inch (8 cm) long 12 or 14 gauge steel shelf brackets, welded to either side of the $\frac{1}{2}$ inch rolled steel rod. The shelf brackets look like two opposed "L"s and form a propeller which is about 6 inches (15 cm) in diameter.
7. A $1\frac{1}{2}$ inch (38 mm) brass ball valve.
8. A hinge and a spring which act as a belt tensioner.
9. A 2000 watt electric water heater element.
10. A water heater thermostat.
11. A $1\frac{1}{2}$ inch diameter piece of steel pipe 3-5 inches (8-13 cm) in length, with male pipe threads on one end.
12. Angle iron, wood, screws, bolts, and other assorted hardware.
13. A long, flat piece of 1-2 inch (3-5 cm) wide steel or aluminum.

Assembly: Mixing Tank

1. Cut a large opening in the top of the steel drum. If the mixing tank is going to have a conical bottom, skip steps 2-4.
2. Drill a $1\frac{1}{2}$ inch hole in the bottom of the side of the drum.
3. Weld a $1\frac{1}{2}$ inch diameter piece of steel pipe in the hole in the bottom of the side of the drum.
4. Attach a $1\frac{1}{2}$ inch brass ball valve to the piece of pipe. This will serve as the drain valve.
5. Drill a hole on the bottom of the drum the same size as the electric water heater element you will be using.
6. Install the water heater element, making sure that the element is not touching the inside of the drum.
7. Wire a thermostat to the water heater element.

Assembly: Chemical Mixer

A mixer which spins below 500 rpm can use a large, heavy propeller. A mixer which spins above 500 rpm will need a small, lightweight propeller. To make your own mixer, you will need an electric motor, a straight rolled steel rod at least $\frac{1}{2}$ inch in diameter, two pulleys, a belt, a hinge, and something to use as a propeller.

1. Attach one pulley to the rolled steel rod and attach the other pulley to the spindle of the electric motor.
2. Weld the propeller to the other end of the steel rod.
3. Attach the rod, pulley, and propeller assembly to one side of the hinge.
4. Weld a piece of angle iron across the top of the drum.
5. Weld the unattached side of the hinge to the angle iron so that the propeller and rod assembly goes into the middle of the drum. The hinge should swing the propeller and rod back and forth.
6. Mount the electric motor on the side of the drum.
7. Put a belt between the pulleys. Tighten the pulleys by wedging a block of wood into the hinge.

Assembly: Conical Bottom (Optional)

A conical bottom is a simple addition to any single tank biodiesel processor. A welding shop can make this.

1. Cut the bottom off of the steel drum with a torch.
2. Make a cone shape with sheet metal, leaving a $1\frac{1}{2}$ inch opening.
3. Weld the cone to the bottom of the drum.
4. Attach a $1\frac{1}{2}$ inch diameter piece of steel pipe to the end of the cone.
5. Attach a $1\frac{1}{2}$ inch brass ball valve to the steel pipe. This is the drain valve.
6. Using angle iron, make a 3 or 4 leg stand for the drum. Make sure there is enough room under the bottom of the cone to put a large bucket or fuel container.

Assembly: Measuring Stick

A long piece of 1-2 inch wide aluminum or steel will allow you to measure the amount of reactants in the mixing chamber. By marking the metal stick with graduations, you will create a measuring stick.

1. Add 10 liters of water to the mixing tank.
2. Put the long piece of aluminum or steel into the mixing tank and mark the level of the water on the stick.
3. Pull the measuring stick out of the water and scratch a line across it where the water level was. Scratch the number 10L into the metal on top of or beside the line.
4. Add another 10 liters of water and repeat the process this time marking the metal with 20L.
5. Put another 10 liters in and mark 30L, then 40L, and so on.
6. Repeat the process until the mixing tank is full of water and the measuring stick is full of measurements. Drain the water.

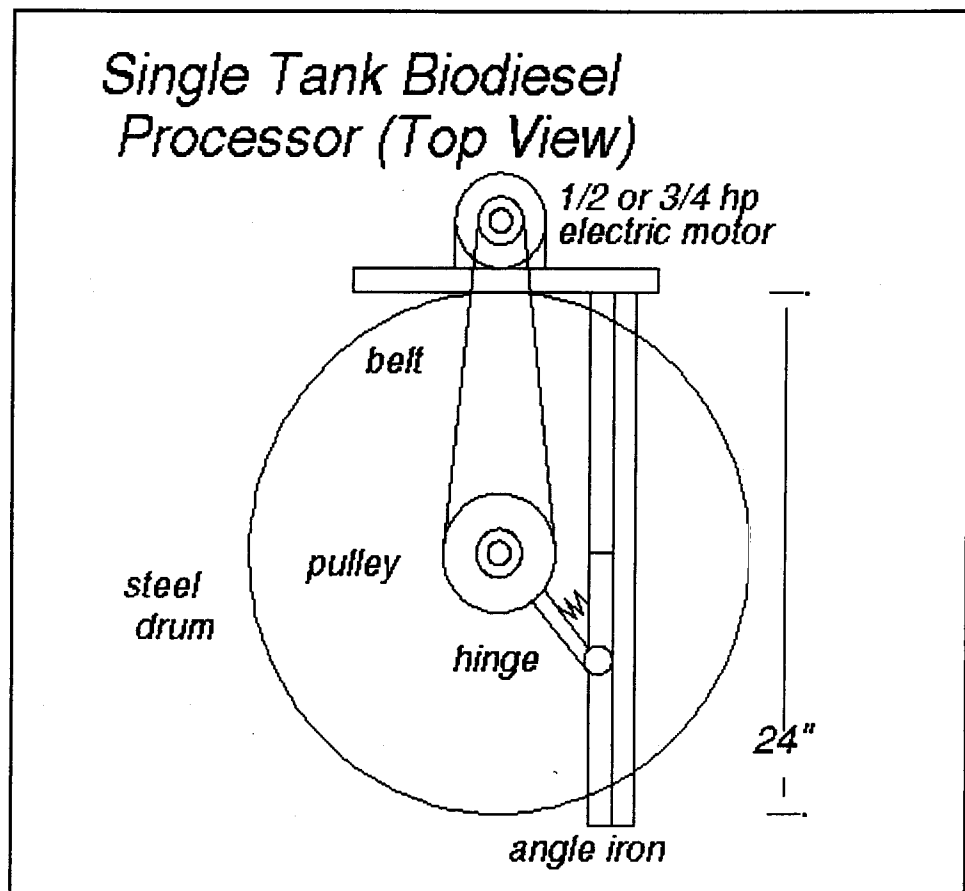
MAKING BIODIESEL IN THE SINGLE TANK PROCESSOR

The only difference in the procedure for making biodiesel in a blender and the procedure for making biodiesel in this processor is that the alcohol/catalyst solution must be mixed with the vegetable oil for 1 hour. To make biodiesel in the single tank processor, refer to the biodiesel procedure in Chapter 6 and follow these steps:

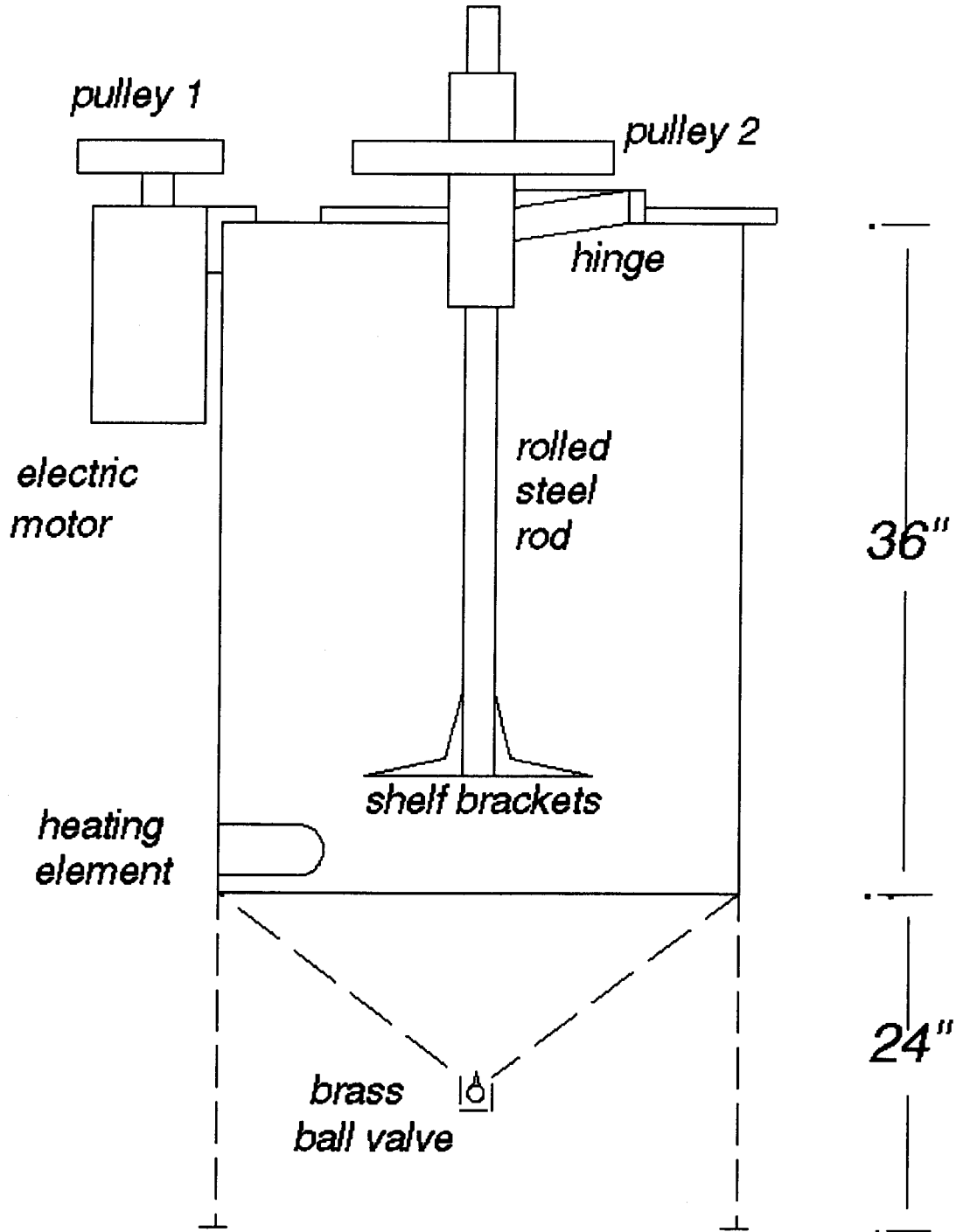
1. Do a titration to determine the amount of free fatty acids in the used cooking oil. If you are using new vegetable oil, skip the titration.
2. Make a mini batch of biodiesel in a blender using 100 milliliters or 500 milliliters of vegetable oil. Did two distinct layers settle out of the mini batch?
 - a. If yes, go to step 3.
 - b. If no, make another mini batch using a different amount of catalyst.
 - c. Do not make a large batch of biodiesel until you can successfully make a mini batch.
3. Measure the amount of vegetable oil, alcohol, and catalyst for the large batch of biodiesel.
4. Dissolve the catalyst in the alcohol by mixing them together for up to 5 minutes.
5. Add the vegetable oil to the alcohol/catalyst solution and mix vigorously for 1 hour.
6. Allow to settle for at least 8 hours.
7. Drain the glycerin.
8. Filter the biodiesel.

Top view of the single tank biodiesel processor based on a steel drum.

Facing Page: Side view of single tank biodiesel processor. The dotted lines show the optional conical bottom. Neither diagram is drawn to scale.



Single Tank Biodiesel Processor



A DUAL TANK BIODIESEL PROCESSOR

A dual tank biodiesel processor has the same basic parts as a single tank processor:

1. A biodiesel mixing tank.
2. A motorized chemical mixer.
3. A heater.
4. Piping and ball valves.

But a dual tank processor also has:

1. A separate tank to mix the alcohol and catalyst.
2. A pump.
3. An optional sight tube.

1. The Alcohol/Catalyst Mixing Tank

This tank allows an accurate amount of alcohol to be mixed with the catalyst. The alcohol/catalyst mixing tank should be a 30 gallon (114 liter) or larger polyethylene chem-mix tank. Alcohol can be poured or pumped into this tank. The polyethylene chem-mix tank available from U.S. Plastic Corp. is semi-translucent and has graduated markings on the side. The level of alcohol can be seen from outside the tank. The same chemical mixer used for the biodiesel mixing tank can be temporarily moved and used with the alcohol/catalyst tank, or the alcohol/catalyst tank can have its own mixer.

2. The Pump

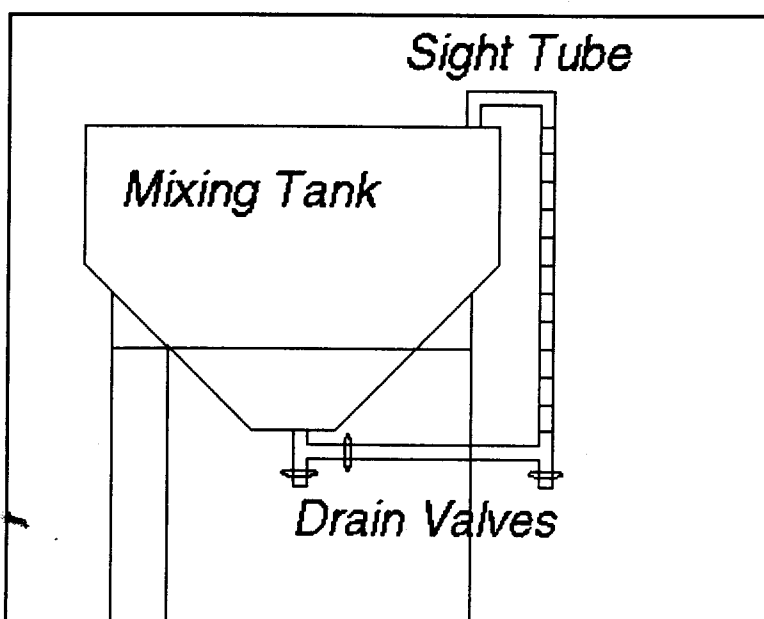
A dual tank biodiesel processor uses a pump to move the sodium methoxide from the alcohol/catalyst tank to the biodiesel mixing tank. A pump can also be used as a mixer by recirculating the biodiesel mixture, but we do not recommend this. The pump used for a biodiesel processor must be resistant to corrosives and be *self-priming*, or able to pump air until it pulls liquid through.

A sight tube is an optional addition to any steel tank. A sight tube allows you to see and measure the contents of a tank.

Potential pump types include impeller pumps, seal-less pumps, magnetic drive pumps, diaphragm pumps, and gear pumps. Pumps are available from U.S. Plastic Corp., chemical handling companies, surplus equipment companies, military auctions, and boat supply stores. Plan to spend between \$100 and \$300 for a new corrosive resistant pump. If you do not want to buy a pump, you can build one from an electric motor and an attachable pump part. Pump parts are available at boat supply stores, hardware stores, and agricultural supply stores.

3. The Optional Sight Tube

When the biodiesel mixing tank is made from steel, there is no way to see inside the tank. The amount of vegetable oil used in the biodiesel reaction must be pre-measured or measured with a graduated measuring stick. A *sight tube* allows



you to see and measure the liquids in a tank. A sight tube is a clear plastic tube that runs along the side of a tank. It is attached to the top of the side of the tank and the bottom of the side of the tank with elbow pipe fittings.

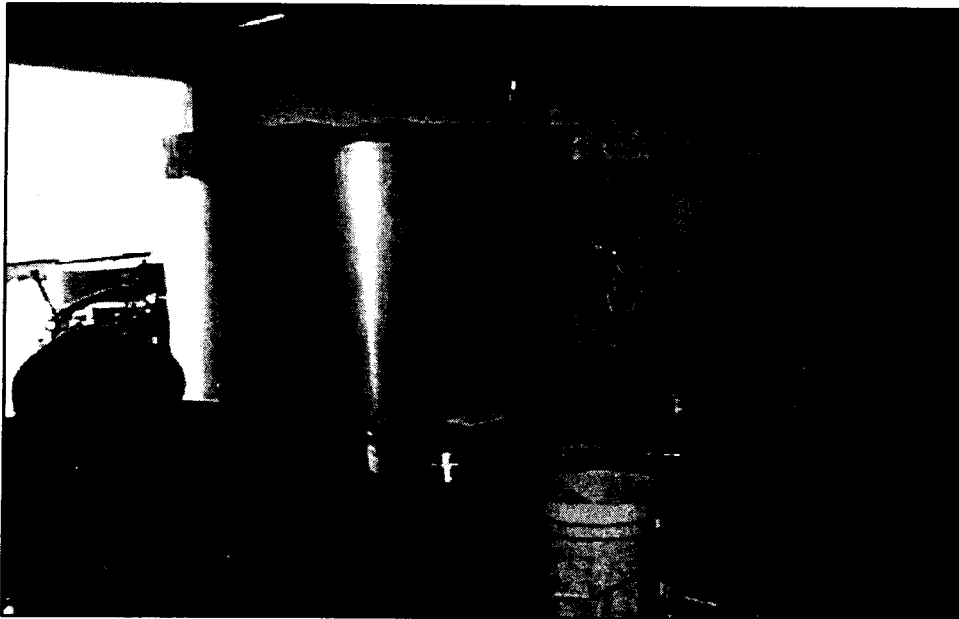
The sight tube is marked with graduations in order to measure the amount of liquids in the biodiesel mixing tank. The sight tube will contain the same liquids at the same levels as the tank.

Two valves should be installed at the bottom of the sight tube. One valve closes the sight tube off from the tank and the other valve opens the sight tube so it can be drained. The sight tube on a biodiesel mixing tank should be closed and its contents should be drained and put back into the tank before the biodiesel reactants are mixed.

Once the mixing is complete, the sight tube should be allowed to fill with the biodiesel reactants. As the biodiesel mixture inside the tank settles, so will the mixture in the sight tube. When the glycerin is drained from the tank, the level of glycerin in the sight tube will drop. When the level of glycerin drops to the bottom of the sight tube, you will know to close the drain valve on the tank.

BUILDING A DUAL TANK BIODIESEL PROCESSOR

The dual tank biodiesel processor consists of an alcohol/catalyst mixing tank and a biodiesel mixing tank. Both tanks can be polyethylene chem-mix tanks. Each tank should be put on a stand so it is above floor level. This will help when draining the chemicals. The chemical mixer can be moved between the two tanks or each tank can have its own mixer. Both tanks should have lids to prevent splashing. The biodiesel mixing tank should only have a sight tube if it is made of steel or stainless steel. The dual tank processor costs approximately \$1,000 with new polyethylene tanks, a new pump, a new chemical mixer, PVC piping, and self-made tank stands.

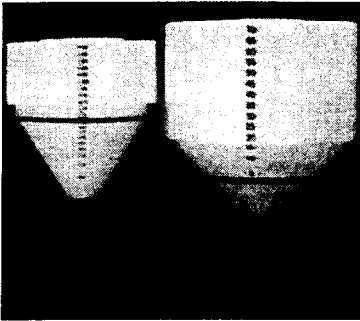


This dual tank processor was established on the Nez Perce Tribe Reservation in Idaho. Notice the stainless steel biodiesel mixing tank, the polyethylene alcohol/catalyst mixing tank, and the large chemical mixer. Photo courtesy of Rico Cruz.

Parts List

This is a basic parts list for the dual tank processor:

1. Alcohol/catalyst mixing tank: 30 gallon polyethylene chem-mix tank or steel 55 gallon drum.
2. Biodiesel mixing tank: 70 gallon (266 liter) polyethylene chem-mix tank or steel 55 gallon drum. A stainless steel tank can also be used.
3. Stands for tanks or materials to construct tank stands.
4. A pump rated for highly corrosive chemicals to move the mixture from the alcohol/catalyst mixing tank to the biodiesel mixing tank. The pump should have a minimum of $\frac{1}{2}$ inch diameter threaded openings.
5. A chemical mixer that rotates at approximately 1500 rpm.
6. Minimum of $\frac{1}{2}$ inch diameter, PVC or better piping, elbows, and threaded fittings for moving the alcohol/catalyst mixture from the alcohol/catalyst mixing tank to biodiesel mixing tank.
7. A minimum of $\frac{1}{2}$ inch diameter PVC ball valve for the bottom of the alcohol/catalyst mixing tank.
8. A small length of $1\frac{1}{2}$ inch diameter PVC pipe for the bottom of the biodiesel mixing tank.
9. A $1\frac{1}{2}$ inch diameter PVC ball valve for the bottom of the biodiesel mixing tank.
10. Some 5 gallon (19 liter) buckets for collecting glycerin.



A biodiesel processor can be made entirely from off the shelf parts. For example, polyethylene conical bottom tanks can be ordered from companies that sell plastic containers. See the Resource Guide for more information.

If the processor is made from two steel drums, then these parts will also be needed:

1. Large sheets of sheet metal for making conical bottoms on the steel drums (optional).
2. Short sections of $1\frac{1}{2}$ inch diameter steel pipe to weld onto the bottom of the tanks.
3. 2 brass ball valves with a $1\frac{1}{2}$ inch openings. These will be the drain valves.

Assembly: Alcohol/Catalyst Mixing Tank

1. Put the chem-mix tank on its stand or construct a 3 or 4 leg stand for the tank.
2. Attach a piece of PVC pipe into the bottom of the cone of the tank, or the *drain point*.
3. Attach a correspondingly sized ball valve onto the piece of PVC pipe.
4. Attach PVC pipe leading directly down from the tank to the floor.
5. Attach a PVC pipe elbow and continue the PVC pipe toward the biodiesel mixing tank.
6. Place the pump between the tanks. The “in” side of the pump should face the alcohol/ catalyst mixing tank. The “out” side of the pump should face the biodiesel mixing tank.
7. Continue the PVC pipe until it reaches the “in” side of the pump. Attach the PVC pipe to the inlet of the pump.
8. Attach more PVC pipe to the “out” side of the pump.
9. Run the PVC pipe to the top of the biodiesel mixing tank. Bring the PVC pipe over the upper edge of the biodiesel mixing tank and terminate the pipe with an elbow fitting facing downward so that pipe empties into the biodiesel mixing tank.

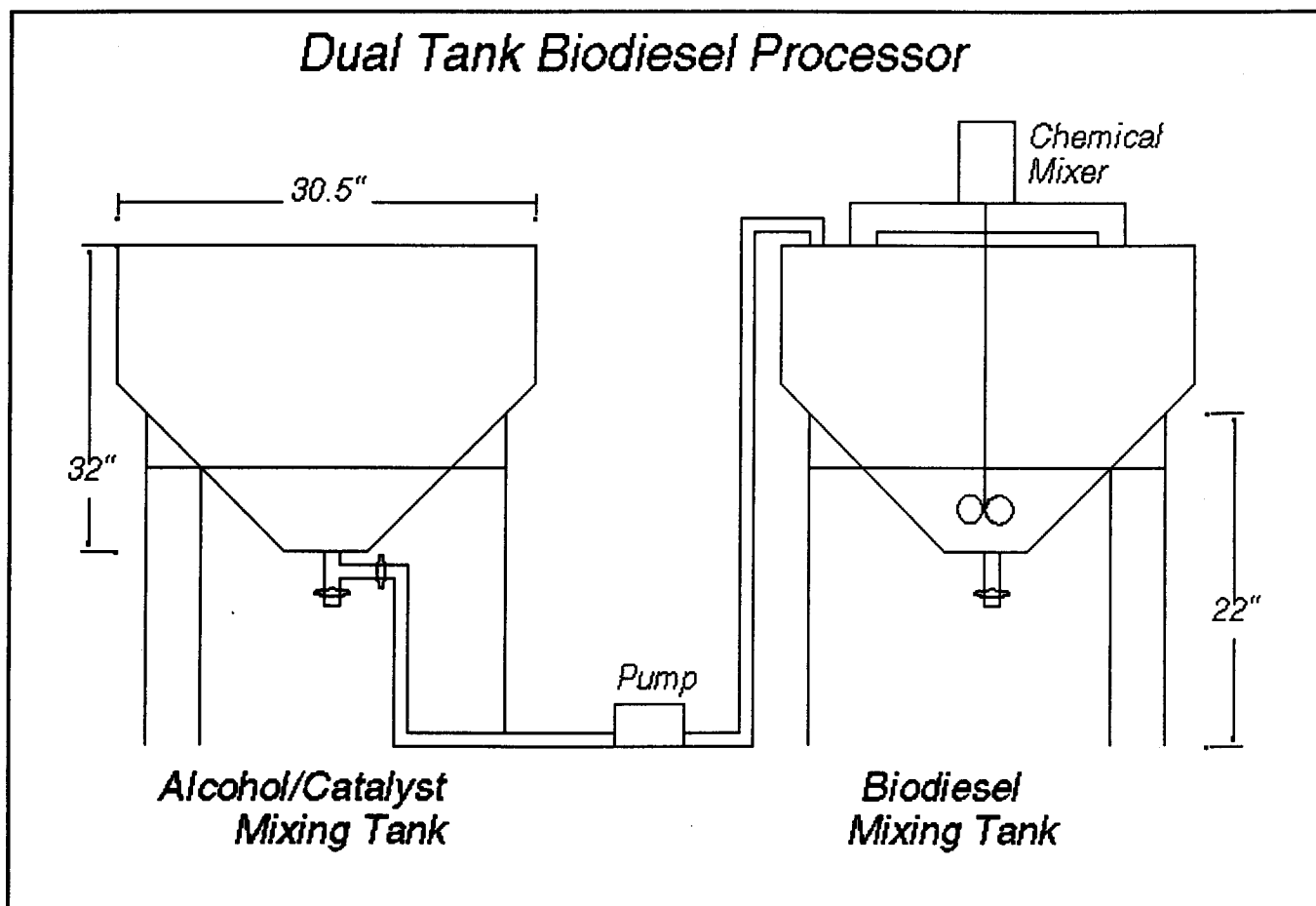
Assembly: Biodiesel Mixing Tank

1. Put the chem-mix tank on its stand or construct a 3 or 4 leg stand for the tank. Make sure there is enough room under the tank to put a large bucket or fuel container.
2. Attach a piece of 1½ inch diameter PVC pipe into the bottom of the cone of the tank.
3. Attach a 1½ inch diameter ball valve onto the piece of PVC pipe.

Assembly: Splash Lids

A splash lid ensures that none of the liquid splashes out of a tank during mixing. The splash lid does not need to seal tightly.

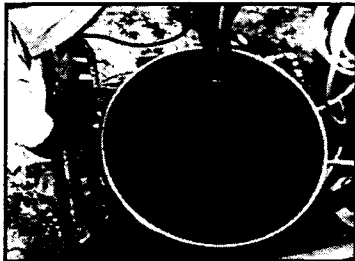
1. Use the lid that comes with the container or fashion a lid from steel or aluminum.
2. Cut a hole in the shape of an elongated “U” in the side of the lid. The U-shaped hole should slide easily around the mixing shaft of the chemical mixer.



This diagram of the dual tank biodiesel processor is based on two 70 gallon polyethylene conical bottom tanks. One chemical mixer can be shared between the two tanks or two chemical mixers can be used. The diagram is not drawn to scale.

MAKING BIODIESEL IN THE DUAL TANK PROCESSOR

The following steps can be used as a guide to making biodiesel in the dual tank processor. Always wear safety goggles, gloves, long sleeved clothing, and shoes when making biodiesel.



In this photo, used vegetable oil is mixed with the alcohol/catalyst solution.

1. Do a titration to determine the amount of free fatty acids in the used cooking oil. If you are using new vegetable oil, skip the titration.
2. Make a mini batch of biodiesel in a blender using 100 milliliters or 500 milliliters of vegetable oil. Did two distinct layers settle out of the mini batch?
 - a. If yes, go to step 3.
 - b. If no, make another mini batch using a different amount of catalyst.
 - c. Do not make a large batch of biodiesel until you can successfully make a mini batch.
3. Close the ball valve on the bottom of the biodiesel mixing tank.
4. Close the ball valve on the bottom of the alcohol/catalyst mixing tank.
5. Mount the chemical mixer on the alcohol/catalyst mixing tank.
6. Pour the vegetable oil into the biodiesel mixing tank. Measure the amount of vegetable oil. If the vegetable oil is solid or lumpy, heat the oil to 120° F (50° C).
7. Determine how much alcohol and catalyst to use based on the amount of vegetable oil you measured.
8. Pour the alcohol into the alcohol/catalyst mixing tank.
9. Pour the catalyst into the alcohol/catalyst mixing tank.
10. Close the lid on the alcohol/catalyst mixing tank. Turn on the chemical mixer.
11. Dissolve the catalyst in the alcohol by mixing them together for up to 5 minutes. Be careful.
12. Turn off the chemical mixer.
13. Unless the biodiesel tank has its own mixer, move the chemical mixer to the biodiesel mixing tank.
14. Open the ball valve on the bottom of the alcohol/catalyst mixing tank. Turn on the pump and pump the alcohol/catalyst solution into the biodiesel mixing tank.
15. Close the lid on the biodiesel mixing tank. Turn on the chemical mixer.
16. Allow the mixer to mix vigorously for at least 1 hour.
17. Turn off the chemical mixer.
18. Let the mixture settle for 8 hours.
19. After the mixture has settled and you can clearly see the layers, slowly open the drain valve on the bottom of the biodiesel mixing tank. Drain the bottom layer of glycerin into a bucket. If the glycerin is hard and will not drain, insert a piece of wire into the drain valve. Be careful, the glycerin can come out very quickly. The glycerin will be much thicker and darker than the top layer of biodiesel.
20. Once the glycerin is drained from the tank, you can drain the biodiesel. You can either drain it into fuel jugs or you can drain or pump it into a fuel storage tank.
21. If you want to wash the biodiesel, do it after the glycerin is drained and before the biodiesel is drained from the tank.
22. If you have one or more filters, you can pump the biodiesel through them before using it in an engine.

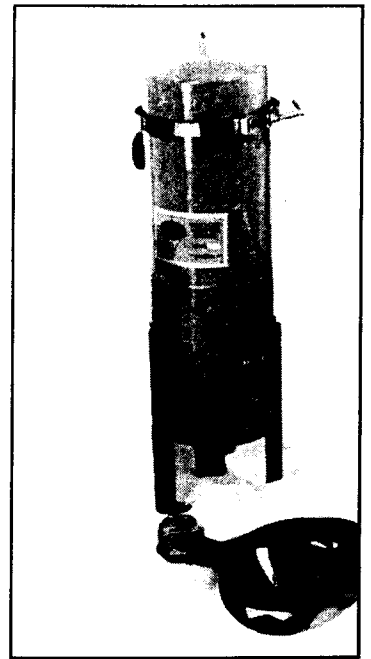
FILTERING THE BIODIESEL

Adding filters to the biodiesel process increases fuel quality by decreasing impurities in the fuel. When it is time to drain the biodiesel, the biodiesel can be pumped directly from the mixing tank through one or more filters. A pump like the one used for the dual tank processor can be used to pump the biodiesel through up to three filters. The filters should be standard automotive oil or fuel filters in the following sizes: 100 micron, 50 micron, and 5 micron. The 100 and 50 micron filters are sometimes called “rock catchers” because they only filter out the biggest particles. These filters are usually used for engine oil or hydraulic oil and are sold as “remote-mount oil filter kits.” The 5 micron filter is a fuel filter. It will catch small particles that could damage an engine. All of these filters can be found at auto parts stores.

Another type of filter is a *sock* or *bag* filter, which looks like a large sock. A sock filter is placed into a sealed cylinder. The fuel pump forces fuel into the top of the cylinder, through the pores in the sock, and out of an opening on the bottom of the cylinder. Sock filters are available in various micron sizes, and they are larger and more expensive than regular automotive filters. Sock filtration equipment is available from pool and spa companies, boat supply companies, water filtration companies, and some agricultural equipment companies.

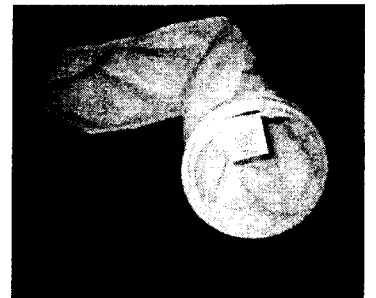
STORING THE BIODIESEL

Biodiesel will store for at least a year and can be stored indefinitely in cold climates. Biodiesel can be stored anywhere petroleum diesel is stored including fuel carry containers, vehicle fuel tanks, underground storage tanks, steel tanks, aluminum tanks, and plastic fuel storage tanks. Biodiesel must be stored in a container which has been approved to store gasoline or petroleum diesel. Biodiesel fuel storage containers should be filled as completely as possible to minimize contact between the biodiesel and air. If biodiesel will be stored in a humid or warm climate, biocide should be added to the biodiesel storage container. See Chapter 3 for more information about biocide. Each year, some glycerin will settle out of the biodiesel mixture. Expect between 0.25 and 4 grams of glycerin to settle out of each liter of biodiesel per year.² Large biodiesel tanks should have 2 in-line fuel filters before the fuel distribution pump. If biodiesel is stored for longer than a year in a moderate or warm climate, the pH of the biodiesel should be tested before it is used to ensure that the acidity has not increased beyond a pH of 10. The specific gravity of the biodiesel should also be tested to ensure that the biodiesel has maintained a specific gravity of less than 0.900.



Top: A sock filter cylinder is usually made from heavy plastic or stainless steel.

Bottom: The filter elements look like large socks and are usually washable.



C H A P T E R 8

HOW TO RUN A DIESEL ON VEGETABLE OIL AND KEROSENE

This chapter explains how to install a second fuel tank in a Diesel automobile and how to make fuel from vegetable oil and kerosene. Fuel made from vegetable oil and kerosene is not biodiesel. Vegetable oil kerosene fuel is not an EPACT approved clean air fuel, nor is it endorsed by any governmental agency. Unlike biodiesel, engine manufacturers do not endorse the use of vegetable oil and kerosene as a fuel.

VEGETABLE OIL KEROSENE FUEL

A Diesel engine can be fueled with a mixture of new or used vegetable oil and kerosene. Mixing kerosene into vegetable oil thins the vegetable oil. Vegetable oil kerosene fuel can clog in fuel lines, it can coke engines, it is unstable, and we do not recommend its use on a long term basis. Vegetable oil kerosene fuel is highly experimental. However, vegetable oil kerosene fuel is quick and easy to make and does not require complex chemical reactions. We drove our Diesel Volkswagen Jetta, "Greasy Gretta," 5,000 miles (8,000 kilometers) on a mixture of used vegetable oil and kerosene using the system described in this chapter.

The mixture ratio of vegetable oil to kerosene is 70-80% vegetable oil to 20-30% kerosene. Jet fuel and diesel #1 fuel can be used in place of kerosene because all three fuels are basically the same. In order to use vegetable oil kerosene fuel reliably, a second fuel tank must be installed. The vegetable oil kerosene fuel will go in the second fuel tank. The Diesel engine will be started on diesel fuel from the main fuel tank and switched to vegetable oil kerosene fuel from the second fuel tank when the engine is warm. When it is time to stop the engine, it is switched back to diesel fuel and allowed to idle for a short while.

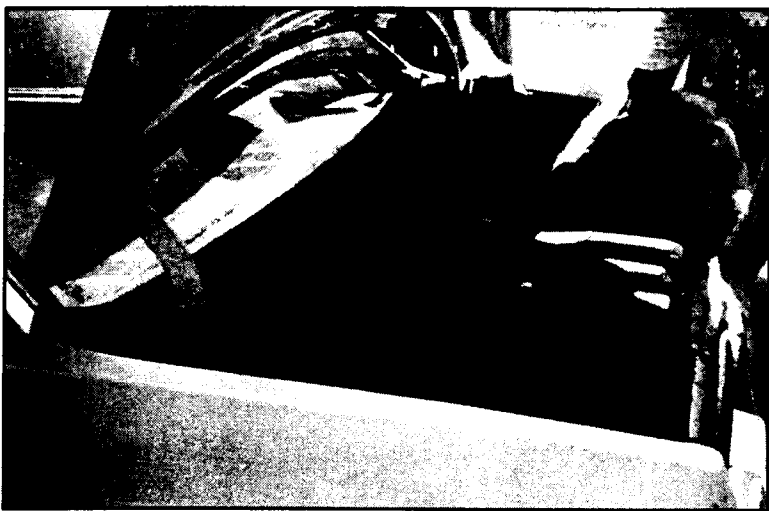
A mechanic can install the second fuel tank, the valve, and the toggle switch needed for this system. Radiator repair shops and off-road outfitters will sometimes install an extra fuel tank. Many of these shops have the equipment to manufacture and install a custom metal fuel tank. If you prefer, you can install the extra tank, valve, and toggle switch yourself.



"Greasy Gretta," a 1982 Volkswagen Jetta, traveled over 5,000 miles on a combination of vegetable oil and kerosene.

How it Works

Diesel cars have a fuel line which leads from the fuel tank to the injector pump and a fuel line which leads back to the fuel tank from the injector pump. The injector pump pulls fuel from the fuel tank and pushes it into the fuel injectors. A Diesel injector pump always pulls a little more fuel than it needs. The injector pump returns the extra fuel in a fuel return line which goes back to the fuel tank.



When a second fuel tank is installed, a special valve is placed between the injector pump and the two tanks. The valve changes the flow and return of fuel from one tank to the other. The type of valve used is a *solenoid operated valve*. The solenoid operated valve is controlled by flipping a toggle switch inside the car. When the toggle switch is flipped, the solenoid valve changes which tank the injector pump pulls fuel from and which tank it returns fuel to.

In this photo, we are attaching the fuel lines during the installation of the second fuel tank in the trunk of Greasy Gretta.

Most Diesel cars have one fuel tank, one feed line, and one return line. In this system, there are two fuel tanks, two feed lines, and two return lines. The four fuel lines lead from the tanks to the solenoid valve. Two other lines go from the solenoid valve to the injector pump. In total, there are six lines leading in and out of the solenoid valve, so we use a 6-port solenoid valve.



A small pot of used cooking oil can be heated on a camping stove before being filtered.

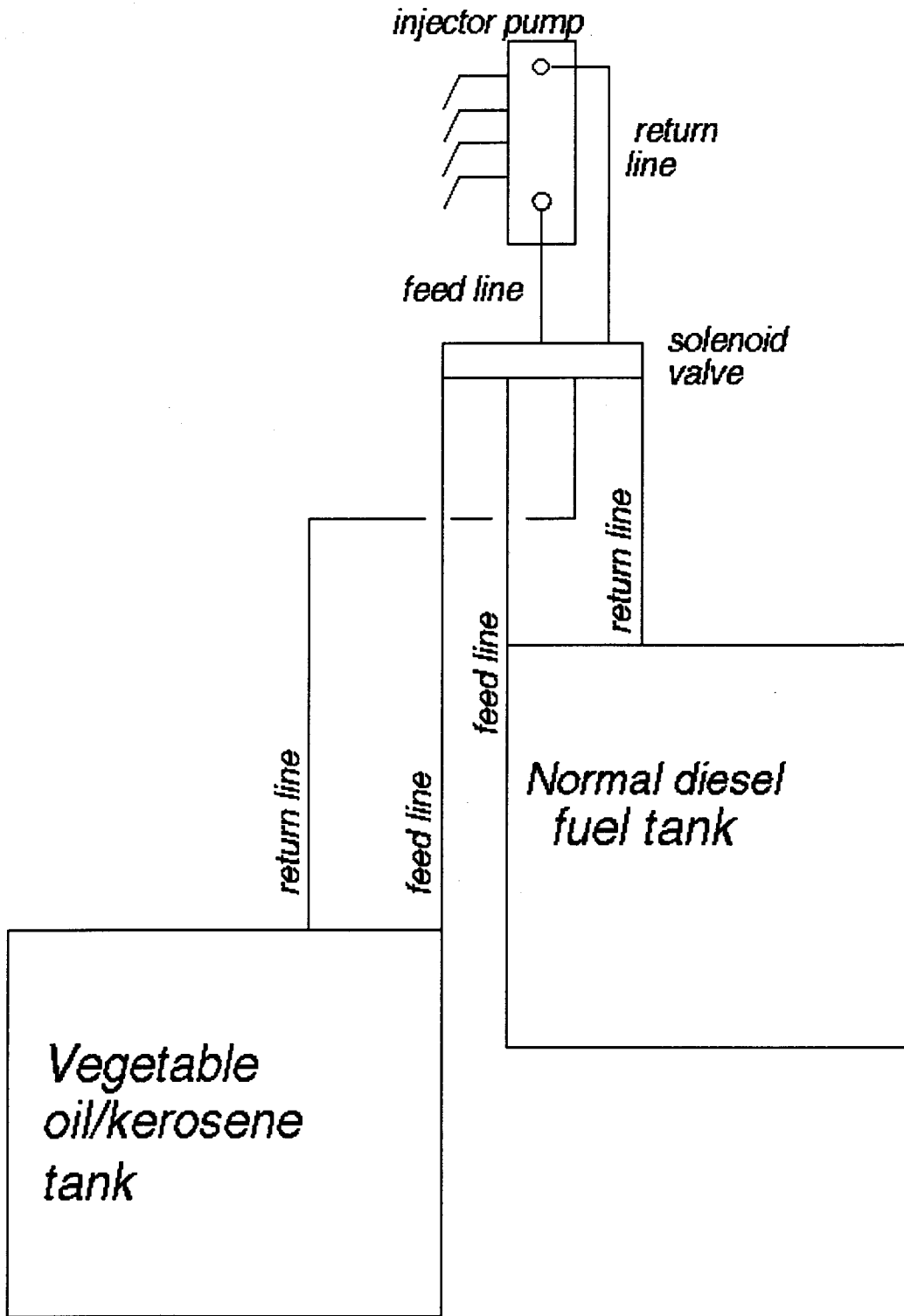
How to Make Vegetable Oil Kerosene Fuel

Making vegetable oil kerosene fuel from used cooking oil involves filtering the cooking oil and mixing it with kerosene. This fuel mixture costs between 35 and 50 cents per gallon.¹

The steps for making vegetable oil kerosene fuel are as follows:

1. Collect kerosene in a fuel jug.
2. Collect used cooking oil from a fast food restaurant.
3. Heat the used oil until it is warm to the touch.
4. Pour the warm oil through some pantyhose or a couple of restaurant fryer filters. Restaurant fryer filters are sold at restaurant supply stores.
5. Repeat the filtration 2-3 times.
6. If the ambient temperature in your area is between 80° and 110° F (27° and 43° C), mix 20% kerosene with 80% filtered used cooking oil.
7. If the ambient temperature in your area is between 50° and 80° F (10° and 27° C), mix 30% kerosene with 70% filtered used cooking oil.
8. At lower temperatures, mix 50% kerosene with 50% filtered cooking oil and see Chapter 3 for information about installing a fuel heating accessory.
9. Pour the vegetable oil kerosene fuel into the second fuel tank of the Diesel car.

Second Tank Fuel Flow Diagram



Right: The solenoid valve is bolted to the sheet metal on the side of the engine compartment. Six fuel lines lead out of the solenoid valve and are routed around the engine compartment. Make sure that the fuel lines do not bend sharply or come in contact with any moving parts.



Bottom: A polyethylene gasoline tank from a boat supply store makes a good second fuel tank. Notice the graduated markings on the side. The tank must be safely secured so it does not shift while the car is moving.



SUPPLIES FOR A SECOND FUEL TANK

6-Port Solenoid Valve

JC Whitney sells a 6-port solenoid operated fuel valve which is made by the Pollak Corporation of Massachusetts. The instructions in this book are based on the Pollak valve and may not be applicable if you use another type of solenoid valve. If you decide later to perform the straight vegetable oil modification which is described in Chapter 9, you will still be able to use the 6-port solenoid valve, but you will only use 3 of the 6 ports. Look in the Resource Guide for JC Whitney's contact information and part numbers. They ship internationally.

Fuel Tank

Only use a tank that is made to carry fuel. The fuel tank can be either metal or plastic. Plastic marine fuel tanks are available in 2, 5, 10, 15, 20 gallon (8, 19, 38, 57, 76 liter) and larger sizes. Marine tanks are horizontal, have filler caps on the top, and have nozzles for fuel feed and return lines. Since fuel tanks can be expensive, we recommend using a 5 gallon (19 liters) marine fuel tank. Five gallons of vegetable oil kerosene fuel will power a Volkswagen Rabbit for up to 250 miles (400 kilometers). The fuel tank must be safely mounted and secured. Read Chapter 9 for information on installing a custom-made metal fuel tank.

Parts List

1. A plastic or metal fuel tank.
2. 20-30 feet (10 meters) of $\frac{3}{8}$ inch (9.525 mm) fuel hose.
3. A 6-port solenoid operated fuel valve.
4. 10-20 feet (3-6 meters) of 18 gauge electrical wire.
5. Some hardware to secure the tank such as wood, nails, screws, and brackets.
6. One 10 amp automobile fuse and fuse holder.
7. 20 $\frac{1}{2}$ inch (12.7 mm) hose clamps.
8. Masking tape.
9. A permanent marker.
10. A small amount of red, white, and blue enamel paint.

You might need other things depending on your car.

INSTALLATION PROCEDURE

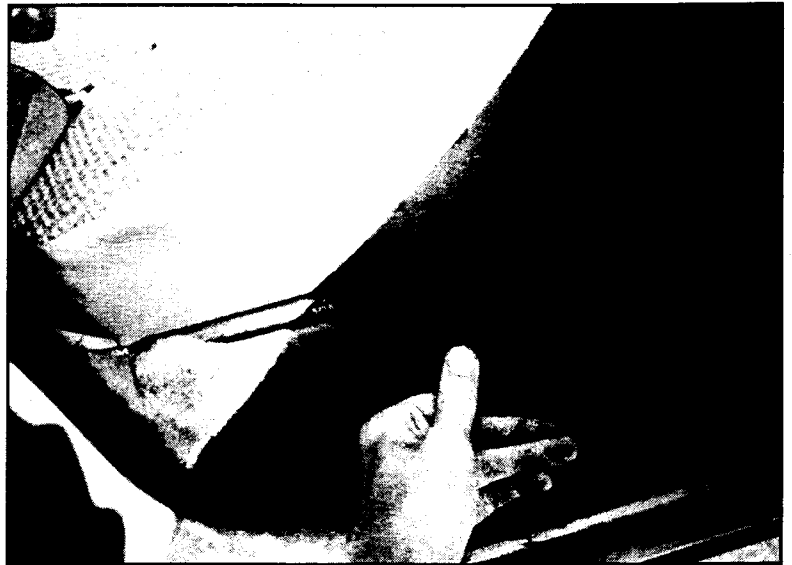
Installation: The Second Fuel Tank

1. Determine a location for the second fuel tank and measure the length, width, and height of the space. The tank can be located in the rear trunk, under a bench seat in the vehicle, in the spare tire compartment, under the dashboard on the passenger's side of the vehicle, in the bed of a pickup truck, or underneath the vehicle near the main fuel tank.
2. Find a plastic or metal tank or have a tank professionally made which meets the dimensions in step 1. The tank must have:
 - a. A *fuel pickup pipe*, or a pipe going down to the bottom of the tank with a nozzle on the top for the fuel feed line.
 - b. Another nozzle on the top of the tank for the fuel return line.
 - c. A vented filler cap. Any normal fuel filler cap has a vent built in to let air into the tank as fuel is consumed by the engine.
3. Secure the tank to the body of the car so the tank cannot move. Make sure there is a way to put fuel into the tank. Do not screw the tank braces into any wires, cables, fuel lines, or hoses.

Running the lines from the second fuel tank under the carpet can hide them from view. But make sure the fuel lines do not get pinched under seats or in tight corners.

Installation: The Fuel Lines

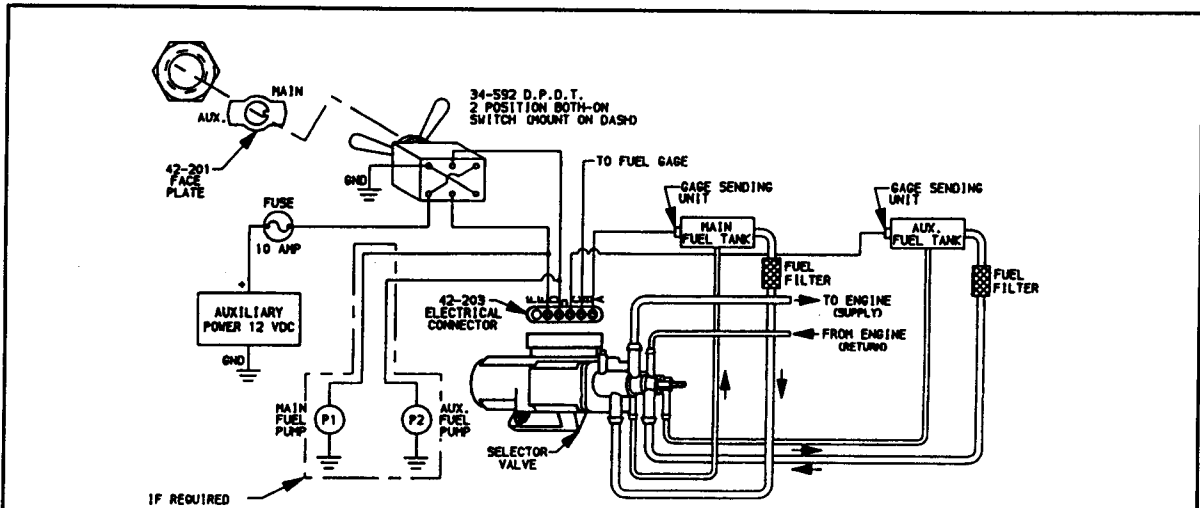
Two new fuel lines will have to be run from the engine compartment to the location of the second fuel tank. Those fuel lines will have to be free of obstructions and they cannot get pinched. Running a fuel line under a seat can mean that fuel flow will be restricted when someone is sitting on the seat. In cases where the fuel line must be routed underneath something or around a corner, it is best to put a protective piece of hard PVC pipe around the line.



1. Open the hood of the car and inspect the *firewall*. The firewall is the sheet metal between the engine compartment and the cabin of the automobile. It is located in front of the dashboard and behind the engine.
2. Determine the route of the fuel lines. The lines can go inside the car under the carpet or underneath the car along the same route as the original fuel lines.
3. If the fuel lines are going inside the car, look for a plug or a hole in the firewall which has a piece of rubber in it. Make sure there is nothing leading through the plug.
4. Locate the other side of the plug. You should be able to find the plug both in the engine compartment and in the cabin of the car.
5. Slit the plug open with a knife or razor blade.
6. If there were no unused plugs in the firewall, find a spot on the firewall and mark it with a permanent marker. Drill a hole there and insert the fuel lines through the hole. Make sure that the place you pick is not close to any wires, hoses, or cables.

7. Run a piece of string from the engine compartment to the tank location. Avoid any places where the fuel line could kink due to a sharp turn.
8. Measure the string and add 3 feet (1 meter) to your measurement. Cut two lengths of the fuel hose to the same length as the string.
9. Mask both ends of one fuel hose and write the word "feed" on each end.
10. Mask both ends of the other fuel hose and write the word "return" on each end.
11. Run the two fuel lines along the path you have established from the engine compartment to the fuel tank.
 - a. Leave about 1 1/2 feet (1/2 meter) extra fuel line at the beginning of the run.
 - b. Make sure the fuel lines are not kinked.
 - c. If the fuel lines must be passed through any sharp sheet metal, wedge a larger piece of rubber hose around them to ensure that they do not get cut.
 - d. If the fuel lines must be passed through a crack, such as the space between the floor and the back seat, pass the fuel lines through a piece of hard PVC pipe and wedge the pipe into the crack. This will ensure that the fuel lines do not get crushed.
12. Attach the fuel line marked "feed" to the nozzle on the second fuel tank which has a fuel pickup pipe.
13. Attach the fuel line marked "return" to the other nozzle on the second fuel tank.

This is a diagram of the solenoid valve, reprinted from the Pollak Fuel Tank Selector Valve instruction sheet.



NOTES:

1. ALL WIRING TO BE 18 GA. OR HEAVIER.
2. REQUIRED FUEL LINE I.D.

VALVE P/N	FUEL SUPPLY	FUEL RETURN	FUEL SYSTEM PRESSURE MAX. (PSI)
42-149	3/8"	5/16"	60
42-149S	3/8"	5/16"	60
42-151	3/8"	—	60
42-153	3/8"	1/4"	60
42-159	3/8"	5/16"	65
42-159S	3/8"	5/16"	65

CAUTION

ATTENTION INSTALLER

① FUEL SYSTEM PRESSURE NOT TO EXCEED SPECIFIED MAX. VALVE PRESSURE. (SEE NOTE 2 ABOVE)

② NOTE SOME LATE MODEL FUEL INJECTION SYSTEMS MAY EXCEED SPECIFIED PRESSURE.

Installation: The Solenoid Operated Valve

The Pollak brand solenoid operated fuel valve is a small cylinder with six nozzles and five wires. There are three small nozzles for the fuel return lines and three large nozzles for the fuel feed lines. The solenoid valve must be installed so that the default, or “off” position feeds fuel from and returns fuel to the original diesel fuel tank. The feed line from the original diesel fuel tank should first connect to the fuel filter and then connect to the solenoid valve. However, the feed line from the second fuel tank should not connect to the diesel fuel filter. Instead, the feed line from the second fuel tank should connect to its own oil screen filter.

To install the solenoid valve:

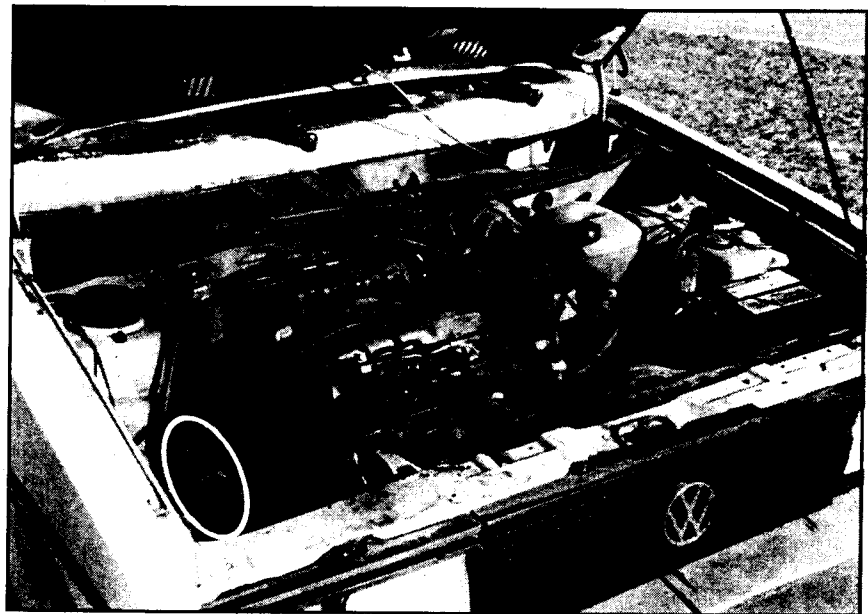
1. Remove the solenoid valve from its box and inspect it. There should be four nozzles on one side and two on the other.
2. Blow through the four nozzles on one side to determine which two are open. One of the two open nozzles is small and the other is large.
3. Mark the small and large open nozzles with some red paint. Red nozzles designate the default fuel flow path when the solenoid valve is turned off.
4. Mark the two nozzles which are not open with white paint. The white nozzles attach to the fuel lines which go to the second fuel tank.
5. Mark the two nozzles on the other side of the solenoid valve with blue paint. Blue nozzles connect to the injector pump lines.
6. Attach the solenoid valve to the sheet metal on the side of the engine compartment. You may have to drill holes and use sheet metal screws.
7. Attach the end of the fuel line marked “feed” to the large white nozzle on the solenoid valve.
8. Attach the end of the fuel line marked “return” to the small white nozzle on the solenoid valve.
9. Remove the hard piece of fuel line which goes between the fuel filter and the injector pump.
10. Use a hose clamp to attach a new piece of fuel hose to the fuel filter.
11. Attach the other end of the new piece of fuel hose to the large red nozzle on the solenoid valve.
12. Use a hose clamp to attach a new piece of fuel hose to the injector pump.
13. Attach the other end of the hose from step 12 to the large blue nozzle on the solenoid valve.
14. Check your work so far. The “feed” line should be connected to the large white nozzle on the solenoid valve. The “return” line should be connected to the small white nozzle on the solenoid valve. There should be a fuel hose from the fuel filter to the large red nozzle on the solenoid valve. There should be another fuel hose from the injector pump to the large blue nozzle on the solenoid valve.
15. Pull the undisturbed fuel line off of the fuel injector pump. Mark this line “diesel tank return line.”
16. Attach the diesel tank return line to the small red nozzle on the solenoid valve.
17. Use a hose clamp to attach a new piece of fuel hose to the injector pump.
18. Attach the other end of the fuel hose in step 17 to the small blue nozzle on the solenoid valve.
19. A 40 micron oil screen filter can be installed into the fuel feed line from the second fuel tank. Oil screen filters are available from Racor.

Installation: The Toggle Switch

A toggle switch is included in the box with the solenoid. This toggle switch is a double pole, double throw (DPDT) switch. Only a DPDT switch will work with the solenoid valve.

1. Mount the toggle switch inside the vehicle within easy reach of the driver. We mounted our toggle switch on a small removable panel under the emergency blinker switch on the dashboard.
2. Follow the wiring instructions included with the toggle switch and solenoid valve. Although the solenoid valve has 5 wires, only 2 wires are necessary to operate the valve. These 2 wires lead to the toggle switch. 2 other wires lead from the car's battery to the toggle switch. When the toggle switch is in the "on" position, it connects the positive and the negative wires from the battery with the two wires from the solenoid valve.
3. Install an automotive fuse and holder near the solenoid valve on the positive wire. If you are not familiar with automotive electronics, find a qualified mechanic or electrician to install the toggle switch and connect power to the battery.
4. Check your work. Leave the toggle switch in the "off" position and disconnect the wires to the solenoid valve.
5. Start the engine and let it idle.
6. Touch the wires from the toggle switch to the solenoid valve. Did the solenoid valve make a "clunk" sound?
 - a. If no, go to step 7.
 - b. If yes, or if sparks occurred or the car stopped, go back and recheck the wiring.
7. Turn the car off and re-attach the wires from the toggle switch to the solenoid valve.
8. Try the experiment again. Proceed when the toggle switch in the "off" position has no effect on the solenoid valve.

You can see the completed installation of the solenoid valve on the lower left side of the engine compartment.



Installation: Priming the Injector Pump

Most Diesel fuel injector pumps are not self-priming. When a pump is self-priming, it will pump air until it pulls liquid through. But a Diesel fuel injector pump must have fuel from the tank, through the line, and into the pump before it can pump the fuel. In order to prime the injector pump, fuel must be manually pumped through the fuel line to the injector pump.

1. Detach the fuel line marked "feed" from the large white nozzle on the solenoid valve.
2. To ensure that there are no blockages in the fuel line, blow air through the fuel line. You should be able to hear bubbles in the second fuel tank.
3. Pull a vacuum in the feed fuel line with a hand-operated suction pump, a vacuum cleaner with a small sucker, or anything that pulls a vacuum.
4. When fuel flows freely from the feed line, re-attach the line to the solenoid valve.

Installation: Pre-Drive Check

Start the car and let it warm up. When the car reaches normal operating temperature, flip the toggle switch. Did the solenoid valve make a "clunk" sound followed by a change in engine idle noise and a change in exhaust odor? If yes, the solenoid valve has switched to the vegetable oil kerosene fuel and your installation is functioning. If nothing happened or if the car stopped completely, first make sure that the wiring at the solenoid valve and the toggle switch is correct. Then make sure that the fuel lines are attached properly. Next, make sure that fuel is flowing from the second fuel tank to the solenoid valve. When the system is working properly, the toggle switch in the "on" position will allow the vegetable oil kerosene fuel to flow from the second fuel tank, through the solenoid, to the injector pump, and into the engine. Even if the system is working properly, check for leaks around the solenoid valve and at the second fuel tank. Remember to cool the vehicle down on diesel fuel before shutting it off.

C H A P T E R 9

HOW TO RUN A DIESEL ON STRAIGHT VEGETABLE OIL

In previous chapters we gave directions for running a Diesel vehicle on biodiesel and running a Diesel vehicle on a mix of vegetable oil and kerosene. In this chapter, we give instructions for running a Diesel vehicle on straight vegetable oil. Any Diesel engine can be modified to run on straight vegetable oil. This modification requires the addition of a solenoid operated fuel valve as described in Chapter 8, plus the installation of a custom-made metal fuel tank and modifications to the engine coolant hoses. These modifications are done in order to heat the vegetable oil so that it has a similar viscosity to diesel fuel. An engine modified to run on straight vegetable oil can still run on diesel fuel. This chapter contains technical instructions which assume the reader has an intermediate understanding of and skill with the Diesel engine.

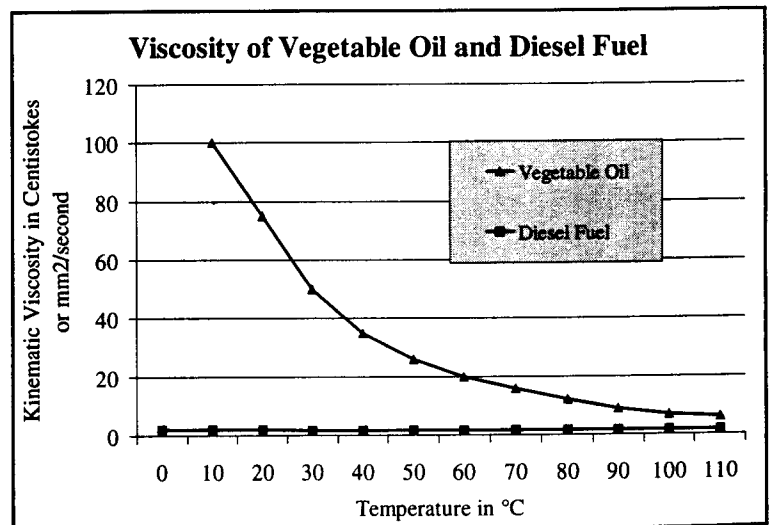
HEATING THE VEGETABLE OIL

There are two reliable ways to fuel a Diesel engine with vegetable oil: make the vegetable oil into biodiesel or heat the vegetable oil with engine coolant. Since used cooking oil is solid at room temperature, it must be heated before it can be used as a Diesel engine fuel. Hot vegetable oil flows easily through Diesel engine fuel lines, fuel injector pumps, and fuel injectors. Injectors can spray hot vegetable oil as well as they spray diesel fuel. If used with caution, vegetable oil can be a reliable Diesel engine fuel.

The key to fueling a Diesel engine with vegetable oil is to reduce the viscosity of the vegetable oil. As the temperature of vegetable oil increases, its viscosity decreases. Once the temperature of vegetable oil reaches 160° F (70° C), its viscosity drops below 20 centistokes. Although most Diesel engine manufacturers specify a maximum fuel viscosity of 10 or 15 centistokes, most Diesel engines will run on vegetable oil with a viscosity of 20 centistokes. When vegetable oil reaches 175° F (80° C), its viscosity drops below 10 centistokes, making it reliable for use in all Diesel engine fuel systems. An engine running on vegetable oil which has been heated to 175° F (80° C) will have similar injector coking and engine wear to an engine running on petroleum diesel. In addition, an engine running on heated vegetable oil will experience significantly lower emissions than an engine running on petroleum diesel.¹



Hydrogenated used vegetable oil is often solid even in the sun.



The viscosity of vegetable oil decreases and it performs more like petroleum diesel as its temperature increases. Sources: Agriculture and Agri-Food Canada, Saskatchewan Research Council, and BioCar®.

Although heating the vegetable oil is an effective method of reducing its viscosity, this method has been ignored by most university and alternative fuel researchers.

...heating the vegetable oil...is a very inexpensive and practical means of reducing the viscosity of vegetable oil for use in a Diesel engine.

In the words of one researcher, the idea of heating the vegetable oil fuel supply was dropped because "the entire distribution and storage system would also require heating, a clearly impractical and expensive approach."² While this approach is not feasible in every situation, it is a very inexpensive and practical means of reducing the viscosity of vegetable oil for use in a Diesel engine.

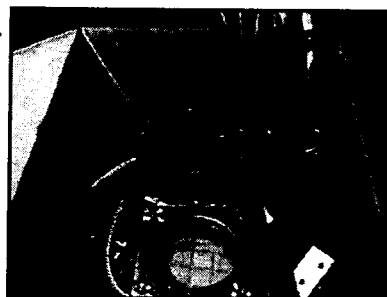
STRAIGHT VEGETABLE OIL CONVERSIONS

The modifications necessary to run a Diesel engine on straight vegetable oil have been duplicated by a number of companies and individuals in different parts of the world. For example, in 1996, France's Center for International Cooperation in Developing Agrotechnical Research ran a Renault station wagon on rapeseed oil for 61,000 miles.³ Other organizations who have successfully modified Diesels to burn straight vegetable oil include Elsbett of Germany, Better World Workshop of Vermont, and BioCar[®] of Germany.

The BioCar[®]

Georg Lohmann fuels his Diesel car with used vegetable oil straight from restaurant fryers. The BioCar[®] system designed and patented by Mr. Lohmann has been installed in many direct and indirect injection Diesel vehicles and Diesel generators.

This box contains all of the components of the BioCar[®] kit, except for the custom-made heated tank.



This system starts a Diesel engine on diesel or biodiesel fuel, heats a tank of vegetable oil, heats the fuel line from the vegetable oil tank to the injector pump, heats and filters the vegetable oil right before the injector pump, and switches the fuel from diesel or biodiesel fuel to vegetable oil. Mr. Lohmann sells a patented, high quality BioCar[®] kit. See the Resource Guide for information on contacting BioCar[®].

The Elsbett Engine

The Elsbett engine is a type of Diesel engine made in Germany that runs on straight vegetable oil. In 1992, *Autocar and Motor Magazine* published an article on a Mercedes 190 which had been retrofitted with a 3-cylinder Elsbett engine. In the article, Elsbett claimed that their Mercedes got 54 miles per gallon in the city and 93 miles per gallon on the highway with a top speed of 105 miles per hour. Although Elsbett engines appear to be superior to the modern Diesel, Elsbett engines are handmade and cost at least twice as much as other Diesel engines. For this reason, the Elsbett company has recently turned its attention to modifying existing Diesel engines to run on straight vegetable oil.

SAFETY PRECAUTIONS

Avoiding Injector Coking

Running a Diesel engine on straight vegetable oil can *coke* the injectors and cause engine damage. Coking means that the tips of the injectors become coated with a thick, hard layer of unburned fuel. After injector coking occurs, the injectors will begin to spray incorrect quantities and patterns of fuel. This can result in damage to cylinder walls and piston rings. Since most of the coking occurs when an engine is started on cold vegetable oil, Diesel engines running on straight vegetable oil must be started on diesel fuel or biodiesel fuel, switched to hot vegetable oil for the majority of the running time, and then idled for a short time on diesel or biodiesel fuel before being shut off. Idling the engine on diesel or biodiesel before shutting the engine off ensures that the fuel injector pump, the injectors, and all of the fuel lines are clear of any vegetable oil.

Diesel engines running on straight vegetable oil must be started on diesel fuel or biodiesel fuel, switched to hot vegetable oil for the majority of the running time, and then idled for a short time on diesel or biodiesel fuel...

Engine Coolant

Coolant is also called antifreeze. Usually, coolant is a mixture of 50% water and 50% green ethylene glycol-based solution. The purpose of coolant is to keep the engine cool. It does this by circulating around the engine. The heat from the engine is transferred to the coolant. The hot coolant then flows through a *radiator* which uses a network of thin metal pipes to transfer the heat into the surrounding air. This cools the coolant which exits the radiator and goes back around the engine.

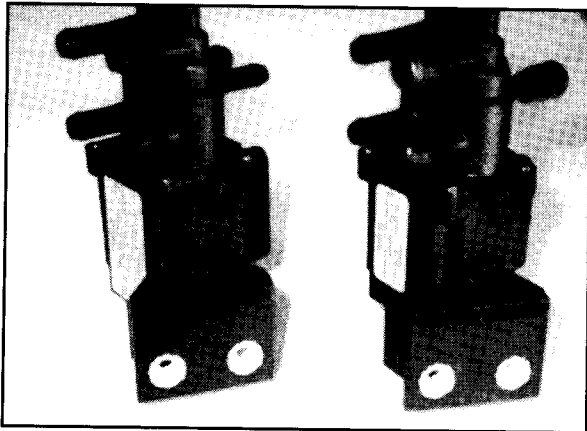
Engine coolant heats to at least 160° F (70° C) when the engine is running. Allow a Diesel engine at least 3 hours to cool down after running before disassembling, cutting, or otherwise modifying engine coolant and heater hoses. Preferably, all work done on the coolant system should be done in the morning after the engine has been turned off all night. Never open the radiator cap of an engine which is warm.

The ethylene glycol in coolant tastes sweet to animals such as cats and dogs. If a sufficient quantity of coolant is swallowed, it can be fatal. Do not allow coolant to drain onto cement where it can form puddles. Always store coolant in sealed containers. Always put engine coolant back into the coolant system.

Installing An Extra Fuel Tank

A few people have written to us concerning the safety of an extra fuel tank. We do not recommend the installation of an extra gasoline tank. Gasoline is very explosive. However, vegetable oil is not explosive. Installing a tank to hold vegetable oil is not dangerous. The installation of a vegetable oil tank into a vehicle is as safe as transporting vegetable oil from a supermarket.

PARTS FOR MODIFYING A DIESEL TO RUN ON STRAIGHT VEGETABLE OIL



The 3-port solenoid valve on the right and the 6-port solenoid valve on the left both have 6 ports, or nozzles. However, the 3-port solenoid valve on the right has rubber caps on 3 of its 6 nozzles.

switch fuel return lines. The straight vegetable oil modification eliminates the need for fuel return lines.

The Fuel Return Loop

Instead of returning fuel to the diesel tank as a normal Diesel vehicle would, the modified Diesel engine will pump fuel from the return side of the injector pump into the feed side of the injector pump. The return fuel line will be cut 2 feet (60 cm) after it leaves the injector pump. After the fuel return line is cut, it will be looped around and connected to the feed line on the injector pump with a tee connector. The injector pump will then pump fuel through the return line, into the feed line, and back into the pump. There will be a circulation of fuel from the injector pump, to the return line, to the feed line, to the injector pump. Meanwhile, more fuel will flow into the feed line. Re-routing the fuel return line into the injector pump eliminates the need to heat a fuel return line to the vegetable oil tank.

The Custom-Made Heated Tank

In order to run a Diesel engine on straight vegetable oil, it is necessary to build a heated, metal fuel tank. It is possible to build the fuel tank from sheet metal, however, aluminum is preferable because it does not rust. The aluminum tank will be installed in the vehicle and used as a second fuel tank. When the bottom and sides of the aluminum tank have been assembled, a loop of copper pipe is laid in a zig-zag pattern along the bottom of the tank. Two holes are drilled in the bottom of the front wall of the tank. This is the tank wall which will face the front of the car. The ends of the copper pipe are then inserted into the holes so that the ends protrude through the wall of the tank. The ends of the copper pipe are soldered to the aluminum tank.

A fuel pickup pipe will bring vegetable oil from the bottom of the tank near the copper pipe up to the feed nozzle on top of the tank. The fuel pickup pipe and feed nozzle will be welded or bolted into the top of the tank. An extra option that the tank builder can install in the top of the tank is a fuel tank sender unit and float. The sender unit and float can be wired to the fuel gauge in the dashboard of the vehicle. The last step of the fuel tank building process involves welding the top of the tank, fuel pickup pipe, and feed nozzle to the aluminum tank. The aluminum tank looks like a normal fuel tank when it is finished, except for the two short pieces of copper pipe protruding through the bottom of the front wall of the tank.

The 3-Port Solenoid Valve

Either the 3-port or the 6-port solenoid operated fuel valve made by the Pollak Corporation and sold by JC Whitney can be used for this modification. At the time of writing, the 3-port valve and the 6-port valve are the same. The only difference between the units is that the 3-port valve comes with 3 of the 6 nozzles capped with rubber caps. To use the 6-port valve for this modification, block off or ignore the 3 smaller fuel nozzles. The 3-port valve will switch the source of fuel from the diesel fuel tank to the vegetable oil tank but it will not

The ends of the copper pipe that is inside the tank will be connected to coolant hoses from the Diesel engine. Coolant from the engine flows through the copper pipe inside the tank. As the engine and coolant heat up, the copper pipe inside the vegetable oil tank also heats up. The hot copper pipe heats the vegetable oil inside the tank.

The vegetable oil tank must have regular automotive fuel cap. This is the cap that you unscrew before filling a car with fuel at a service station. This cap has a small vent in it that allows air to slowly enter the tank as fuel is consumed by the engine. If the vegetable oil tank has a tight sealing cap instead of an automotive fuel cap, the tank could collapse in upon itself.

The vegetable oil tank can be built and installed by a professional fuel tank builder. Fuel tank building is done by some radiator repair shops, some boat builders, some automotive racing shops, and some off-road outfitters. To find an aluminum fuel tank builder, look in off-roading magazine ads and call boat builders and radiator shops.

The Hose Within a Hose

The *hose within a hose* is a length of translucent polyethylene hose inside a larger diameter black hi-temp heater hose. Vegetable oil flows in the polyethylene hose and coolant flows in the heater hose, but the two liquids never mix. The purpose of the hose within a hose is to heat the vegetable oil from the vegetable oil tank to the engine compartment. Since the vegetable oil is surrounded by hot coolant, the vegetable oil heats quickly and evenly.

The two ends of the hose within a hose are identical. One end of the hose within a hose is in the engine compartment near the solenoid valve. The other end of the hose within a hose is next to the vegetable oil tank. At each end of the hose within a hose, the vegetable oil line passes through an adapter which is attached to the coolant hose. An o-ring is slid down the vegetable oil line until it meets the adapter. A compression nut is then slid down the vegetable oil line and screwed onto the adapter, clamping the o-ring around the vegetable oil line and making a tight seal between the coolant hose and the vegetable oil line.

Before the vegetable oil line is inserted into the coolant hose, a tee connector is spliced into the hose near each end. At the end of the hose within a hose in the engine compartment, the tee connector connects to one of the car's two heater hoses. At the end of the hose within a hose next to the vegetable oil tank, the tee connector connects to one of the two ends of the copper heating pipe in the vegetable oil tank. A separate coolant hose is attached between the other end of the copper heating pipe and the other heater hose in the engine compartment.



A fuel tank cap has a very small opening in it that allows air to enter the tank as fuel is consumed by the engine.

The purpose of the hose within a hose is to heat the vegetable oil from the vegetable oil tank to the engine compartment. Since the vegetable oil is surrounded by hot coolant, the vegetable oil heats quickly and evenly.

Once the vegetable oil heating system is complete, there will be a circulation of engine coolant from the heater hoses in the engine compartment, through the hose within a hose, to the vegetable oil tank, and back to the heater hoses. Coolant will flow through the system in the following order:

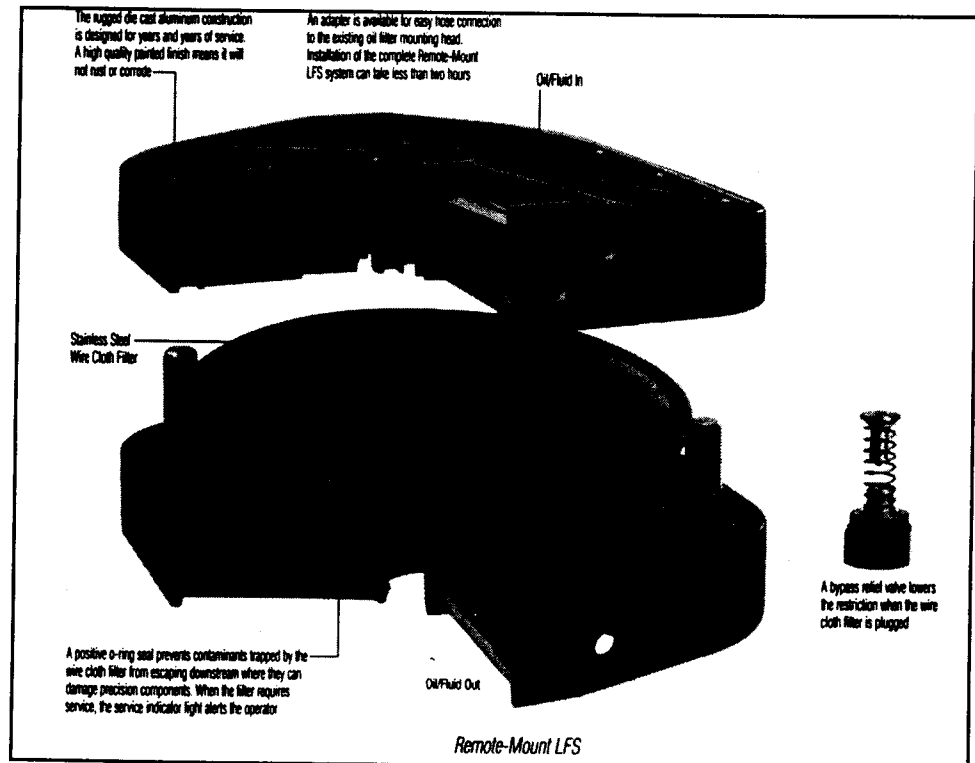
1. From the hot engine
2. Through one of the car's heater hoses
3. Into the tee connector on the hose within a hose
4. Through the hose within a hose
5. Out of the tee connector on the other end of the hose within a hose
6. Into one end of the copper heating pipe in the vegetable oil tank
7. Out of the other end of the copper heating pipe in the vegetable oil tank
8. Into another coolant hose called the *coolant return hose*
9. Into the other heater hose in the engine compartment
10. Back into the engine

The Vegetable Oil Filter

A Diesel engine will run on used cooking oil that is passed through a 40 micron filter. The used cooking oil does not need a filter pre-heater for a 40 micron filter as long as it has been heated at the vegetable oil tank and has been flowing in the hose within a hose. 40 micron filters are available for engine oil, hydraulic oil, and farming equipment. The Racor LFS remote-mount oil filter comes with a removable, washable 40 micron mesh screen which works well.

Although a Diesel engine will run on vegetable oil which is passed through only a 40 micron filter, it is advisable to pass the vegetable oil through a 25, 15, or even 10 micron oil filter before the vegetable oil is injected into the engine. These smaller micron oil filters require that vegetable oil is heated with a fuel filter pre-heater.

The Racor Remote-Mount LFS is designed to filter engine oil on boats and is perfect for filtering hot vegetable oil. Both 28 and 40 micron stainless steel mesh screens are available for the LFS. Reprinted from Racor Brochure No. 7501 USA, "Marine Filtration Products."



The Fuel Filter Pre-Heater

There are a number of fuel filter pre-heaters which are designed to heat diesel fuel right before it enters the fuel filter. These heaters can heat vegetable oil enough to pass through a small micron fuel filter. Fuel filter pre-heaters are either coolant operated or electric. In general, coolant operated heaters will bring vegetable oil to a higher temperature than electric heaters. Racor makes a coolant operated fuel heater as well as several electric fuel heaters. Another brand of electric fuel heater is the Dieseltherm. Look in the Resource Guide for Racor and Dieseltherm.

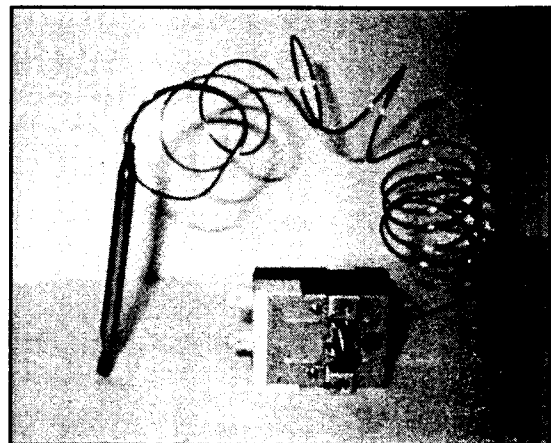
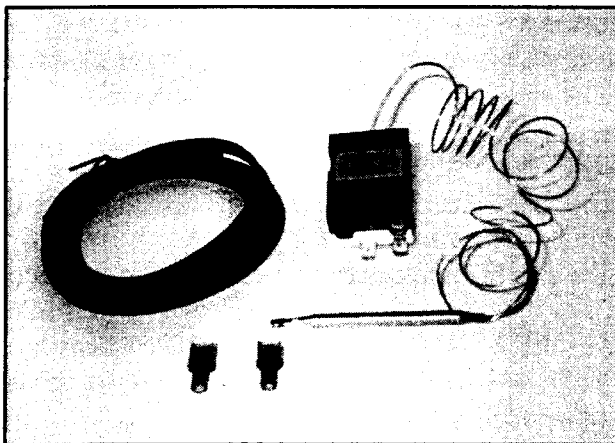
When the thermostitch senses that the coolant is the temperature which you have selected, it will activate the solenoid valve which will switch the fuel from diesel fuel to vegetable oil.

The Thermostitch (Optional)

A *thermostitch* is a temperature activated switch. A thermostitch is also called a thermostat switch. Most automobile radiators have a thermostitch mounted on them. When the radiator gets hot, the thermostitch turns on a fan to cool the radiator. Good thermostitches are adjustable. Adjustable thermostitches are available at automotive parts stores and through JC Whitney. The use of the thermostitch is not for a radiator, but for the vegetable oil tank.

The switching of the vegetable oil fuel system can be automated by adding a thermostitch to the coolant hose near the vegetable oil tank. When the thermostitch senses that the coolant is the temperature which you have selected, it will activate the solenoid valve which will switch the fuel from diesel fuel to vegetable oil. Even if a thermostitch is installed, switching the automobile back to diesel fuel before shutting the engine off will still be done manually.

The thermostitch can be installed inside one of the coolant hoses near the vegetable oil tank. Adjusting the thermostitch is done by measuring the temperature in the vegetable oil tank with a thermometer and comparing it to the temperature in the coolant hose. When the temperature in the vegetable oil tank is 160° F (70° C), the thermostitch should activate the solenoid operated valve.



Left: The thermostitch available from JC Whitney includes wire, tab connectors, and a mounting bracket. **Right:** The temperature adjustment knob is on the other side of the thermostitch. The wire between the sensor probe and thermostitch is very fragile. The switch has an operating range of 140° F (60° C) to 270° F (132° C).

PARTS LISTS

Following are the parts needed for the straight vegetable oil conversion. O.D. means "outer diameter." I.D. means "inner diameter." These parts are based on standard measurements. We include the metric conversion for each of the sizes. These parts are available in the United States at hardware stores and automotive parts stores. However, exact equivalents of some hoses and fittings which are available in standard measurements in the U.S. are not available in countries which use the metric system. If you live outside the U.S., use similar metric sizes for the parts listed here.

Parts: Tank and Coolant Return Hose

1. A custom-made aluminum fuel tank with a loop of copper pipe installed into the bottom of the tank. The tank must have a fuel pickup pipe, a fuel nozzle, and a normal automotive filler cap.
2. Some brackets to secure the tank.
3. 20-30 feet (10 meters) of $\frac{5}{8}$ inch (15.875 mm) I.D. hi-temp heater hose. Buy this black, flexible hose at an automotive parts store. We refer to this as the coolant return hose.
4. Two $\frac{5}{8}$ inch O.D. or $\frac{3}{4}$ inch (19.05 mm) O.D. copper, aluminum, or plastic tee connectors. The size of these tee connectors should correspond to the size of the heater hoses in your vehicle.
5. Six $\frac{3}{4}$ inch hose clamps.
6. Masking tape.
7. A permanent marker.

Parts: Solenoid Valve, Thermostat, and Filter

1. A 6-port solenoid operated valve with the 3 smallest of the 6 nozzles plugged or ignored.
2. 6 feet (2 meters) of $\frac{3}{8}$ inch (9.525 mm) I.D. black automotive fuel hose.
3. One $\frac{3}{8}$ inch O.D. plastic fuel line tee connector.
4. Six $\frac{3}{4}$ inch hose clamps.
5. A small amount of red, white, and blue enamel paint.
6. 10-20 feet (3-6 meters) of 18 gauge electrical wire.
7. One 10 amp automobile fuse and fuse holder.
8. An adjustable thermostat.
9. Oil filter of your choice, such as the Racor LFS with the 40 or 28 micron screen filter or a smaller micron filter and a fuel filter pre-heater.

Parts: Hose Within a Hose

There are many ways to make a hose within a hose. The parts listed here are the correct size to connect to the Pollak brand solenoid valve.

1. 20-30 feet of $\frac{5}{8}$ inches I.D. hi-temp heater hose. We refer to this as the coolant hose.
2. 20-30 feet of $\frac{3}{8}$ inches I.D. $\frac{1}{2}$ inch (12.7 mm) O.D. polyethylene hose. This is a translucent piping which is often used for fountain drink machines and ice makers. We refer to this as the vegetable oil line.
3. Two $\frac{5}{8}$ inch or $\frac{3}{4}$ inch plastic, copper, or aluminum tee connectors for the coolant hose. The tee connectors can be slightly larger than the inner diameter of the coolant hose to create a tight fit.

4. Two $\frac{1}{2}$ inch o-rings. The o-rings must be the same diameter as the outer diameter of the vegetable oil line.
5. Two $\frac{1}{2}$ inch compression nuts. The threads on these nuts are actually $\frac{5}{8}$ inches in diameter, but the nuts are made to slide onto a $\frac{1}{2}$ inch diameter pipe.
6. Two $\frac{1}{2}$ inch male threaded to $\frac{3}{4}$ inch coarse female threaded adapters.
7. Two $\frac{3}{4}$ inch coarse male threaded to $\frac{5}{8}$ inch hose nipple adapters. The hose nipples on these adapters go into the coolant hose. The male threaded ends of these $\frac{3}{4}$ inch adapters screw into the female threaded ends of the $\frac{1}{2}$ inch male threaded fittings. You can eliminate these adapters if you can find $\frac{1}{2}$ inch male threaded to $\frac{1}{2}$ inch hose nipple adapters.
8. Eight $\frac{3}{4}$ inch hose clamps.

PREPARATION AND ASSEMBLY PROCEDURES

Preparation: Custom-Made Heated Tank

1. Determine the location where the aluminum tank will be installed. Possible locations include: in the trunk, under a bench seat inside the vehicle, in the spare tire compartment, under the dashboard on the passenger's side of the vehicle, under the vehicle near the main fuel tank, or in the bed of a pickup truck.
2. Measure the space where the fuel tank is to be mounted. If the tank is to have a custom shape, draw the shape and measure all dimensions.
3. Using the dimensions you noted in step 2, make a mock tank out of cardboard.
4. Fit the cardboard tank into the space where the real tank will be installed and determine:
 - a. How the tank will be mounted to the frame of the vehicle. What special hardware will be needed to mount the tank. What special flanges or brackets (if any) will have to be welded to the tank.
 - b. Where the fuel line and coolant hoses will be routed.
 - c. Where on the tank the fuel line will connect to the tank.
 - d. Where the two coolant hoses will connect to the tank.
 - e. From where the tank will be filled. Possible locations for a fill opening are in the side of the vehicle, in the trunk, or in the engine compartment.
 - f. The route of the *filler pipe*. This is the pipe that goes from the tank to the fill opening.
 - g. Any modifications that will have to be done to the chassis of the vehicle to accommodate the new tank.
5. Mark the locations on the mock tank where the fuel and coolant nozzles and the filler pipe will be located. Also mark any bracket locations.
6. Take the mock tank to an aluminum shop or a fuel tank builder.

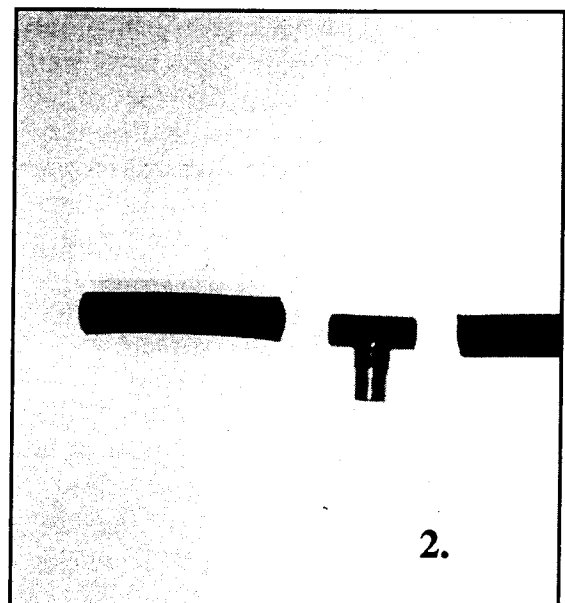
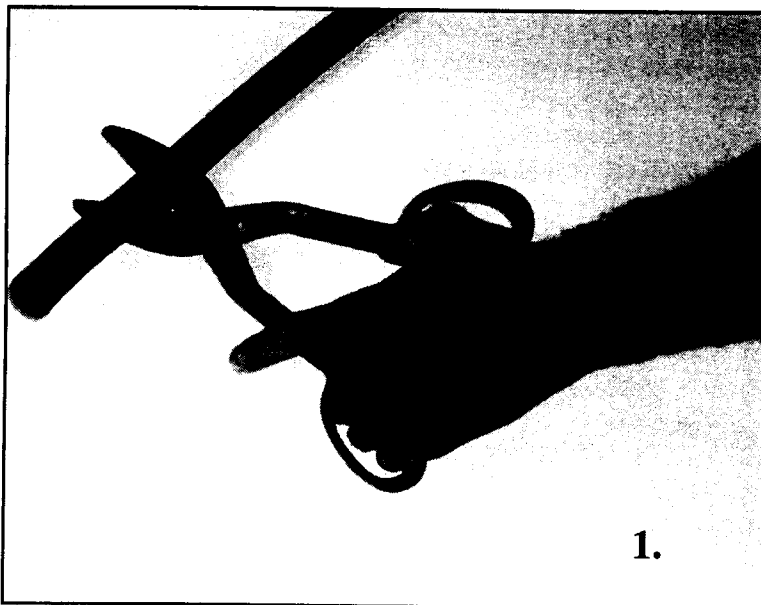
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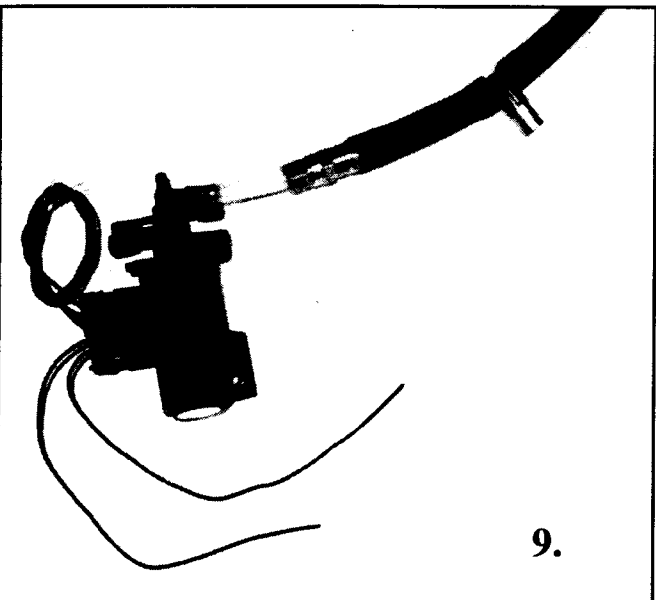
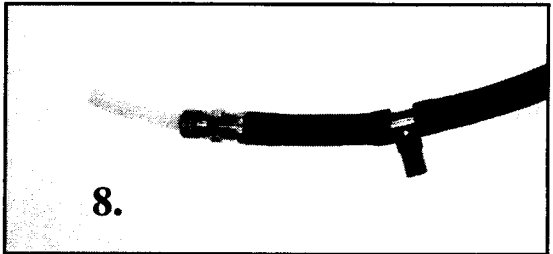
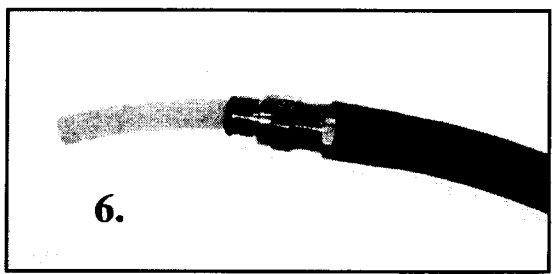
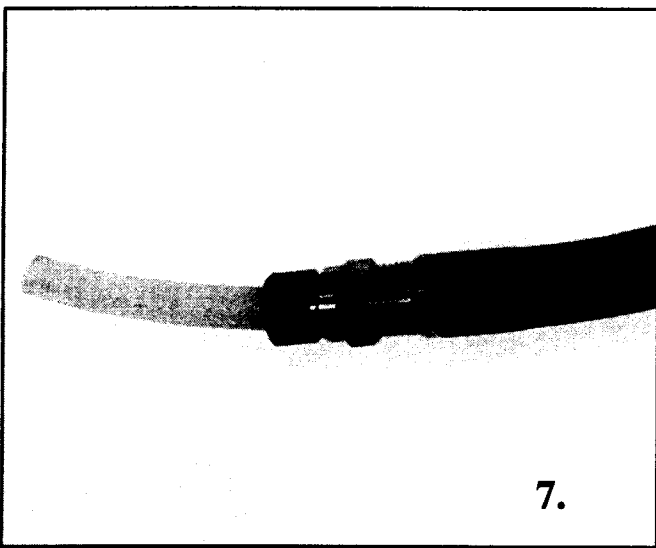
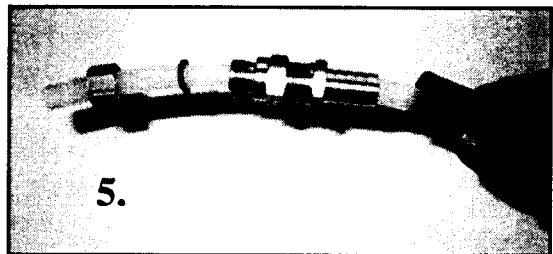
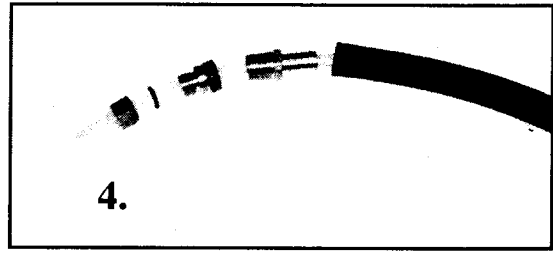
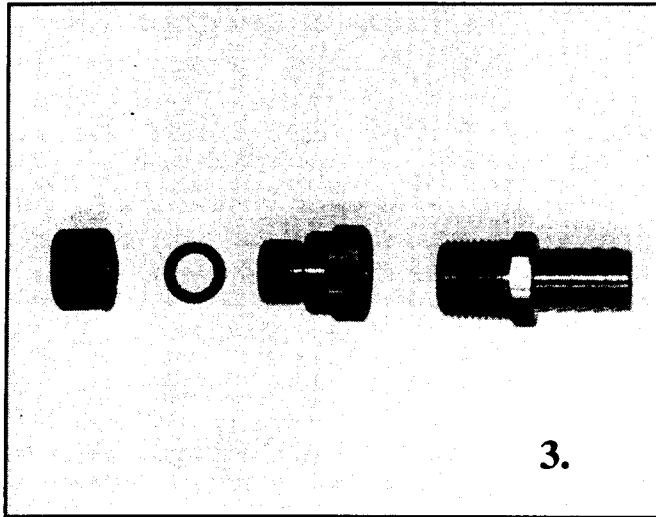
Assembly: Hose Within a Hose

1. Measure the route from the vegetable oil tank to the *heater hoses* inside the engine compartment. The heater hoses are the two hoses which come out of the engine and go through the firewall to the vehicle heater. Use a piece of string to get an accurate measurement.
2. Cut the coolant hose to the length measured in step 1. Leave 6-8 inches (18 cm) extra.
3. Insert a tee connector 4 inches (10 cm) before each end of the coolant hose. Secure the tee connectors with hose clamps.
4. Run the vegetable oil line inside the coolant hose. Leave about 10 inches (25 cm) of extra polyethylene hose hanging out of each end of the coolant hose. Cut the vegetable oil line.
5. Put a hose clamp loosely onto one end of the coolant hose.
6. Slide a $\frac{3}{4}$ inch male threaded to $\frac{5}{8}$ inch hose nipple adapter over the vegetable oil line until it meets with the coolant hose.
7. Push the hose nipple adapter into the coolant hose and secure it with a hose clamp.
8. Slide a $\frac{1}{2}$ inch male threaded to $\frac{3}{4}$ female coarse threaded adapter down the vegetable oil line until it meets the $\frac{3}{4}$ inch male threaded adapter.
9. Apply some thread seal tape to the $\frac{3}{4}$ inch male threaded adapter.
10. Screw the two adapters together. Tighten them together with two wrenches.
11. Slide an o-ring down the vegetable oil line. Push the o-ring down until it meets the male threaded compression fitting.
12. Slide a female threaded compression nut down the vegetable oil line. Screw it onto the male threaded compression fitting. This should cinch the o-ring around the polyethylene hose and create a watertight seal.

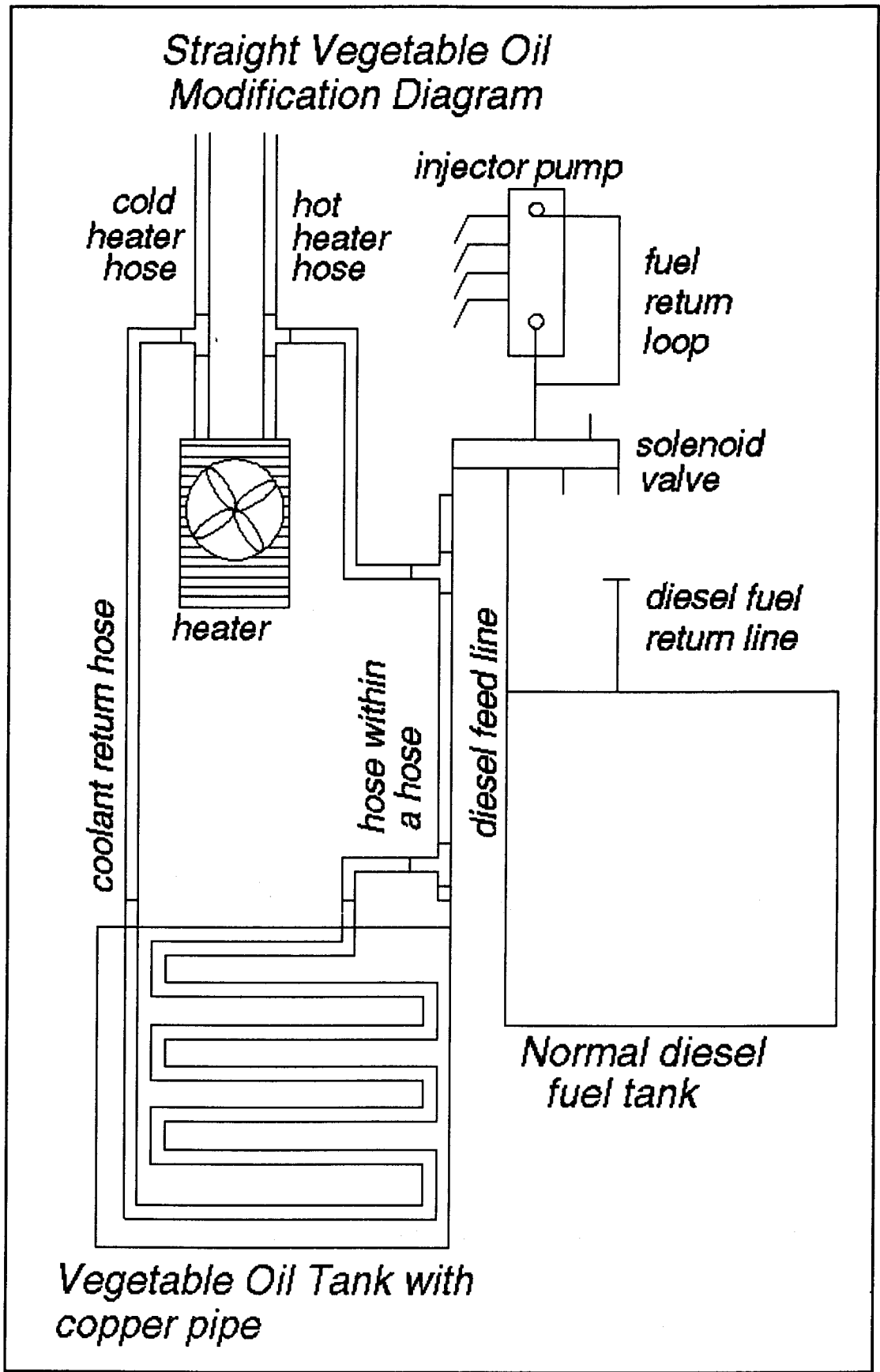
Follow steps 5-12 for completing the other end of the hose within a hose.

Assembling the hose within a hose is perhaps the most important part of the straight vegetable oil modification. 1. In order to insert a tee connector into the coolant hose, it is necessary to cut the hose first. 2. Once the hose is cut, a metal, copper, or plastic tee connector is inserted into the hose. The tee connector must be secured with a hose clamp on each side.





3. The brass adapters slide onto the end of the polyethylene hose in this order. Teflon thread seal tape should be placed around the male threaded brass fittings prior to assembly. 4. These brass adapters will clamp the o-ring around the polyethylene hose. When the compression adapters are screwed together, they will form a tight seal between the coolant hose and the polyethylene hose. 5. The o-ring will be clamped between the male and female compression fittings. 6. The nipple adapter slides into the coolant hose and the o-ring is forced around the polyethylene hose and pushed down against the male compression fitting. 7. The female compression fitting is screwed on. 8. The end of the hose within a hose is complete except for hose clamps. 9. The hose within a hose is preliminarily attached to the solenoid valve to check for proper fit and spacing. The last step in assembling the ends of the hose within a hose is to secure all of the adapters with hose clamps.



INSTALLATION PROCEDURES

The *heater hoses* take coolant to and from the vehicle heater. These hoses pass through the firewall in the back of the engine compartment. One heater hose takes hot coolant to the car's heater and the other heater hose brings cooler coolant from the heater back to the engine. We refer these hoses as the "hot" and "cold" heater hoses. These heater hoses are usually either $\frac{5}{8}$ inch or $\frac{3}{4}$ inch inner diameter. If you cannot tell which hose is hot and which is cold or where the heater in your vehicle is, get a good service manual with pictures.

Installation: Tank and Hoses

1. Route and secure the hose within a hose from the vegetable oil tank location to the heater hoses in the engine compartment.
2. Cut a length of coolant hose to the same length as the hose within a hose. This new hose will be the coolant return hose from the vegetable oil tank back to the engine compartment.
3. Route and secure the coolant return hose along the same path as the hose within a hose.
4. Install the vegetable oil tank.
5. Attach the vegetable oil line of the hose within a hose to the fuel nozzle on the vegetable oil tank.
6. Attach the coolant return hose to one of the copper pipes on the bottom of the vegetable oil tank. Secure the hose with a hose clamp.
7. Measure the distance between the tee connector near the end of the hose within a hose at the vegetable oil tank and the unused copper pipe on the bottom of the tank.
8. Cut a small length of coolant hose and attach it between the tee connector near the end of the hose within a hose and the unused copper pipe on the vegetable oil tank. Secure each end with a hose clamp.

Installation: Hoses in the Engine Compartment

1. Determine the location of the two heater hoses in the engine compartment.
2. Determine which heater hose is cold and which is hot. Sometimes it is necessary to turn on the vehicle and the heater and feel the heater hoses to determine which becomes hotter. The hotter of the two hoses will be the hot hose. The cooler hose will be the cold hose.
3. Put a piece of masking tape on each hose and label them "hot" and "cold."
4. Follow the directions in your vehicle's service manual to drain the coolant system. Save the coolant in a sealed container.
5. Cut the cold heater hose in the engine compartment at the point where you would like to attach the coolant return hose from the vegetable oil tank.
6. Put a hose clamp on each end of the cold heater hose you cut.
7. Insert a tee connector into the cold heater hose and tighten the hose clamps.
8. Attach the coolant return hose to the tee connector and secure it with a hose clamp.
9. Cut the hot heater hose at the point where you would like to attach the hose within a hose.
10. Put a hose clamp on each end of the hot heater hose you cut.
11. Insert a tee connector into the hot heater hose and tighten the hose clamps.
12. Cut a small length of coolant hose.

13. Attach one end of the small length of coolant hose to the tee connector in the hot heater hose. Secure it with a hose clamp.
14. Attach the other end of the small length of coolant hose to the tee connector near the end of the hose within a hose. Secure it with a hose clamp.

Installation: Refill Coolant and Check for Leaks

Now you have attached all of the coolant hoses and the tank end of the vegetable oil line. The engine end of the vegetable oil line is still unattached.

1. Open the plastic coolant overflow container and pour the coolant you drained from the system back in. Close the cap, start the engine and check for leaks.
2. Let the vehicle idle and warm up and see if the vegetable oil tank gets warm.
3. Check the coolant level after the car has run for some time. If the level is low, add distilled water to the plastic coolant overflow container. Do not open the radiator cap under any circumstances.

Installation: The Solenoid Operated Valve

The solenoid operated valve has 6 nozzles and 5 wires. We are only concerned with the 3 large nozzles and the two wires which lead to the toggle switch.

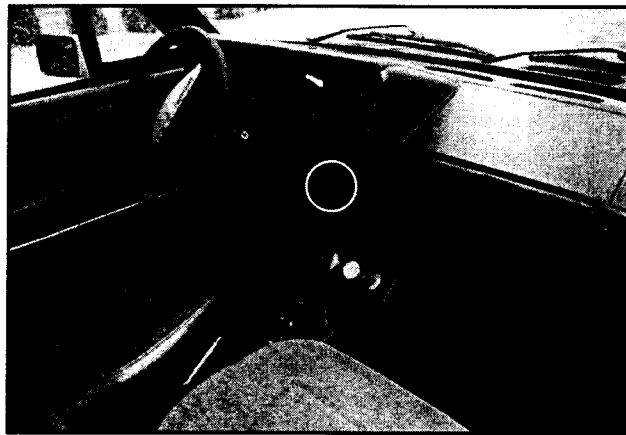
1. Remove the solenoid valve from its box and inspect it. There should be one large nozzle on one side of the solenoid valve and two large nozzles on the other side.
2. Blow through the two large nozzles on one side to determine which one is open.
3. Mark open nozzle with some red paint. The red nozzle designates the default fuel flow path when the solenoid valve is turned off.
4. Mark the blocked nozzle with white paint. The white nozzle must attach to the vegetable oil line.
5. Mark the nozzle on the other side of the solenoid valve with blue paint. The blue nozzle connects to the fuel pump feed line.
6. Attach the solenoid valve to the sheet metal on the side of the engine compartment. You may have to drill holes and use sheet metal screws.
7. Attach the vegetable oil line from the hose within a hose to the white nozzle on the solenoid valve.
8. Follow the directions that come with your oil filter. Install the filter into the vegetable oil line directly before the solenoid valve.
9. Remove the hard piece of fuel line which goes between the fuel filter and the injector pump.
10. Use a hose clamp to attach a new piece of fuel hose to the fuel filter.
11. Attach the other end of the new piece of fuel hose to the red nozzle on the solenoid valve.
12. Use a hose clamp to attach a new piece of fuel hose to the injector pump.
13. Attach the other end of the hose from step 11 to the blue nozzle on the solenoid valve.
14. Check your work so far. There should be a fuel hose from the fuel filter to the large red nozzle on the solenoid valve. There should be another fuel hose from the injector pump to the large blue nozzle on the solenoid valve. The vegetable oil line from the hose within a hose should be connected to the large white nozzle on the solenoid valve.

15. There is another fuel line on the injector pump which we have not touched. This fuel line is the return line to the diesel fuel tank. Pull this line off of the injector pump.
16. Plug the end of the line with a screw and a hose clamp.
17. Wrap the fuel return line up into a coil and secure it out of the way. Label it "diesel tank return line." You will not use this line again.
18. Use a hose clamp to attach a 24 inch (60 cm) long piece of fuel line to the injector pump. This is the new fuel return line.
19. Cut the fuel line leading from the blue nozzle on the solenoid valve to the injector pump about 3 inches (8 cm) before the injector pump.
20. Insert a small plastic tee connector into the fuel line you just cut. Attach a hose clamp to each side of the tee connector.
21. Making sure that the fuel return line does not bend sharply or kink, bring the new fuel return line from the fuel injector pump to the tee connector. Make a mark on the new fuel return line where it meets the tee connector.
22. Cut the excess hose off the fuel return line and attach it to the tee connector with a hose clamp.

Installation: The Toggle Switch

A toggle switch is included in the box with the solenoid valve. This toggle switch is a double pole, double throw (DPDT) switch. Only a DPDT switch will work with the solenoid valve.

1. Mount the toggle switch inside the vehicle within easy reach of the driver.
2. Follow the wiring instructions included with the toggle switch and the solenoid valve. Although the solenoid valve has 5 wires, only 2 wires are necessary to operate the valve. These 2 wires lead to the toggle switch. 2 other wires lead from the car's battery to the toggle switch. When the toggle switch is in the "on" position, it connects the positive and negative wires from the battery with the two wires from the solenoid valve.
3. Install an automotive fuse and holder near the solenoid valve on the positive wire. If you are not familiar with automotive electronics, find a qualified mechanic or electrician to install the toggle switch and connect power to the battery.
4. Check your work. Leave the toggle switch in the "off" position and disconnect the wires to the solenoid valve.
5. Start the engine and let it idle.
6. Touch the wires from the toggle switch to the solenoid valve. Did the solenoid valve make a "clunk" sound?
 - a. If no, go to step 7.
 - b. If yes, or if sparks occurred or the car stopped, go back and recheck the wiring.
7. Turn the car off and re-attach the wires from the toggle switch to the solenoid valve.
8. Try the experiment again. Do not proceed until the touching of the wires has no effect on the solenoid valve.



Mount the toggle switch on the dashboard within easy reach of the driver. Photo courtesy of John Wiles.

In order to prime the injector pump, fuel must be manually pumped through the fuel line to the injector pump.

Installation: Priming the Injector Pump

Most Diesel fuel injector pumps are not self-priming. When a pump is self-priming, it will pump air until it pulls liquid through. But a fuel injector pump must have fuel from the tank, through the line, and into the pump before it can pump the fuel. In order to prime the injector pump, fuel must be manually pumped through

the fuel line to the injector pump.

1. Detach the fuel line attached to the white nozzle on the solenoid valve. This is the feed line from the vegetable oil tank.
2. To ensure that there are no blockages in the vegetable oil line, blow air through it or shoot some compressed air through the hose. Remove the fuel cap from the tank before you do this. You should be able to hear bubbles in the vegetable oil tank.
3. Pull a vacuum on the vegetable oil line with a hand-operated suction pump, a vacuum cleaner with a small sucker, or anything that pulls a vacuum.
4. When vegetable oil flows freely from the vegetable oil line, re-attach the line to the solenoid valve.

Installation: The Thermoswitch

The adjustable thermoswitch sold by JC Whitney consists of an adjustable switch with two wires and one sensor probe. The thermoswitch wires will be connected in series in the positive wire between the toggle switch and the solenoid valve. The sensor probe will be inserted into the coolant return hose where it connects to the vegetable oil tank. When the coolant which is returning from the vegetable oil tank to the engine gets hot enough, the thermoswitch will activate the solenoid valve which switches the fuel source to vegetable oil.

1. Disconnect the coolant return hose at the vegetable oil tank. You may need to partially empty the coolant system before doing this to avoid spilling coolant.
2. Insert the probe from the thermoswitch into the coolant hose.
3. Reconnect the coolant hose to the vegetable oil tank. Be careful not to cut the probe wire. Secure the coolant hose firmly with a hose clamp.
4. Turn the toggle switch to the "off" position.
5. Cut the positive wire between the toggle switch and the solenoid valve.
6. Use 18 gauge wire to extend each end of the newly cut wire to the location of the thermoswitch. If the toggle switch is mounted on the dashboard but the vegetable oil tank is in the trunk then you will need to make each wire long enough to reach the thermoswitch.
7. Attach one thermoswitch wire to the positive wire from the toggle switch.
8. Attach the other thermoswitch wire to the positive wire from the solenoid valve.
9. Adjust the thermoswitch so that it activates the solenoid valve when the temperature of the vegetable oil in the tank reaches 160° F (70° C).

PUTTING IT ALL TOGETHER

Here is an example of how your modified Diesel car will run on straight vegetable oil. It is a cold day. You get into your modified Diesel car and start the engine. Since there is diesel fuel or biodiesel fuel in the main tank, your Diesel engine starts normally. As you think about the 30 minute drive ahead of you, you flip the toggle switch on your dashboard and arm the vegetable oil system. Meanwhile, the vegetable oil in your second fuel tank is turning from a solid block of lard into hot, flowing vegetable oil. In the few minutes that it takes to drive out of your neighborhood, hot engine coolant is circulating in the pipe inside the vegetable oil tank, heating the vegetable oil.

When the thermostwitch near the vegetable oil tank senses that the coolant has reached the temperature you selected, the thermostwitch switches on and turns the solenoid valve on. The valve from the main diesel tank is closed and valve from the vegetable oil tank is opened. Your

Diesel engine does not miss a beat. You notice that it idles a little more quietly. As you roll down your window to let in some fresh air, you notice the sweet smell of french fries. Upon nearing your final destination, you flip the toggle switch to the "off" position. Electricity stops flowing to the solenoid valve, which instantaneously switches the fuel source back to the diesel tank. As you pull into a parking space, your engine purrs along, washing the vegetable oil from the fuel pump and the injectors. You turn your Diesel off and wonder why nobody believed you when you told them you were going to run your car on french fry oil.

As you roll down your window to let in some fresh air, you notice the sweet smell of french fries... You turn your Diesel off and wonder why nobody believed you when you told them you were going to run your car on french fry oil.

C H A P T E R 1 0

TROUBLE SHOOTING AND SUCCESS STORIES

This chapter focuses on the experiences of people experimenting with biodiesel and vegetable oil in their backyards, workshops, kitchens, and laboratories. The first part of this chapter answers common questions and problems about biodiesel and vegetable oil and their use in a Diesel engine. The second part of the chapter is a compilation of success stories from researchers and pioneers who have used numerous techniques to fuel their Diesel vehicles with biodiesel and vegetable oil. Both sections contain valuable information for anyone considering the use of vegetable oil as an alternative fuel.

TROUBLESHOOTING: USED COOKING OIL

Most restaurants in my area have contracts with grease recycling companies. How do you suggest I get the oil from them?

You will need to establish a good rapport with the manager of at least one restaurant. Family run restaurants are often more willing to give used cooking oil away. Using a few gallons of used vegetable oil to begin experimentation will not infringe upon a recycling contract. If you begin using large quantities of used cooking oil, you can establish your own recycling contract with a restaurant.

The used cooking oil that I've collected is very dirty. How do I tell if it's too dirty to use?

Try making a mini batch of biodiesel from 100 milliliters or 500 milliliters of the used oil. If it works on a small scale, it will work on a larger scale. To use the oil in a straight vegetable oil Diesel engine modification, first heat the oil and pass it through a mesh screen or restaurant fryer filter.



I am worried about the used cooking oil I have gathered going bad. How long can I store it?

Vegetable oil should be kept in dark containers in as cool and dry a location as possible. Keep containers as full as possible to minimize contact with air and moisture. In warm climates, microorganisms can grow in used vegetable oil in as little as a month. In colder climates, used vegetable can store indefinitely. If the oil is processed into biodiesel, it will store for up to a year in most climates, and indefinitely in colder climates.

If the used cooking oil you collect is very dirty, you can test it by making a mini batch of biodiesel.

TROUBLESHOOTING: METHANOL

Where do you suggest I store methanol?

Store methanol in a cool, dry location in containers which have been approved to contain fuel. Make sure the methanol is labeled. Keep in mind that methanol is extremely flammable. Keep methanol out of the reach of children.

TROUBLESHOOTING: BIODIESEL REACTION

I made biodiesel with new canola oil and it came out fairly dark, with the glycerin being very dark. Is this coloration normal?

As long as there are two distinct layers and the bottom layer is substantially darker than the top layer, you have probably made biodiesel. To be sure, test the specific gravity with a hydrometer. The glycerin is always dark brown. The biodiesel varies in color from golden to dark amber. Biodiesel is slippery and pours easily. Glycerin is thick and sometimes gelatinous.



The titration is the most accurate means of determining how much catalyst to use. Photo courtesy of DOE/NREL.

After I've made biodiesel a few times, do I still have to do the titration?

The titration is the most accurate means of determining how much catalyst is needed to neutralize the free fatty acids in used cooking oil. Since every batch of oil is slightly different, we advise that you determine the amount of catalyst needed for each reaction. Making trial and error mini batches of biodiesel is the other means of determining the necessary quantity of catalyst.

About a month ago, I performed a titration on some used cooking oil and I mixed the correct amount of lye and methanol together. I finally got around to mixing the sodium methoxide into the vegetable oil today, but it did not form two layers as it should have. Is there some glaring error that I have missed?

Yes, the error is that you mixed sodium methoxide and then let it sit for a month. The biodiesel reaction is time sensitive. You must mix the sodium methoxide with the vegetable oil immediately after the sodium methoxide is created.

Something went wrong with my reaction, how do I tell if I added too much or too little lye?

Using too much lye will result in hard soap. The soap will create suds if water is added to it. Too little lye will result in unreacted vegetable oil and methanol. To determine the precise amount of lye to use, you must correctly perform a titration. The purpose of the titration is to neutralize the free fatty acids in the sample of used cooking oil. When performing a titration, the ideal pH to achieve is between 8 and 9. If the pH is below 8, you have not added enough lye. If the pH is above 9, you have added too much lye.

I have made biodiesel but I am afraid to use it without washing it. How essential is the water wash? What are the potential problems that could occur if I do not wash my fuel?

Washing biodiesel removes minute quantities of catalyst, glycerin, and methanol. Since a small amount of impurities does not adversely affect the performance of a Diesel engine running on biodiesel, we do not wash the biodiesel that we make. According to tests done by the Nez Perce Tribe biodiesel project, unwashed biodiesel produced normal wear patterns when tested in a variety of Diesel engines.¹

I'm afraid of having excess water in my biodiesel if I attempt to wash the fuel. What does excess water in the biodiesel do to the engine?

Although the ASTM specifications for biodiesel allow for only 0.05% or 500 parts per million of water in the fuel, up to 0.25% or 2,500 parts per million of water in the fuel will not harm most Diesel engines. Most homemade biodiesel fuel will have between 0.05% and 0.20% (500-2,000 parts per million) of water in it.² Excess water in the fuel can cause pitting of the metal in fuel injectors as well as pitting of cylinders and pistons. Good Diesel engine fuel filters have a clear bowl at the bottom in which water will collect. There is a small valve on the bottom of the bowl which can be opened to drain the water. Although it is not essential, you can purchase such fuel filters from Racor and other filter manufacturers. You can also install a water absorber in the fuel tank to absorb water in the fuel. Water absorbers are sold by Hiperfuels, see the Resource Guide for more information.

I would like to remove the excess alcohol in my biodiesel. Can I do this by heating the biodiesel, rather than by washing it with water?

You can remove excess alcohol in biodiesel by heating it past the boiling point of the alcohol you used in the reaction. Heat the biodiesel for 10-15 minutes in an open container in a well ventilated area to 148° F (65° C) if you used methanol in the reaction and 175° F (79° C) if you used ethanol in the reaction. This is an energy intensive process. We do not recommend removing the excess alcohol from biodiesel unless your vehicle has rubber fuel hoses or you are making biodiesel to meet ASTM specifications.

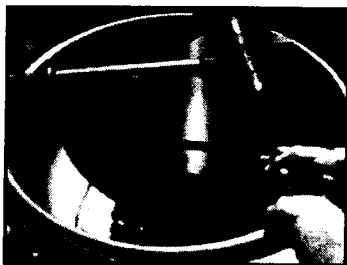
You can remove excess alcohol in biodiesel by heating it past the boiling point of the alcohol you used in the reaction.

I have made 25 gallons of biodiesel in my homemade processor. It looks good, however, there is a thin layer of clear, crystalized stuff floating on top of the biodiesel. What is this and what should I do about it?

It sounds like you produced some glycerin soap with a high oxygen content. Scoop the glycerin layer off the top of the biodiesel with a mesh strainer and compost it.

How do I know if the biodiesel I have made is clean enough to go into the engine?

If the biodiesel has been filtered through a 10 micron filter, it will be free of any particles. Check the specific gravity of the biodiesel with one of the hydrometers listed in the Resource Guide. The specific gravity of biodiesel should be between 0.860 and 0.900.



Cleaning the glycerin from the biodiesel mixing tank after a biodiesel reaction is very important.

I have successfully made biodiesel in my homemade processor. Do I have to clean the reaction tanks, and if so how often and with what? How much does it affect the chemistry to have a little leftover biodiesel and glycerin in the fresh batch?

Do not leave any glycerin in the reaction vessel after the reaction. The lye in the glycerin can disturb the next reaction. Make sure there is no water in the reaction tanks. It is fine to leave some biodiesel in the biodiesel mixing tank. It is not necessary to wash the tanks after each batch of biodiesel. When our equipment looks dirty, we wash it with glycerin soap and water. The tanks can also be wiped down with a mild alcohol to ensure there is no chemical residue. As long as the glycerin is removed, cleaning the equipment is more a matter of personal preference than anything else.

TROUBLESHOOTING: MAKING SOAP

How pure is the glycerin byproduct I have made?

Homemade biodiesel produces a crude glycerin which may contain unreacted alcohol, catalyst, food particles, and water. This glycerin can be used as a degreasing soap or composted on the ground. This glycerin is not of the same purity as industrially produced glycerin, however, it is non-toxic and biodegradable. The glycerin can be heated to remove excess alcohol and water. When heated, the glycerin becomes liquid and can be filtered to remove food particles. Fragrances and other soap agents can be added to the glycerin to make it a more pleasant soap.

I attempted to make a large batch of biodiesel today and ended up with a container full of "jelly." I think I used too much lye. Can I use the jelly as soap or is there methanol in it?

To avoid future mistakes, make a miniature batch of biodiesel using the same proportions you intend to use in your large reaction before you make the large batch. If the mini batch fails, change the amount of catalyst and make another mini batch.

...if something goes wrong and you use too much lye in the biodiesel reaction, you will create soap. If there is a hard substance and a liquid substance, the harder substance is soap and the liquid substance is vegetable oil, soap, and biodiesel.

Nevertheless, if something goes wrong and you use too much lye in the biodiesel reaction, you will create soap. If there is a hard substance and a liquid substance, the harder substance is soap and the liquid substance is vegetable oil, soap, and biodiesel. First, drain any runny liquid from the main portion of the hard, jelly-like soap. You will now have two products, a liquid and a soap.

You can attempt to re-transisterify the liquid. Simply go through the transesterification procedure, including the titration. If the pH of the vegetable oil/alcohol mixture in the titration is higher than 7, you will only need to add between 1 and 3 grams of lye per liter of liquid. Perform a series of trial and error mini batches to determine if you can get the liquid to react. Once you have performed a successful mini batch, try re-reacting all of the liquid.

If your mistake created hard soap or just one gelatinous mixture, you can complete the *saponification* reaction and make useful soap. First, heat the soap mixture past 148° F (65° C), which is the boiling point of methanol or 175° F (79° C), which is the boiling point of ethanol. This will boil any alcohol out of the mixture. Do this in a well ventilated area in an open container and do not breathe the fumes. Allow the mixture to stay heated for at least 10 minutes and then allow the mixture to cool.

If your mistake created hard soap or just one gelatinous mixture, you can complete the saponification reaction and make useful soap.

Now you have a mixture of vegetable oil and lye. Subtract the amount of lye you used per liter of vegetable oil in your biodiesel reaction from 135 grams. We will call this number (L). For example, if you used 6.5 grams of lye per liter of vegetable oil in your biodiesel reaction, you will get (L) = 128.5 grams. Now multiply (L) times the number of liters of mixture you have. This is the total number of grams of lye you will need to add to make your mixture into true soap.

If you used KOH instead of lye in the biodiesel reaction, subtract the amount of KOH you used per liter of vegetable oil from 190 grams. This number is (K). Multiply (K) times the number of liters of mixture you have. This is the total number of grams of KOH you will need to add to make your mixture into true soap.

Multiply the number of liters of mixture times 340 milliliters. For example, if you have 10 liters of mixture, multiply 10 x 340 milliliters = 3,400 milliliters or 3.4 liters. We will call this number (W) and it will represent the amount of water to use. Pour (W) milliliters of water into a pyrex, iron, or enamel cooking pot. Bring the water to 90° F (32° C). Slowly add (L) grams of lye or (K) grams of KOH to the water and stir until the catalyst is dissolved. Keep the catalyst/water at 90° F (32° C). Wear gloves and protective clothing.

In a separate, large pot, bring the vegetable oil mixture from your biodiesel reaction to 110° F (43° C). Pour the catalyst/water solution into the vegetable oil mixture in a thin, slow stream. Continue to heat the mixture as you stir slowly and evenly for 10-20 minutes or until the soap mixture begins to thicken. When the mixture thickens, pour the still warm soap mixture into

...pour the still warm soap mixture into a thick cardboard or wooden box which has been lined with a damp cotton cloth. The cotton cloth should be soaked in water, wrung almost dry, and then placed in the box.

a thick cardboard or wooden box which has been lined with a damp cotton cloth. The cotton cloth should be soaked in water, wrung almost dry, and then placed in the box. Put the box in a pan in case it leaks. Once the soap mixture has been poured into the box with the cotton cloth, put a board on top of the box. Then put an old blanket or rug on top of the box to keep the heat in. Leave the box for 24 hours.

Remove the block of soap by pulling the sides of the cloth out of the box. Once the block of soap has been removed, it can be cut into smaller blocks. Allow the blocks of soap to sit in the open air for 2-4 weeks before using them.

TROUBLESHOOTING: DIESEL ENGINES

After switching from diesel fuel to biodiesel, our Diesel VW Vanagon experienced a significant loss of power. The van already had a top speed of 55 and labored going uphill but now it can't even make it up some of the hills in our area. We thought that maybe this was due to injector clogging. If it is, then what can we do about it?

If your vehicle is experiencing more than a 5% power decrease with biodiesel, there is a problem in your fuel delivery system or in another system. The first thing to do anytime your Diesel vehicle experiences a problem that could be fuel-related is to replace the air filter.

If your vehicle is still having problems after you replace the air filter, replace the fuel filter. Some people pour fuel from the old filter into the new filter, do not do this. Instead, fill the new fuel filter with new fuel before screwing it on. While you are replacing the fuel filter, check the fuel line leading from the fuel tank to the fuel filter housing. Make sure it is not swollen, it does not have any signs of cracking, it

...check the fuel line leading from the fuel tank to the fuel filter housing. Make sure it is not swollen, it does not have any signs of cracking, it is not sticky to the touch, and it is not leaking.

is not sticky to the touch, and it is not leaking. Next, check the fuel line leading from the injector pump back to the fuel tank. Again, look for signs of wear or swelling. If either of the fuel lines are suspect, replace them with Viton® or another brand of flouroelastomer synthetic hose. When you replace the fuel filter, also check that fuel is flowing freely through the fuel line from the fuel tank to the fuel filter. To check for proper fuel flow, you might have to pull a vacuum on the fuel line.

If you have replaced both the air filter and the fuel filter and the vehicle is still having problems, check the fuel in the fuel tank. Biodiesel can loosen slime, rust, oil, and general gunk that can settle inside the fuel tank over the years that the vehicle was running on petroleum diesel. If you pull a sample of fuel from the fuel tank and there is gunk floating in it, you will need to have the fuel tank in your vehicle removed, drained, cleaned, and checked for rust.

If you replaced the filters, checked the fuel in the fuel tank, and your Diesel is still experiencing problems, then it is worth checking the injectors. Get a good automotive repair manual for your vehicle and follow the directions for removing the injectors. If the injectors have black, coked residue on their tips, you can attempt to clean them. While there are more professional means of cleaning the injectors, you can clean injectors with a toothbrush and parts cleaning solvent. Wear gloves and eye protection and do this in a well ventilated area.

Once the injectors have been cleaned, they can be tested with an injector tester such as the one sold by China Diesel. Each injector should spray an even, circular pattern of fuel. If you are unfamiliar with your vehicle and would prefer to have it professionally serviced, make sure you take it to a mechanic who specifically works on Diesels.

When I started using biodiesel in my brand new Diesel vehicle, the “water in fuel” or the “service engine” light came on. The engine is running well. Do you think there is water in the fuel?

Unless the light came on while you were using regular diesel fuel, there is probably no water in the biodiesel fuel. The sensor on the fuel system is made to sense high levels of oxygen. Normally, extra oxygen would mean that there is water in the fuel. Since biodiesel is an *oxygenated* fuel, it has more oxygen than diesel fuel. The sensors in some new Diesel vehicles sense the oxygen in biodiesel and turn on the water in fuel light or the service engine light. These sensors cannot change the operation of the engine, they are only a warning mechanism. To check for water in the fuel, follow the manufacturer’s directions to unscrew the drain valve on the bottom of the fuel filter. If water drains out, replace the fuel filter. If fuel drains out, close the valve on the fuel filter and ignore the warning light.

Since biodiesel is an oxygenated fuel, it has more oxygen than diesel fuel. The sensors in some new Diesel vehicles sense the oxygen in biodiesel and turn on the water in fuel light...

I have made the vegetable oil/kerosene extra tank modification to my Diesel car, but the extra tank seems to be getting fuller with use, rather than emptier.

You have the fuel return lines crossed on the 6-port solenoid valve. Your car is pulling fuel from one tank and returning it to the other tank. To correct the problem, switch the fuel return lines on the solenoid valve.

Can I blend vegetable oil with gasoline instead of kerosene and run that mixture in a Diesel engine?

We recommend that you do not do this. Diesel engines are not designed to run on gasoline. Fueling a Diesel engine with gasoline can result in rapid and catastrophic engine failure.

TROUBLESHOOTING: COLD WEATHER

I want to store 200 gallons of homemade biodiesel over the winter. Do I have to put chemicals in the fuel to prevent gelling? Will microorganisms still grow in the fuel when the weather is cold?

Anti-gel formulas are unpredictable at best. We have had some success with Amsoil Diesel Fuel Additive. If the fuel will be stored in a barn or outdoor shed in cold conditions, you will have to find a way to heat the fuel if it gels. Microorganisms generally do not grow in cold weather. To ensure that microorganisms do not grow, add some biocide or biostat to the biodiesel and fill the fuel containers all the way to the top.

Can I use a winterizing agent or anti-gel formula in straight vegetable oil or vegetable oil kerosene fuel?

No. Winterizing agent forms an emulsification in diesel fuel. A winterizing agent or anti-gel formula would just float on top of straight vegetable oil or vegetable oil kerosene fuel because they are too thick for the emulsification to take place.

SUCCESS STORIES

Everyday folks all over the world are using vegetable oil as an alternative fuel. Here are the stories of some of the many vegetable oil pioneers and engineers.

I took it in my lab, made minor adjustments in the recipe, and made a gallon of beautiful fuel from grease. Wow! As a chemist, I had a wonderful time for the next few months making “transesterified waste vegetable oil” from many feedstocks.

The History of McDiesel

In the summer of 1989, I learned about the conversion of animal fats and vegetable oils to their methyl esters for fuel purposes. The process is called transesterification and is quite simple. Being interested in alternate fuels, I mulled this over in my subconscious and in November 1989, I wondered what happened to all that good oil/fat when it was “used up.” I found that there are over a billion gallons (over 3.8 billion liters) a year under the heading “yellow grease” which are used for soap, cattle feed and other products, but it has a very low

value (<\$1/gallon) relative to new oil.

I wondered if it could be used to make the esters for fuel. I went to our local McDonald’s and got a gallon of “waste grease” from their grease dumpster in back. (UGH!) I took it in my lab, made minor adjustments in the recipe, and made a gallon of beautiful fuel from grease. Wow! As a chemist, I had a wonderful time for the next few months making “transesterified waste vegetable oil” from many feedstocks. I even made it from bacon grease at Christmas in my daughter-in-law’s kitchen from grocery store components.

At that time, the Denver RTD bus company was considering alternate bus fuels. I approached the bus company to see if they were interested in this alternative clean fuel. They were, but they needed more than a gallon to test. I went to our laboratory at the Colorado School of Mines and made 100 gallons (380 liters) in 2 drums for testing by RTD.

I decided to call it McDiesel. I applied for a copyright. I even approached McDonald’s to see if they were interested. They were, but said they would sue me if I used that name.

I didn’t think “transesterified waste vegetable oil” was a very good name, so, considering the source, I decided to call it McDiesel. I applied for a copyright. I even approached McDonald’s to see if they were interested. They were, but said they would sue me if I used that name. Later people came to call these fuels “biodiesel,” and I now live with that. However, I would love to have had McDonald’s sue me – what publicity!

I formed a company with two other people to make and promote McDiesel. We published a number of papers, talked to many people, and even entered into an agreement with a chemical engineering company.

We discovered that there was NO political base for using low cost waste grease for an alternate fuel. There was a tremendous base for spending much more money to make biodiesel from soy oil. Now biodiesel is highly political and there is a newsletter telling of test results and new companies hoping for government subsidies courtesy of global warming. Check them out at www.biodiesel.org.

In February 1990, we tested the fuel in a bus and it ran fine and had low emissions. We have published a number of papers on biodiesel from waste grease, but no one is particularly interested. Meanwhile biodiesel from soy is still \$3-\$4 a gallon.

Thomas B. Reed, Director
 Biomass Energy Foundation
 Golden, Colorado

We discovered that there was NO political base for using low cost waste grease for an alternate fuel. There was a tremendous base for spending much more money to make biodiesel from soy oil. Now biodiesel is highly political...

From Idaho to the Islands

We have been producing biodiesel since 1987 and have extensively tested the fuel in both stationary and mobile vehicles here in Idaho. I have been promoting the use of biodiesel since then. With my volunteer work overseas, I was able to set up a pilot plant in the Philippines in 1995, utilizing coconut oil. The coconut biodiesel is used in a pickup truck and in small Diesel generators. Here in Idaho, I have been using used/waste cooking oil from area restaurants to turn into biodiesel since 1996. We used the biodiesel in a 1996 Dodge Ram 2500 pickup truck with a Cummins Diesel Engine, a 1997 Chevy Suburban, a 1992 Ford 250, and a 1974 Mercedes Benz 240D. Last year our funding from the U.S. DOE ended, so everything ceased. We have used the Dodge Ram in long trips from Idaho to Florida and back, also to Tennessee and back. We still have our production equipment which has a 300 gallon (1,140 liter) per day capacity and we are making biodiesel in our spare time.

The pilot plant in the Philippines is still producing about 25 gallons (95 liters) a day, and I'm trying to expand the project there. This year alone, I have been in the Philippines 3 times and will be back there at the end of this month to promote and expand the biodiesel project. I am committed to promote the use of biodiesel worldwide.

Dr. Rico Cruz
 Craigmont, Idaho

I was able to set up a pilot plant in the Philippines in 1995, utilizing coconut oil. The coconut biodiesel is used in a pickup truck and in small Diesel generators.

Biodiesel in Yellowstone National Park

The "Truck in the Park" Biodiesel Demonstration Project has been a 3-year effort. The truck was fueled with canola ethyl ester from off-spec Montana-grown canola oil from Koch Ag Services, and fuel ethanol from potato waste at JR Simplot's Caldwell, Idaho plant.

Initially, the park officials were concerned that bears might be attracted to the truck since the exhaust smells like french fries.

The vehicle used for biodiesel testing in Yellowstone was a 1995 Dodge three quarter ton 4x4 pickup with a 5.9 liter B-series Cummins Diesel engine. Dodge donated the truck to the project. The truck was equipped with a standard winterization package for Diesel engines. No modifications were made to the truck's engine or fuel system.

Initially, the park officials were concerned that bears might be attracted to the truck since the exhaust smells like french fries. Bear attractant tests showed that bears were not interested in the exhaust smell.

The truck was driven over 97,600 miles (157,040 kilometers) without any major fuel related problems. Items carried with the truck as a precaution included: fuel filters for the truck and fuel pump, replacement fuel lines, and an L-shaped rubber fuel elbow that went from the fuel tank to the fuel pump. This rubber elbow piece was first replaced in the spring of 1996 when the end fell off the engine as the truck was pulling off the road to re-fuel. The 100% biodiesel softened the rubber, causing the part to become loose. After this incident, the elbow was changed about every two oil changes.

Operation during two Yellowstone winters showed that normal cold weather diesel modifications were sufficient to enable the use of biodiesel in cold weather operations. These included engine coolant, an engine block heater, battery heaters, an external (electric, magnetic) fuel tank heater, and a heating loop to the slip tank. The truck was parked in a garage at night or plugged into an outlet when night temperatures dipped below 20° F (-6.7° C). The truck failed to run on only one occasion with a daytime temperature of -37° F (-38.3° C), a time when most things were running for cover.

Both sets of emissions tests showed carbon monoxide (CO), total unburned hydrocarbons (HC), and oxides of nitrogen (NO_x) were reduced by increasing the percentage (to 20%, 50% and 100%) of biodiesel in the fuel. Particulate matter (PM) was unaffected or slightly increased with increasing percentages of biodiesel. The catalytic converter operated more efficiently when biodiesel was used. The preliminary findings indicate that emissions have not increased over time, and the catalytic converter does not appear to be fouled by the use of biodiesel.

H. E. Haines and J. Evanoff
Yellowstone National Park, Wyoming

Reprinted from "Environmental and Regulatory Benefits Derived from the Truck in the Park Biodiesel Emissions Testing and Demonstration in Yellowstone National Park."

Aussie Farmers for Biodiesel

We represent a group of farmers from a place called Beacon, 3½ hours northeast of Perth in Western Australia. We are called the “Creative Cockies” (Cockies being a term for farmers). As part of our focus on a Better Business Training session, we all looked at value adding our products. We grow canola (rapeseed), chick peas, lupines, barley, oats, and wheat. We then got on to using the canola oil as an alternative fuel source. We did a bit of a search on the net and that’s where we came across your website.

We have trailed the biodiesel in a Lister engine and a tractor. Both went very well and the smell was very pleasant compared to the diesel.

We have just finished making our first batch of biodiesel, from the recipe in your book. We have trailed the biodiesel in a Lister engine and a tractor. Both went very well and the smell was very pleasant compared to the diesel. Our mixture, having stood for the 8 hours, separated into two layers. The bottom one was very dark and appeared to be the soapy type substance you refer to.

We are excited about biodiesel and we plan to make larger batches in the future. Thank you!

Sally Rapton and Peta Kirby
Beacon, Australia

Alaskan Biodiesel

Having read about your book/manual in *Home Power Magazine*, I sent off for it, and I have read it cover to cover. I studied the lab procedure and performed three successful reformulations with new corn and canola oil. I successfully ran a Diesel generator with the biodiesel. I am sincerely interested in the possibilities for biodiesel here in Juneau, Alaska. There are more than 60 restaurants disposing of used oil here in the landfill. I was having some difficulty making biodiesel from used cooking oil but then I finally figured out what the titration thing was all about and figured out the correct amount of lye for the used oil.

My largest batch so far is 5 liters. I’m working on the washing process and it is going well. I cannot find acetic acid in Juneau. It’s a hazardous substance, so getting it shipped up here is prohibitive. Though washing with water is settling out a lot of the free glycerin.

I am sincerely interested in the possibilities for biodiesel here in Juneau, Alaska. There are more than 60 restaurants disposing of used oil here in the landfill.

So we’re continuing to work on it, and looking for a Diesel vehicle. You wouldn’t know anybody interested in a gas-burning Honda Civic, would you?

Tom Osborn
Juneau, Alaska

Down the Road with Vegetable Oil

I have been experimenting with vegetable oil fuels in my Diesel Volkswagen Rabbit for over two years and 20,000 miles (32,000 kilometers). I've tried some different fuel blends including biodiesel with varying degrees of success. The best arrangement I have found, in terms of cost, convenience, reliability, cleanliness and pollution reduction, is to use waste restaurant fryer oil (which is free!) thinned

The best arrangement I have found, in terms of cost, convenience, reliability, cleanliness and pollution reduction, is to use waste restaurant fryer oil (which is free!) thinned with kerosene (30-50% final volume – less in summer, more in winter).

with kerosene (30-50% final volume – less in summer, more in winter). I use a 5 gallon (19 liter) jug as a second fuel tank and separate, heated fuel lines to keep the vegetable oil fuel thin in winter.

From the start I had trouble finding other people with hands-on experience or knowledge of vegetable oil fuels. There was some research done in the early 1980s, but virtually all of it studied large direct injection agricultural Diesels running on new oil either neat or as a low

percentage fuel extender. Small indirect injection engines, such as those in most cars, were ignored and no one was looking at waste fryer oil as a fuel stock or kerosene as a thinning agent.

Here are a few vegetable oil fuel basics gleaned from journal articles and experiences. Most concern fuel injector fouling (which, if neglected, can potentially lead to stuck rings and cylinder scoring).

- High-oleic canola and peanut oil are the best.
- Store oil in topped-off plastic jugs in a dark place to reduce oxidative gum formation.
- You can clean the tips of the injectors with solvent.
- With a double fuel tank set-up, start and warm up the car on diesel and switch back to diesel before shut down.

The double tank system uses a five gallon jug, which rides in the back of the car, and metal fuel lines which run under the car along the exhaust pipe to keep the fuel warm in winter and allow switching between diesel and vegetable oil. To refill, I simply exchange the empty jug for a full one. The valves that join the vegetable oil fuel lines to the rest of the fuel system are operated by choke cables from the passenger compartment.

Lee Connah
Hood, Virginia

Reprinted from *Home Power Magazine* #45.

The BioRabbit

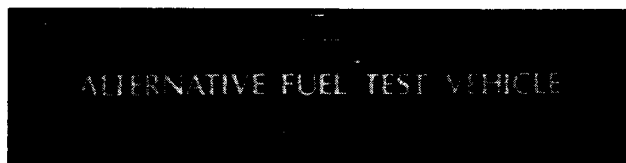
I would like to share my biodiesel story with you. It started with reading about the Veggie Van and biodiesel last summer in *Home Power Magazine*. At the time I was employed by a company that owned five McDonald's restaurants. The idea that I could power an auto with the used and wasted soy oil drove me crazy. I had to try it. I soon purchased a 1981 VW Rabbit pickup truck, and was burning my first gallon of biodiesel the day I brought it home. It is now about a year later and my project sports a new paint job and lettering stating what it is and what it does. Some days the "BioRabbit" stops traffic. Some people ask questions and some just don't believe it. That is, until they get a whiff of Chicken McNuggets (my choice for used oil) coming from the tailpipe. I have used many different blends of biodiesel. At this time, I am running 100% soy oil in a heated and pressurized tank. This tank allows the BioRabbit to run with ease, even in cold Maryland winters.



The BioRabbit uses two extra fuel tanks. The extra tank in the rear stores 10 gallons of used cooking oil. The extra tank under the hood, the *use* tank, provides fuel for the engine. The use tank under the hood retains heat longer. Both tanks are made of metal, the storage tank is from an old VW Beetle. Both tanks are heated by heat produced from the engine. Antifreeze is directed through the engine to the tanks and back to the engine through copper piping. The temperature of both tanks can be regulated. The fuel from the 10 gallon storage tank is pumped into the use tank at 3 p.s.i. A pressure switch at the use tank cycles the fuel pump on and off as fuel is needed. This system was a compromise using parts that were already on hand. A single fuel pump with a bellows and float switch would be better.

The BioRabbit uses three fuel tanks: The original diesel fuel tank, a vegetable oil storage tank, and a small pressurized tank in the engine compartment.

The heated tanks are branched off of the heater hose before entering the heater. The copper pipe is wrapped and soldered to the outside of the tanks; I don't like drilling holes in things unless I really have to. The temperature inside the tanks is regulated by the same type of valve that controls the heat in a car's cabin. My tanks warm to about 105° F (40° C). I lose a lot of heat from poor heat transfer, but that's no big deal because 105° is plenty warm. In addition to this system I could add an electric heater, the kind that heats and pumps antifreeze through the cooling system.



I have not installed an electric solenoid valve yet but do have one on the drawing board. I warm up and cool down my engine on diesel fuel. The system on the drawing board will do this automatically. The solenoid valve will be operated by two timers, one will start counting when the engine starts. This timer will count about 5 minutes and then switch the fuel supply from diesel to soy oil. After stopping and turning the ignition off, the second timer will switch back to diesel and keep the engine running for about five minutes.

Signs on the BioRabbit let people know that this is no ordinary Volkswagen. Photos courtesy of John Wiles.

I've had a lot of trouble finding a filter that lasts more than a week or two without diminished fuel flow. I have had to pull out my fuel injectors several times since experimenting with biodiesel to clean them due to the lack of a good filter. I'm going to order an oil filter system. The kit allows you to relocate your car's oil filter to a remote location so it is easier to change when you do an oil change. This kit will allow me to use an oil filter to filter my fuel. Good oil filters can catch particles as small as 15 microns. For now, I have a Frymaster filter machine in my basement. I filter my oil very well and also use a product called Magnasol. This is a product McDonald's uses when it filters its oil. Magnasol is a white powder that is placed on the filter paper before filtering. It forces the food particles to clog together, making them easier to filter. When I use Magnasol, the filtered oil is cleaner and is actually lighter in color than before filtering.

I have started looking for a replacement for the BioRabbit. The BMW 524TD made from 1985 to 1986 looks like a good replacement, a little more horsepower and a lot more comfort. The injection pump and injectors are the same as in the VW diesel.

I would like to thank you for starting me down this road, I've enjoyed the ride.

John Wiles
Mechanicsville, Maryland

Jatropha Rabbit

The Better World Workshop has just completed the conversion of a VW Rabbit automobile to be powered by jatropha oil. The car's operation on jatropha oil was so completely satisfactory on its maiden voyage of 50 miles (80 kilometers) on June 10, that we drove 300 miles (480 kilometers) on June 11 to a business meeting in Auburn, Maine. There has been no visible exhaust smoke with jatropha oil, and fuel consumption is approximately 45 miles per gallon (19.2 km/liter), approximately the same as with diesel fuel. We are switching back to diesel about one mile before shutdown when we expect to stop the car for several hours.

The conversion consists of a separate 5 gallon (19 liter) fuel tank for jatropha oil, located within the passenger compartment between the dashboard and the firewall on the passenger side of the vehicle. Electrically operated fuel switching valves permit switching between diesel fuel and jatropha oil from a switch on the dashboard. The jatropha oil cartridge filter is heated by the engine cooling water to prevent the buildup of wax on the filter. The jatropha oil tank is heated by the passenger compartment heater whenever the heater is in operation, enabling oil to flow freely from the tank even in cold weather. There is a small console on the dashboard with two hour meters and two gauges. The hour meters show the total engine operating time and the time the engine has operated on jatropha oil. The gauges show the engine coolant temperature and lube oil pressure.

Carl Bielenberg
Marshfield, Vermont
Reprinted from "Testing a VW Rabbit Diesel Automobile with Jatropha Oil Fuel" in *Better World Workshop Newsletter*, Summer 1997 issue.

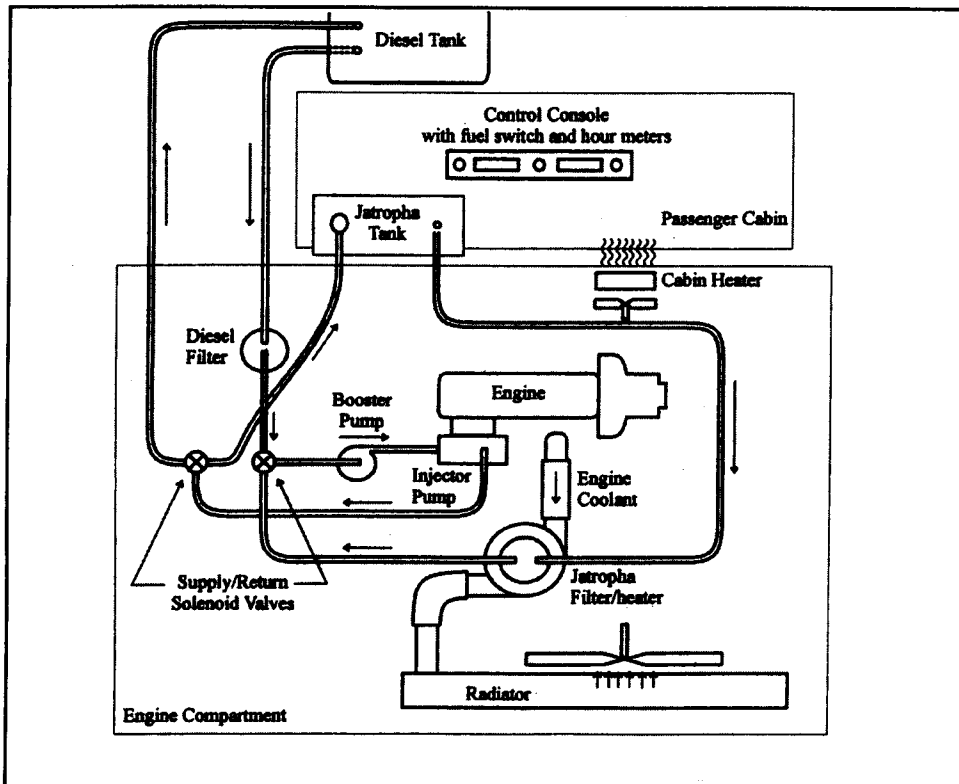


The Better World Workshop VW Rabbit runs on straight Jatropha oil. The Jatropha oil tank is installed under the dashboard on the passenger's side. Photo courtesy of Carl Bielenberg.

Veggie Tractor

I help run a vineyard and renewable energy centre in the southeast of England. We've subscribed to *Home Power Magazine* for four years now. Well, the biodiesel article you recently published was totally inspiring. I have since ordered the book from the Tickells and I can thoroughly recommend it to any of your readers. Since then, I've been zipping around fast food joints scavenging as much old cooking oil as possible. They did make a small mention in their article that the Diesel engine was originally intended to run on peanut oil. So, I jumped in at the deep end and poured several pints of filtered, but otherwise unchanged oil, straight into our tractor! After a few minutes, the smell of the exhaust did change, and that was all. The smell was the only give away that the tractor was now partly running on old cooking oil. Since then, I've added more and more oil to the fuel tank and I can now say that the tractor has been happily running on nothing but old cooking oil for about a month. Starting is just as reliable as with petroleum based diesel, although I guess that this is because the engine has a high compression ratio and never needed glow plugs in the first place. Thank you Josh and Kaia Tickell! We now have a renewable energy-powered tractor!

Tom Mudd
 Colchester, England
 Reprinted from *Home Power Magazine* #67.



The Better World Workshop Jatropha Rabbit circulates engine coolant around a modified fuel filter to heat the Jatropha oil before it enters the injector pump. Graphic courtesy of Carl Bielenberg.

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Chapter 6 How to Make Biodiesel

1. The amount of lye used in the transesterification reaction is actually 0.35% of the weight of the vegetable oil but we use the word "volume" because the volume of vegetable oil in liters is easier to measure than the weight of vegetable oil in kilograms. Each liter (1000 milliliters) of vegetable oil weighs approximately 1 kilogram (1000 grams). Therefore, 1 milliliter of vegetable oil = 1 gram of vegetable oil. Thus, 3.5 grams of lye per liter (1000 grams) of vegetable oil = 0.35%.
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1. The cost of homemade biodiesel varies depending on the price of methanol, which varies widely from region to region. We have found the cost of homemade biodiesel to range from 50 cents a gallon to \$1 a gallon, using free used vegetable oil. This cost reflects the price of methanol and lye and does not include equipment or labor.
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APPENDIX 1

DIESEL VEHICLE CHART

Make	Model(s)	Engine model and size	Features	Rating
Audi	5000 4 door & wagon	5 cyl 2L	ii, turbo used	****
BMW	524TD 1985-86	6 cyl	ii, turbo used	****
Chevrolet/Pontiac	Chevette, Pontiac T-1000 2 & 4 door	4FB1 Isuzu 4 cyl 1.8L	ii used	***
Chevrolet	LUV S Pickup Truck	C223 Isuzu 4 cyl 2.2L	ii used	***
Chevrolet/GM	Pickup Truck, Van, Suburban	V-8 6.2L, V-8 6.8L	ii used	*
Datsun/Nissan	810 Maxima 4 door & wagon	LD28 6 cyl 2.8L	used	****
Datsun/Nissan	Pickup	SD22 4 cyl 2.16L	used	****
Dodge	RAM 2500 HD Pickup	Cummins V-8 5.9L	TDI new	****
Ford	Econoline Van, F250/F350 Trucks	V-8 6.9L, V-8 7.3L	turbo used	**
Ford	Taurus, Escort	4 cyl 1.8L	turbo used	***
Ford	Ranger Pickup	Mazda S2 4 cyl 2.2L	used	***
Ford	F250,350,450,550, and heavy duty models	Powerstroke V-8 7.3L	TDI new	***
Hummer	2 & 4 door, wagon	GM V-8 6.5L	TDI new	***
Isuzu	I-Mark 2 & 4 door	4FB1 4 cyl 1.8L	used	***
Jeep	Jeep Cherokee	Renault 4 cyl 2.1L	ii, turbo used	***
Mazda	B2200 Pickup Truck	S2 4 cyl 2.2L	used	***
Mercedes	220D, 240D, 2 & 4 door, wagon	616 4 cyl 2.4L	ii used	***
Mercedes	E300D, 2 & 4 door, wagon	617 5 cyl 3L	ii, turbo used	***
Mercedes	E300 Turbo Diesel, 4 door	6 cyl 3L	TDI new	****
Mitsubishi	MightyMax Pickup Truck, Dodge D-50	4D55 4 cyl 2.3L	turbo used	****
Oldsmobile/GM	2 & 4 door, wagon	V-6 4.3L, V-8 5.7L	used	*
Peugot	4 door	XD90/XD2 4 cyl 2.3L	turbo used	***
Toyota	Pickup Truck, Camry, Landcruiser	L Series 4 cyl 2.2L	turbo used	****
Volkswagen	Rabbit, Golf, Jetta, Quantum, Scirocco, Fox	4 cyl 1.6L	ii, turbo used	****
Volkswagen	Vanagon, Pickup	4 cyl 1.6L	ii, turbo used	****
Volkswagen	New Beetle, Jetta, Golf	4 cyl 1.9L	TDI new	****
Volvo	2 & 4 door, wagon	D24 6 cyl 2.4L	turbo used	*

Key: # cyl = number of in line cylinders L = engine displacement in liters ii = indirect injection turbo = turbocharger optional TDI = turbo direct injection engine new = vehicle is available new used = vehicle is available used only

Rating: * = vehicles or engines have problems and are not recommended ** = vehicles or engines are difficult to maintain

*** = solid vehicle, but expensive or difficult to maintain **** = recommended vehicle ***** = highly recommended vehicle

Ratings are based on reader input, personal experience, interviews, and consumer reports. This is only a partial list of Diesel vehicles available in the U.S. Hundreds of Diesel vehicles have been produced in different parts of the world. You may own or want to buy a Diesel vehicle which is not on this list or you may own a Diesel vehicle which we gave a bad rating. Just remember that all Diesels can run on vegetable oil and any Diesel vehicle which has been properly serviced and maintained can be reliable.

APPENDIX 2

MATERIAL SAFETY DATA SHEET

SECTION I PRODUCT IDENTIFICATION

Common Name: Biodiesel
Chemical Name: Fatty Acid Methyl Esters
Formula: C14-C24 Methyl esters
Chemical Family: CAS No: 67784-80-9

SECTION II INGREDIENTS AND HAZARDOUS CLASSIFICATION

Typical Composition : Alkyl C14-C24 Methyl Esters
Percent: 99
OSHA ACGIH PEL/TLV: none/none
Hazard: NONE
Sara Hazard: NONE. This product contains no hazardous materials.
SARA Title III Section 313 : Not Listed

SECTION III - PHYSICAL/CHEMICAL CHARACTERISTICS

Boiling Point: >400° F
Vapor Pressure (mm Hg): <5 mm Hg @ 72° F
Specific Gravity (H₂O = 1) 0.87 @ 25° C
Melting Point: -1° C
Evaporation Rate: less than .005 versus (Butyl Acetate = 1)
Solubility in Water: insoluble
Appearance and Odor: Light to dark yellow Clear Liquid/ Light musty odor

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flash Point (Method Used): 321° F PMCC
Flammable Limits: N/A
HMIS Rating HEALTH: 0
FIRE: 1
REACTIVITY: 0
Extinguishing Media: Use water spray, dry chemical, foam or carbon dioxide
Special Fire
Fighting Procedures: Treat as Oil fire
Unusual Fire and
Explosion Hazards: Rags soaked with any solvent present a fire hazard and should be stored in an approved UL listed covered container

SECTION V - REACTIVITY DATA

Reactivity:	Stable
Conditions to Avoid:	None Known
Incompatibility (Materials to Avoid):	Strong Oxidizing agents
Hazardous Decomposition or Byproducts:	Carbon monoxide, Carbon dioxide
Hazardous Polymerization:	Will Not Occur

SECTION VI - HEALTH HAZARD DATA

Inhalation:	No known problems
Skin Contact:	Not classified as a skin irritant or corrosive material
Eye Contact:	Not classified as eye irritants
Ingestion:	LD50 >2000 mg/kg (rat)
Carcinogenicity:	NTP: No, IARC: No, OSHA: No

Emergency and First Aid Procedures:

Ingestion:	Rinse mouth with water, contact physician.
Eyes:	Rinse with water 15 min., contact physician
Skin:	Rinse with water and soap

SECTION VII - PRECAUTIONS FOR SAFE HANDLING AND USE

Steps to be taken in case

material is released or spilled: Avoid uncontrolled releases. Contain spilled material. Transfer to secure containers. Use absorbent media if necessary

Disposal: Dispose of according to federal, state and/or local regulations

Precautions To Be Taken in

Handling and Storing: Avoid open flames

Other Precautions: None

SECTION VIII - CONTROL MEASURES

Respiratory Protection:	None required
Ventilation:	Mechanical
Protective Gloves:	Rubber
Eye Protection:	Safety Glasses/splash goggles
Other Protective Clothing or Equipment:	None required
Work/Hygienic Practices:	Use general hygienic work procedures

Transportation

DOT Code:	N/A
DOT Shipping Name:	fatty acid esters
Other Regulatory:	Listed in TSCA inventory

APPENDIX 3

EXAMPLE WARRANTY FROM A U.S. BIODIESEL MANUFACTURER

AFTER-MARKET WARRANTY

Pursuant to Section 303 of the Energy Policy Act of 1992 (EPACT), and in order to comply with subsequent United States Department of Energy guidance regarding the certification of diesel-powered vehicles under the act, this is to CERTIFY and WARRANT that biodiesel "Bio G-3000™," an alternate fuel manufactured and offered for sale by GRIFFIN INDUSTRIES INC., meets or exceeds the ASTM provisional biodiesel specification adopted by the D2 Committee on Petroleum Products and Lubricants in December 1998 and any damage to a covered vehicle, directly attributable to the use of Bio G-3000™, will be repaired or parts replaced including labor by Griffin Industries Inc. This warranty shall run concurrent with the OEM warranty for each specific vehicle which utilizes "Bio G-3000™." Each such vehicle shall be considered an alternative fuel vehicle conversion within the terms of EPACT and subsequent rulings by the Department of Energy.

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APPENDIX 4

CUMMINS DIESEL FUEL SPECIFICATIONS

CUMMINS RECOMMENDED DIESEL FUEL SPECIFICATIONS			
TEST PROPERTY	ASTM TEST METHOD	ACCEPTABLE VALUE(S)	UNIT OF MEASURE
Specific Gravity	D287	0.816-0.876	g/cm ³ at 15° C
Cloud Point	D97	6° C (10° F) below lowest operating temperature	
Kinematic Viscosity at 40° C	D445	1.3-5.8	mm ² /sec. at 40° C (104° F)
Water & Sediment	D1796	0.050 max.	% vol
Sulphur	D2622	0.05 max.	% mass
Carbon Residue	D129 or 1552	0.50 max.	% mass
Cetane Number	D613	40 min. above 0° C 45 min. below 0° C	
Sulfated Ash	D482	0.020 max.	% mass
Neutralization/Acid Number	D664	0.10 max.	mg/100 ml
Lubricity	U.S. Army BOCLE test	3100 min.	grams

CUMMINS EMERGENCY DIESEL FUEL SPECIFICATIONS			
TEST PROPERTY	ASTM TEST METHOD	ACCEPTABLE VALUE(S)	UNIT OF MEASURE
Specific Gravity	D287	0.750-0.965	g/cm ³ at 15° C
Cloud Point	D97	lowest temp. fuel handling equipment will permit	
Kinematic Viscosity at 40° C	D445	1.2-13.1	mm ² /sec. at 40° C (104° F)
Water & Sediment	D1796	0.50 max.	% vol
Carbon Residue	D129 or 1552	5.00 max.	% mass
Cetane Number	D613	35 min. above 0° C 40 min. below 0° C	
Sulfated Ash	D482	0.050 max.	% mass
Neutralization/Acid Number	D664	0.20 max.	mg/100 ml
Lubricity	U.S. Army BOCLE test	2300 min.	grams

Source: "Fuels for Cummins Engines" Cummins Service Bulletin # 3379001-05.

APPENDIX 5

OIL-PRODUCING CROPS

PLANT	LATIN NAME	KG OIL/HECTARE
corn	<i>Zea mays</i>	145
cashew nut	<i>Anacardium occidentale</i>	148
oat	<i>Avena sativa</i>	183
palm	<i>Erythea salvadorensis</i>	189
lupine	<i>Lupinus albus</i>	195
rubber seed	<i>Hevea brasiliensis</i>	217
kenaf	<i>Hibiscus cannabinus</i> L.	230
calendula	<i>Calendula officinalis</i>	256
cotton	<i>Gossypium hirsutum</i>	273
hemp	<i>Cannabis sativa</i>	305
soybean	<i>Glycine max</i>	375
coffee	<i>Coffea arabica</i>	386
linseed	<i>Linum usitatissimum</i>	402
hazelnut	<i>Corylus avellana</i>	405
euphorbia	<i>Euphorbia lagascae</i>	440
pumpkin seed	<i>Cucurbita pepo</i>	449
coriander	<i>Coriandrum sativum</i>	450
mustard	<i>Brassica alba</i>	481
camelina	<i>Camelina sativa</i>	490
sesame	<i>Sesamum indicum</i>	585
crambe	<i>Crambe abyssinica</i>	589
safflower	<i>Carthamus tinctorius</i>	655
buffalo gourd	<i>Cucurbita foetidissima</i>	665
rice	<i>Oriza sativa</i> L.	696

PLANT	LATIN NAME	KG OIL/HECTARE
tung oil tree	<i>Aleurites fordii</i>	790
sunflower	<i>Helianthus annuus</i>	800
cocoa	<i>Theobroma cacao</i>	863
peanut	<i>Arachis hypogaea</i>	890
opium poppy	<i>Papaver somniferum</i>	978
rapeseed	<i>Brassica napus</i>	1000
olive tree	<i>Olea europaea</i>	1019
piassava	<i>Attalea funifera</i>	1112
gopher plant	<i>Euphorbia lathyris</i>	1119
castor bean	<i>Ricinus communis</i>	1188
bacuri	<i>Platonia insignis</i>	1197
pecan	<i>Carya illinoensis</i>	1505
jojoba	<i>Simmondsia chinensis</i>	1528
babassu palm	<i>Orbignya martiana</i>	1541
jatropha	<i>Jatropha curcas</i>	1590
macadamia nut	<i>Macadamia terniflora</i>	1887
brazil nut	<i>Bertholletia excelsa</i>	2010
avocado	<i>Persea americana</i>	2217
coconut	<i>Cocos nucifera</i>	2260
oiticia	<i>Licania rigida</i>	2520
buriti palm	<i>Mauritia flexuosa</i>	2743
pequi	<i>Caryocar brasiliense</i>	3142
macauba palm	<i>Acrocomia aculeata</i>	3775
oil palm	<i>Elaeis guineensis</i>	5000

APPENDIX 6

BIODIESEL FORMULAS

Use these tables to determine how much alcohol and catalyst to use in a large biodiesel reaction. First, determine how much vegetable oil you will be using in the reaction in either gallons or liters. Use the standard measurement tables if you are working in gallons. Use the metric measurement tables if you are working in liters. Use the top two tables to determine the amount of methanol or ethanol to use in the biodiesel reaction. Use the middle two tables to determine how much lye to use in the biodiesel reaction. If you are using KOH instead of lye, refer to the bottom two tables. To determine how much catalyst to use in the biodiesel reaction, perform a titration and count the number of milliliters of catalyst solution that are dropped into the vegetable oil solution. For lye, add the number of milliliters used in the titration to 3.5 and then find that number on the chart. For KOH, add the number of milliliters used in the titration to 9 and then find that number on the chart. *This column represents to amount of catalyst to use with new vegetable oil.

STANDARD MEASUREMENT TABLES

Vegetable Oil	Methanol or Ethanol	Ethanol
5 gallons	1 gallon	1.5 gallons
10 gallons	2 gallons	3 gallons
20 gallons	4 gallons	6 gallons
30 gallons	6 gallons	9 gallons
40 gallons	8 gallons	12 gallons
50 gallons	10 gallons	15 gallons

METRIC MEASUREMENT TABLES

Vegetable Oil	Methanol or Ethanol	Ethanol
20 liters	4 liters	6 liters
40 liters	8 liters	12 liters
80 liters	16 liters	24 liters
120 liters	24 liters	36 liters
160 liters	32 liters	48 liters
200 liters	40 liters	60 liters

QUANTITY OF LYE TO USE IN OUNCES

Amount of Vegetable oil	Titration Results:				
	3.5*	4.5	5.5	6.5	7.5
5 gallons	2.34 oz	3.00 oz	3.67 oz	4.34 oz	5.00 oz
10 gallons	4.67 oz	6.00 oz	7.34 oz	8.68 oz	10.00 oz
20 gallons	9.34 oz	12.00 oz	14.68 oz	17.36 oz	20.00 oz
30 gallons	14.00 oz	18.00 oz	22.02 oz	26.04 oz	30.00 oz
40 gallons	18.68 oz	24.00 oz	29.36 oz	34.72 oz	40.00 oz
50 gallons	23.35 oz	30.00 oz	36.70 oz	43.40 oz	50.00 oz

QUANTITY OF LYE TO USE IN GRAMS

Amount of Vegetable oil	Titration Results:				
	3.5*	4.5	5.5	6.5	7.5
20 liters	70 g	90 g	110 g	130 g	150 g
40 liters	140 g	180 g	220 g	260 g	300 g
80 liters	280 g	360 g	440 g	520 g	600 g
120 liters	420 g	540 g	660 g	780 g	900 g
160 liters	560 g	720 g	880 g	1040 g	1200 g
200 liters	700 g	900 g	1100 g	1300 g	1500 g

QUANTITY OF KOH TO USE IN OUNCES

Amount of Vegetable oil	Titration Results:				
	9*	10	11	12	13
5 gallons	6.00 oz	6.68 oz	7.34 oz	8.00 oz	8.68 oz
10 gallons	12.00 oz	13.35 oz	14.69 oz	16.00 oz	17.36 oz
20 gallons	24.04 oz	26.70 oz	29.38 oz	32.04 oz	34.72 oz
30 gallons	36.06 oz	40.05 oz	44.07 oz	48.06 oz	52.08 oz
40 gallons	48.08 oz	53.40 oz	58.76 oz	64.08 oz	69.44 oz
50 gallons	60.10 oz	66.75 oz	73.45 oz	80.10 oz	86.80 oz

QUANTITY OF KOH TO USE IN GRAMS

Amount of Vegetable oil	Titration Results:				
	9*	10	11	12	13
20 liters	180 g	200 g	220 g	240 g	260 g
40 liters	360 g	400 g	440 g	480 g	520 g
80 liters	720 g	800 g	880 g	960 g	1040 g
120 liters	1080 g	1200 g	1320 g	1440 g	1560 g
160 liters	1440 g	1600 g	1760 g	1920 g	2080 g
200 liters	1800 g	2000 g	2200 g	2400 g	2600 g

APPENDIX 7

GLYCERIN SOAP RECIPES

Liquid Glycerin Soap

The glycerin byproduct from a biodiesel reaction will contain almost 100% of the catalyst used in the biodiesel reaction. Therefore, the glycerin and lye or KOH have already formed soap by the time the glycerin is drained from the biodiesel reaction container. The liquid or gelatinous glycerin soap is good for cleaning greasy hands or equipment.

During the biodiesel reaction, some unreacted alcohol will fall into the glycerin. To make the glycerin into a nice hand soap, the glycerin must be heated past the boiling point of the alcohol used in the biodiesel reaction. This will cause the alcohol to evaporate, leaving only glycerin soap. If you used methanol in the biodiesel reaction, heat the glycerin past 148° F (65° C). If you used ethanol in the biodiesel reaction, heat the glycerin past 175° F (79° C). Do this in a well ventilated area in an open container and do not breathe the fumes. Allow the glycerin to stay heated for at least 10 minutes and then allow the glycerin to cool.

Essential oils and fragrances can be added to the liquid glycerin soap to enhance its smell. For each liter of glycerin, add 150 milliliters of manufactured fragrance oil or 50 milliliters of essential oil. In addition, you can add up to 300 grams of herbal powder and/or 300 grams of dried flower. The glycerin soap will usually be brown, but its color can be slightly altered by adding artificial colorants.

Heat the glycerin in a pot until it liquefies. If the glycerin came from dirty used cooking oil and it contains some food particles, filter the glycerin by heating it and pouring it through a mesh screen or some pantyhose. Pour in the fragrance oil, herbal powder, and dried flowers while the glycerin is in a liquid state. Stir lightly to evenly distribute the ingredients. Pour the glycerin into a plastic container and allow it to cool. Let the soap sit in the open air for a week. The resulting liquid soap should be mild and pleasant smelling.

Hard Glycerin Soap

By adding more lye or KOH to the glycerin soap, the soap can be hardened and its lather will increase. In order to make the glycerin into hard soap, first evaporate the alcohol as described for liquid glycerin soap. Fragrances can also be added to the glycerin as described for liquid glycerin soap.

Next, divide the total number of grams of catalyst used in the biodiesel reaction by the number of liters of glycerin. For example, if a biodiesel reaction used 100 grams of lye and the reaction produced 4 liters of glycerin, you would divide 100 by 4 = 25. We will call this number (C) and it will represent the amount of catalyst in each liter of glycerin. If you used lye as the catalyst, subtract (C) from 70 grams. We will call this number (L). Following the example, you would subtract (C) from 70 grams to get (L) = 45. Now multiply (L) times the number of liters of glycerin produced during the biodiesel reaction. This is the total number of grams of lye you will need to add to make your glycerin into hard soap. In our example, (L) x 4 liters of glycerin = 180 grams of lye.

If you used KOH as the catalyst instead of lye, use the same formula, but subtract (C) from 100 grams. This number will be (K). Multiply (K) times the number of liters of glycerin produced during the biodiesel reaction. This is the total number of grams of KOH you will need to add to make your glycerin into hard soap.

Next, multiply the number of liters of glycerin times 340 milliliters. For example, if you have 4 liters of glycerin, multiply 4×340 milliliters = 1,360 milliliters or 1.36 liters. We will call this number (W) and it will represent the amount of water to use. Pour (W) milliliters of water into a pyrex, iron, or enamel cooking pot. Bring the water to 90° F (32° C). Slowly add (L) grams of lye or (K) grams of KOH to the water and stir the catalyst until it is dissolved. Keep the catalyst/water at 90° F (32° C). Wear gloves and protective clothing.

In a separate, large pot, bring the glycerin from your biodiesel reaction to 110° F (43° C). Pour the catalyst/water solution into the glycerin in a thin, slow stream. Continue to heat the mixture of glycerin, catalyst, and water as you stir slowly and evenly for 10-20 minutes or until the mixture begins to thicken. When the mixture thickens, pour the still warm mixture into a thick cardboard or wooden box or other container which has been lined with a damp cotton cloth. The cotton cloth should be soaked in water, wrung almost dry, and then placed in the box. Put the box in a pan in case it leaks. Once the soap mixture has been poured into the box with the cotton cloth, put a board on top of the box. Then put an old blanket or rug on top of the box to keep the heat in. Leave the box for 24 hours.

Remove the block of soap by pulling the sides of the cloth out of the box. Once the block of soap has been removed, it can be cut into smaller blocks. Allow the blocks of soap to sit in the open air for 2-4 weeks before using them.

Since each batch of glycerin produced during the biodiesel reaction is different, each batch of glycerin soap will also be different. You can experiment with more or less catalyst and water to change the consistency and lather of the soap.

APPENDIX 8

ASTM STANDARDS FOR BIODIESEL

AMERICAN SOCIETY FOR TESTING AND MATERIALS STANDARDS FOR BIODIESEL			
TEST PROPERTY	ASTM TEST METHOD	ACCEPTABLE VALUE	UNIT OF MEASURE
Specific Gravity	D1298	0.86-0.90	g/cm ³ at 15° C
Gross Heating Value	D2382	17.65 min.	btu/lb
Cloud Point	D2500	Report to customer*	degrees Fahrenheit
Pour Point	D97	28 max.	degrees Fahrenheit
Flash Point	D93	100 min.	degrees Celsius
Kinematic Viscosity at 40° C	D445	1.9-6.0	mm ² /sec.
Water & Sediment	D2709	0.05 max.	% vol.
Copper Strip Corrosion	D130	No. 3b max.	degree of corrosion
Sulphur	D2622	0.05 max.	% mass
Carbon Residue	D4530	0.05 max.	% mass
Cetane Number	D613	40 min.	
Sulfated Ash	D482	0.02 max.	% mass
Neutralization/Acid Number	D664	0.80 max.	mg/g
Methanol	Gas Chromatography	0.20 max.	% mass
Free Glycerin	Gas Chromatography	0.02 max.	% mass
Total Glycerin	Gas Chromatography	0.24 max.	% mass
Oil Ester	Gas Chromatography	97.50 min.	% mass

*The highest allowable cloud point temperature was 38° F (3° C) in the 1996 ASTM biodiesel standards.

TYPICAL ELEMENTAL ANALYSIS OF BIODIESEL			
ELEMENT	ASTM TEST METHOD	ACCEPTABLE VALUE	UNIT OF MEASURE
Carbon	D3176	76.5	%
Hydrogen	D3176	12.5	%
Sulphur	D3177	0.02	%
Oxygen	D3176	11.0	%

RESOURCE GUIDE

PARTS AND EQUIPMENT IN THE BOOK

Chapter 3 Diesel Engines

Racor

3400 Finch Rd., P.O. Box 3208, Modesto, CA 95353

Phone: 800-344-3286 or 209-521-7860 for the name of a local distributor

Email: kedge@parker.com

Website: <http://www.racor.com>

Products: Fuel, air, and oil filters, diesel fuel heaters, fuel/water separators, fuel/air separators, and fuel additives. Racor Diesel Biocide is alcohol free, fuel and water soluble, and kills both fungi and bacteria in fuel. Racor sells the following diesel fuel heaters:

Nomad Coolant operated fuel heater. Part # 320HTR4T.
Nomad Electric fuel heater. This is a 300 watt heater which draws 21.4 amps. The alternator must have a 65 amp minimum rating. Part # 14278.

Thermoline Electric fuel heater. This is the heated fuel hose. It is a 150 watt heater which draws 10.7 amps. The alternator must have a 65 amp minimum rating. Part # HEATER150.

Davco Manufacturing, LLC

1600 Woodland Drive, Saline, Michigan 48176

Phone: 313-429-5665

Products: Davco 380 Fuel Pro with a optional engine coolant heating unit can be used to simultaneously heat and filter biodiesel. It uses electric power to start heating and then shifts to engine coolant when hot.

Dieseltherm

ATG GmbH, Raiffeisenstr. 4, D-89353 Glött, Germany

Phone: 090-758-644

Fax: 090-758-804

Email: autotechnik@t-online.de

Website: <http://home.t-online.de/home/autotechnik/>

Products: Dieseltherm 12 or 24 volt DC pre-filter heater. Removes wax crystals before fuel filter, heats fuel to 104° F.

Advanced Maintenance Technologies

P.O. Box 250, Mountain Road, Stowe, VT 05672

Phone: 800-995-7707

Fax: 802-253-7815

Email: info@advancemaintenance.com

Website: <http://www.advancedmaintenance.com>

Products: U.S. distributor of Dieseltherm. Also, supplier of ThermalCharger brand coolant operated fuel heater.

Amsoil Inc.

AMSOIL Building, Superior, WI 54880

Phone: 715-392-7101

Fax: 715-392-5225

Email: info@amsoil.com

Website: <http://www.amsoil.com>

Products: Diesel Fuel Additive Concentrate 16 oz. Lowers gelling temperature of diesel fuel (and/or biodiesel fuel). Part # ADC-CN.

Chapter 4 Biodiesel Fuel

Viton hoses

Phone: 800-853-5515 for the name of the closest licensed supplier

Website: <http://www.viton.com/products/viton/default.html>

Products: Fuel hoses, gaskets, seals, o-rings, and other alcohol resistant fluoroelastomer parts.

Chapter 5 Grow Your Fuel

Täbypressen

Skeppsta Maskin AB, Täby Skeppsta, SE-705 94 Örebro, Sweden

Phone: 461-922-8005

Fax: 461-922-8005

Email: skeppsta.maskin@mbox200.swipnet.se

Website: <http://www.oilpress.com>

Products: A line of electric and Diesel powered screw presses ranging from table top size to industrial size.

Magic Mill

382 Route 59 Sec. #338, Tallman, NY 10952

Phone: 914-368-2532

Fax: 914-368-2533

Products: U.S. distributor of the TäbyPressen Type 20, or Electrolux table top press.

Better World Workshop
RFD 1, Marshfield, VT 05658
Phone: 802-456-8993
Products: A ram press which can be hand operated, Diesel engine powered, or electrically powered.

Ecogenics
115 West Loop Road, Sevierville, TN 37862
Phone: 423-428-0314
Fax: 423-908-0023
Email: ecogenics@icx.net
Website: <http://www.dabney.com/ecogenics/>
Products: Books, courses, and supplies for small scale algae production.

Chapter 6 How to Make Biodiesel

Edmund Scientific
101 East Gloucester Pike, Barrington, NJ 08007-1380
Phone: 609-573-6250
Fax: 609-573-6295
Email: info@edsci.com
Website: <http://www.edmundscientific.com>
Products: Various scientific products. The following products are useful for making biodiesel:
Pocket pH Tester, microprocessor-based. Price: \$62.95. Part # CR35-558Q.
Acculab Economy GS-200 Balance. 200 gram capacity scale, 0.1 gram sensitivity. Price: \$99.00. Part # CR53-805.
Carry-With-You Twin Beam Balance. 4 gram capacity, sensitive to 0.05 grams. Price: \$29.95. This scale is perfect for making mini-batches of biodiesel. Part # CR36-028.

Chem Lab Supplies
1060-C Ortega Way, Placentia, CA 92670
Phone: 714-630-7902
Fax: 714-630-3553
Website: <http://www.chemlab.com>
Products: Laboratory supplies and supplies used for soap-making including sodium hydroxide and potassium hydroxide in 16 ounce and 25 pound quantities, litmus paper, pH meters, scales, thermometers, and safety equipment.

W.L. Walker Company
1009 South Main St., Tulsa, OK 74119
Phone: 918-583-3109
Fax: 918-583-9255
Email: sales@wlwalker.com
Website: <http://www.wlwalker.com>
Products: Liquid measurement and testing supplies including hydrometers and cylinders. Their 12 inch specific gravity hydrometer that ranges from 0.650 to 1.00 is perfect for testing biodiesel. Price: \$14.31. Part # 35062. The 15 inch plastic cylinder that holds 500 milliliters is \$10.85. Part # 22310.

Miller and Weber, Inc.
1637 George Street, Ridgewood, Queens NY 11385-5342
Phone: 718-821-7110
Fax: 718-821-1673
Email: milwebnyc@aol.com
Website: <http://www.millerweber.com>
Products: Same hydrometer as described above. Price: \$14.95. Part # H-6000.

Chapter 7 How to Build a Biodiesel Processor

United States Plastic Corp.
1390 Neubrecht Rd., Lima, OH 45801-3196
Phone: 800-809-4217
Fax: 800-854-5498
Website: <http://www.usplastic.com>
Email: usp@usplastic.com
Products: Tanks, pumps, pipes, hoses, valves, lab containers, and chemical handling equipment.
70 Gallon Chem-Mix Tank. Price: \$130. Part # 9351.
Stand for 70 Gallon Chem-Mix Tank. Price: \$170. Part # 9354.
Super Chemical Mixer for up to 200 gallons, 1725 rpm. Price: \$235. Part # 15223.

Surplus Center
1015 West "Q" Street, P.O. Box 82209, Lincoln, NE 68501-2209
Phone: 800-499-3407
Products: Motors, pumps, and other industrial surplus equipment.

Chapter 8 How to Run a Diesel on Vegetable Oil and Kerosene

JC Whitney

1 JC Whitney Way, PO Box 3000, LaSalle, IL 61301-0300

Orders: 312-431-6102 open 24 hrs./7 days

Parts/Tech.: 312-431-6129 8:00 a.m.-6:00 p.m.

Fax: 800-537-2700 or 312-431-6095

Website: <http://www.jcwhitney.com>

Products: Auto parts and accessories.

6-port fuel tank selector valve. Page 22, catalog #626J.

Price: \$53. Part # 81DN2705U.

15 gallon polyethylene fuel tank. This is made for the Jeep as a replacement tank, but it is perfect for a vegetable oil kerosene conversion. Price: \$140. Part # 81DN7815W.

Northern Tool and Equipment Company

2800 Southcross Drive West, Burnsville, MN 55337

Phone: 800-533-5545

Website: <http://www.northern-online.com>

Products: Tools and power equipment.

600 gallon per hour 12 volt diesel fuel pump will pump vegetable oil if the oil is warm enough. Price: \$140.

Part # 360-C136.

720 gallon per hour 120 volt AC diesel and fuel oil pump also will pump vegetable oil if the oil is warm enough.

Price: \$150. Part # 381-C136.

30 gallon truck toolbox and fuel tank combination. Welded steel. Price: \$300. Part # 348051-C136.

Chapter 9 How to Run a Diesel on Straight Vegetable Oil

Georg Lohmann BioCar®

Welfenstr. 12, 81541 München, Germany

Phone/Fax: 498-948-4837

Website: <http://www.biocar.de>

Products: The BioCar® kit including fuel tank, hose within a hose, filter, heater, electronics, and wiring.

JC Whitney (see contact information under Chapter 8)

Products: 3-port fuel tank selector valve. Page 22, catalog #626J. Price: \$56. Part # 81DN2687U. Note: This is actually a 6-port valve with rubber caps on the three small nozzles. It functions as either a 6-port or a 3-port valve.

Mechanical Adjustable Switch. Turns on or off when coolant reaches any temperature between 140° F and 270° F. Page 213, catalog #626J. Part # 37DN8602B.

Racor (see contact information under Chapter 3)

Products: Remote mount oil filter. This unit is designed to filter engine oil on boats. It has a removable mesh screen available in either 28 or 40 microns. It has a service indicator light which comes on when the filter screen needs to be cleaned. It also contains a by-pass valve that allows oil to flow through when the screen becomes plugged. Works well for filtering hot vegetable oil.

Part # LFS35.

Chapter 10 Troubleshooting and Success Stories

Racor (see contact information under Chapter 3)

Products: Model #215 Fuel filter and water separator with an optional 200 watt in-bowl fuel heating element. Use with 30 micron filter element for the best fuel/water separation. A variety of other models exist. Ask your local dealer which one might be best for your vehicle. Or ask for brochure No. 7529 USA from Racor for a complete list of filters.

Hiperfuels (see contact information under Biodiesel Suppliers)

Products: Fuel Dri water absorber which floats inside the fuel tank.

China Diesel (see contact information under Diesel Generators)

Products: Diesel injector tester. Price: under \$200.

GENERAL BIODIESEL INFORMATION

National Biodiesel Board

P.O. Box 104898, Jefferson City, MO 65110

Phone: 800-841-5849 or 573-635-3893

Fax: 573-635-7913

Email: info@biodiesel.org

Website: <http://www.biodiesel.org>

Joshua and Kaia Tickell

PMB 311, 15 Paradise Plaza, Sarasota, FL 34239

Phone/Fax: 813-354-2377

Email: biofuel@best.com

Website: <http://www.veggievan.org>

Services: The authors are available for biodiesel consulting and to speak at conferences and events.

National Renewable Energy Laboratory (NREL)

1617 Cole Blvd., Golden, CO 80401

Website: <http://www.nrel.gov>

Canadian Renewable Fuels Association
90 Woodlawn Road W., Guelph, Ontario N1H 1B2
Phone: 519-767-0431
Fax: 519-837-1674
Website: <http://www.greenfuels.org/bioindex.html>

BIODIESEL SUPPLIERS

Griffin Industries
(Biodiesel Plant located in Butler, KY)
PMC Marketing Group, Inc
P.O. Box 59553, Birmingham, AL 35259
Phone: 509-698-4555
Fax: 509-698-4556
Email: hemenergy@aol.com
Website: <http://www.griffinind.com/html/biodiesel.html>

NOPEC
P.O. Box 2868, Lakeland, FL 33806
Phone: 941-683-7199
Fax: 941-683-1058
Email: sales@nopec.com
Website: <http://www.nopec.com>

Columbus Foods
730 North Albany Ave., Chicago, IL 60612
Phone: 773-265-6500
Fax: 773-265-6985
Website: <http://columbusfoods.com>

Pacific Biodiesel
590 Lipoa Parkway, Suite 231, Kihei, HI 96753
Phone: 808-875-2390
Fax: 808-875-2391
Email: bking@biodiesel.com
Website: <http://www.biodiesel.com>

Ag Environmental Products
9804 Pflumm Rd., Lenexa, KS 66215
Phone: 913-599-6911
Fax: 913-599-2121
Website: <http://www.soygold.com>

Chemol Company, Inc.
2300 Randolph Ave., Greensboro, NC 27406
Phone: 336-333-3051
Fax: 336-273-4645

CytoCulture Environmental Biotechnology
249 Tewksbury Ave., Pt. Richmond, CA 94801
Phone: 510-233-0102
Fax: 510-233-3777
Email: cyto@cytoculture.com
Website: <http://www.cytoculture.com>

Hiperfuels, High Performance Fuels and Additives
Houston, TX
Phone: 713-942-6645
Fax: 713-942-6645
Email: jhewitt@ix.netcom.com
Website: <http://www.hiperfuels.com>

West Central Cooperative
P.O. Box 68, Ralston, IA 51459
Phone: 712-667-3200
Fax: 712-667-3399
Website: <http://www.soyplus.com>

World Energy Alternatives
One Broadway, Suite 600, Cambridge, MA 02142
Phone: 617-621-1522
Fax: 617-621-1523
Email: geneg@worldenergy.net
Website: <http://www.worldenergy.net>

BIODIESEL INTERNET RESOURCES

The World of Biodiesel
Website: <http://www.veggievan.org/biodiesel/>
Description: Links to websites around the world pertaining to biodiesel.

DieselNet, Diesel Emissions Online
Website: <http://www.dieselnets.com>
Description: The online information service on diesel exhaust emissions, emission controls, Diesel engines, fuels, and more.

Biodiesel International
Website: <http://www.biodiesel-intl.com>
Email: bdi@biodiesel-intl.com
Description: Biodiesel organization in Europe.

Alternative Fuels Data Center Resource Guides
Website: http://www.afdc.doe.gov/resource_guide.html
Description: Online resource guides available for methanol, ethanol, and biodiesel.

UNIVERSITIES RESEARCHING BIODIESEL

University of Idaho
Phone: 208-885-7906
Website: <http://www.uidaho.edu/bae/biodiesel/>
Products: Reports on biodiesel available for a fee.

University of Missouri
235 Agricultural Engineering Building, Columbia, MO 65211
Phone: 573-882-2126
Website: <http://web.missouri.edu/~pavt0689/biofuel.html>

University of Graz
 Institute for Organic Chemistry
 Heinrichstrasse 28, A-8010 Graz, Austria
 Phone: 433-163-805-353
 Fax: 433-163-809-841
 Email: mittelba@balu.kfunigraz.ac.at
 Website: <http://boch35.kfunigraz.ac.at/~mittelbach/>

METHANOL RESOURCES

American Methanol Institute
 800 Connecticut Ave. NW, Suite 620, Washington, DC 20006
 Phone: 202-467-5050
 Fax: 202-331-9055
 Email: AmMethInst@aol.com
 Website: <http://www.methanol.org>
 List of plants:
<http://www.methanol.org/methanol/fact/wmethplants.html>
 Description: Main methanol advocacy organization in the U.S. A list of world wide methanol plants is available on their website.

Millennium Petrochemicals, Inc.
 P.O. Box 429550, Cincinnati, OH 45249
 Phone: 513-530-6500 or 800-422-7515
 Website: <http://www.millenniumpetro.com>
 Description: Methanol manufacturer.

Borden Chemicals and Plastics
 P.O. Box 427, Geismar, LA 70734
 Phone: 504-673-0683
 Fax: 504-673-0450
 Description: The second largest producer of methanol in the United States, with an annual capacity of 330 million gallons.

Celanese Ltd. Chemical Group, Inc.
 1601 West LBJ Freeway, Dallas, TX 75234
 Phone: 972-443-4014
 Fax: 972-443-4950
 Email: info@celanese.com
 Website: <http://www.celanese.com>
 Description: Methanol manufacturer.

Lyondell Petrochemical Company
 One Houston Center, Suite 1600
 P.O. Box 3646, Houston, TX 77253-3646
 Phone: 713-652-7349
 Fax: 713-652-7432
 Website: <http://www.lyondell.com>
 Description: Methanol manufacturer.

Methanex Methanol Inc.
 12377 Merit Drive, Suite 490, Dallas, TX 75251
 Phone: 972-308-0445
 Fax: 972-233-1266
 Website: <http://www.methanex.com>
 Description: Global methanol production and marketing organization.

Terra Industries Inc.
 600 4th Street, PO Box 6000, Sioux City, IA 51102
 Phone: 712-277-1340
 Fax: 712-277-7296
 Website: <http://www.terraindustries.com>
 Description: Methanol manufacturer.

United Catalysts, Inc.
 P.O. Box 32370, Louisville, KY 40232
 Phone: 502-634-7212
 Fax: 502-634-7722
 Description: Methanol manufacturer.

ICI Katalco
 P.O. Box 1, Billingham, Cleveland, TS23 1LB England
 Phone: 441-642-522-675
 Telex: 587443 ICI AGH G
 Fax: 441-642-522-542
 Email: iciinfo@icinorthamerica.com
 Website: <http://www.icinorthamerica.com>
 Description: Methanol manufacturer.

Mitsubishi Gas Chemical Company, Inc.
 Mitsubishi Building, 5-2 Marunouchi 2-Chome,
 Chiyoda-Ku, Tokyo, Japan
 Phone: 813-3283-5000
 Fax: 813-3287-0833
 Website: <http://www.mitsubishi.or.jp>
 Description: Methanol manufacturer.

Trinidad and Tobago Methanol Company, Ltd.
 Goodrich Bay Road, Point Lisas, Trinidad, West Indies
 Phone: 809-636-2906
 Fax: 809-363-4501
 Description: Methanol manufacturer.

ETHANOL RESOURCES

Note: Only 100% pure ethanol will work for biodiesel production.

The American Coalition for Ethanol
P.O. Box 85102, Sioux Falls, SD 57104
Phone: 605-334-3381

Fax: 605-334-3389

Website: <http://www.ethanol.org>

Description: Non-profit organization devoted to promoting the increased production and use of ethanol.

Murtagh & Associates
160 Bay Court, Winchester, VA 22602
Phone: 540-667-7757
Fax: 540-667-8091

E-mail: murtagh@distill.com

Website: <http://www.distill.com>

Directory: <http://www.distill.com/offlinks.html>

Description: Beverage, fuel and industrial alcohol production consultants who publish the 900 page *World Wide Directory of Distilleries* which costs a hefty \$250 for the paper version or \$1,300 for the CD-Rom and paper version. Their website contains a brief directory of distilleries around the world.

Reeve Agri Energy, Inc.
P.O. Box 1036, Garden City, KS 67846
Phone: 316-275-0234
Fax: 316-275-8393

Description: High quality ethanol production plant.

Parallel Products
12281 Arrow Route, Ranch Cucamonga, CA 91739
Phone: 909-980-1200
Description: Produces ethanol from beer and soft drink waste.

Broin Ethanol Products
25784 Cottonwood Ave., Sioux Falls, SD 57107
Phone: 888-209-8153 or 605-503-5091
Email: bobscott@broin.com
Website: <http://www.broin.com>

Description: Broin has built 8 ethanol plants in Minnesota and South Dakota. They sell denatured ethanol.

CSR Distilleries
PO Box 934, North Sydney, New South Wales 2059, Australia
Phone: 02-964-1722
Fax: 02-964-1731

Description: Main producer of ethanol in Australia with plants in Victoria, New South Wales, and Queensland.

SOAP-MAKING RESOURCES

Majestic Mountain Sage
880 N. 1430 W., Orem, UT 84057

Phone: 801-227-0837

Fax: 801-227-0026

Website: <http://www.the-sage.com>

Description: Soap-making products including fragrances, oils, colors, containers, and books. Their website has soap recipes and soap-making tips as well as a "Lye Calculator" for creating soap formulas.

Soap Crafters
363 East 3300 South, Suite #5, Salt Lake City, UT 84115
Phone: 801-484-5121
Fax: 801-487-1958

Website: <http://www.soapcrafters.com>

Description: Soap-making kits and products. There is an ongoing soap-making discussion group on their website.

Soap Recipes
Website: <http://members.aol.com/oelaineo/soapmaking.html>
Description: Free soap recipes and directions from Elaine White, author of the book *Soap Recipes*.

DIESEL VEHICLE WEBSITES

Volkswagen
Website: <http://www3.vw.com/cars/jetta/tdi.htm>

Dodge
Website: <http://www.4adodge.com/ram/>

Ford
Website: <http://www.fordvehicles.com/superduty/power4.html>

Hummer
Website: <http://www.hummer.com>

Mercedes
Website: <http://www.usa.mercedes-benz.com/models/E300DT.html>

DIESEL GENERATORS

China Diesel
15749 Lyons Valley Rd., Jamul, CA 91935
Phone: 800-341-7027
Email: cdi@chinadiesel.com
Website: <http://www.chinadiesel.com>
Products: Diesel marine engines, generators, and tractors.

Fischer Panda Generators, Inc.
1218 SW 1st Avenue, Fort Lauderdale, FL 33315
Phone: 954-462-2800
Fax: 954-462-2801
Email: sales@fischerpanda.com
Website: <http://www.fischerpanda.com>
Products: Full line of Diesel generators including very small, quiet, and powerful water cooled models.

Onan
Website: <http://www.onanrv.com/pline/qdiesel/index.html>

Yanmar
Website: <http://www.yanmar.com>

MULTI-FUEL LIGHTING AND STOVES

BryteLyt
9516 Lake Drive, New Port Richey, FL 34654
Phone: 727-856-9245
Email: info@britelyt.com
Website: <http://www.petromax.com>
Products: Petromax brand lanterns and stoves which can run on vegetable oil and biodiesel.

MISCELLANEOUS DIESEL ENGINES

Zoche Aero-Diesels
Michael Zoche Antriebstechnik, Keferstrasse 13-80802,
Munich, Germany
Phone: 498-934-4591
Fax: 498-934-2451
Email: 101613.444@compuserve.com
Website: <http://193.26.97.194/index.html>
Products: Expecting to market certified, 150 hp and 300 hp Diesel airplane engines by the year 2001.

Polaris Diesel
712 N. Beach St., Daytona Beach, FL 32114
Phone: 904-255-4255
Fax: 904-255-6463
Website: <http://www.polarisofdaytona.com/diesel.htm>
Products: Diesel All Terrain Vehicle.

VEGETABLE OIL MOTOR LUBRICANT

Agro Management Group
1127 W. Colorado Ave., Colorado Springs, CO 80904
Website: <http://www.agromgt.com>
Products: "AMG 2000 is a specially processed and formulated all vegetable premium crankcase lubricant designed for and tested in a wide range of air cooled and water cooled 4 cycle engines."

Inventors: James W. Lambert and Duane L. Johnson
Patent Number: US005,888,947 A
Source: The IBM Intellectual Property Network
Website: <http://www.patents.ibm.com>
Description: This is a mixture of vegetable oils which is used as engine oil. The patent lists the vegetable oils used and describes how they are mixed. Price of patent: \$3.

CROP INTERNET DATABASES

United States Department of Agriculture
Website: <http://www.ncaur.usda.gov/NC/NCDB/info.htm>

Purdue University Department of Horticulture
Website: http://www.hort.purdue.edu/newcrop/Indices/index_ab.html

Australian New Crops Project
Website: <http://www.uq.edu.au/~gagkregio/index.htm>

Interactive European Network for Industrial Crops and their Applications
Website: <http://www.csl.gov.uk/ienica/>

GENERAL ALTERNATIVE ENERGY RESOURCES

Biomass Energy Foundation
1810 Smith Rd., Golden, CO 80401
Website: <http://www.webpan.com/bef/>
Description: Non-profit organization dedicated to promoting biomass energy. Has a line of books available.

Real Goods
555 Leslie St., Ukiah, CA 95449
Phone: 800-762-7325
Website: <http://www.realgoods.com>
Description: Sells renewable energy products.

Alternative Energy Engineering
1155 Redway Dr., Redway, CA 95560
Phone: 800-777-6609
Website: <http://www.alt-energy.com>
Description: Sells renewable energy products.

Center for Alternative Technology
Machynlleth, Powys, Wales, SY20 9AZ, United Kingdom
Phone: 44-1654-702-400
Fax: 44-1654-702-782
Email: cat@gn.apc.org
Website: <http://www.foe.co.uk>
Description: Europe's foremost Eco-Center and source for renewable energy information.

Alternative Technology Association
PO Box 2001, Lygon St North, Brunswick East, Victoria
3057, Australia
Phone: 61-39-388-9311
Fax: 61-39-388-9322
Email: altec@netspace.net.au
Website: <http://www.ata.org.au>
Description: Non-profit renewable energy education-oriented organization.

RECOMMENDED BOOKS AND MAGAZINES

Books

Crown's Diesel Repair Manual: Audi/Volkswagen, Datsun, Dodge, Ford, General Motors, Isuzu, Mazda, Mercedes-Benz, Mitsubishi, Peugeot, Toyota, Volvo
Mort Shultz, 1984, Crown Publishers, New York
ISBN 0-517-55220-5
Price: Originally \$13.95

Ordering info: From an out of print book service or from Amazon books at <http://www.amazon.com>

Description: This out of print book is the best single resource for 1970-1985 water cooled Diesel vehicles. The author covers each vehicle in layman's terms. The book is packed with great photos and diagrams.

The Coming Oil Crisis
C.J. Campbell, 1988, Multi-Science Publishing Company and Petroconsultants S.A., Essex, England
ISBN 0-906-52211-0

Price: \$33.00 U.S. shipping included
Ordering info: EcoSystems, P.O. Box 7080, Santa Cruz, CA 95061

Phone: 408-425-8523
In Australia: call 02-9368-1941 or email sydtrans@enternet.com.au

Description: This book presents the most thoroughly researched argument for the end to cheap petroleum. It is written and researched by geologist, oil explorer, and consultant to the UN, C.J. Campbell.

Convert It: A Step-By-Step Manual For Converting An Internal Combustion Vehicle to Electric Power

Michael P. Brown with Shari Prange, 1993, Future Books, Ft. Lauderdale, FL

ISBN 1-879-85794-4

Price: \$30 U.S. shipping included

Ordering info: Electro Automotive, POB 1113-HP, Felton, CA 95018-1113.

Phone: 831-429-1989

Email: electro@cruzio.com

Website: <http://www.electroauto.com>

Description: If you would like to transform your gasoline automobile into a clean and quiet electric vehicle, then this book is for you. This book is based on the Voltsrabbit™ kit which is used to convert any Volkswagen Rabbit vehicle to electric propulsion. Mike and Shari also give plenty of advice and consideration for converting other types of vehicles. Lots of good photos and wiring diagrams.

How to Produce Your Own Alcohol

Marc Cardoso, Ecogenics

Price: \$15 book, \$350 course

Ordering info: See Ecogenics contact information under resources for Chapter 5.

Description: Marc began producing ethanol fuel in his backyard during the oil shocks of the 1970s. His work with ethanol has continued for almost 30 years. His ethanol manual is one of the only resources on making ethanol fuel. It includes detailed instructions for establishing an ethanol plant and converting a carbureted, gasoline engine to run on ethanol.

Biomass Downdraft Gasifier Engine Systems Handbook

T. Reed and A. Das, 1988, SERI

ISBN 1-890-60700-2

Price: \$25.00 + \$4.50 postage in the U.S. or \$10.50 postage for foreign orders

Ordering info: Biomass Energy Foundation Press, 1810 Smith Rd., Golden, CO 80401

Website: <http://www.webpan/bef/>

Description: Over a million wood gasifiers were used to power cars and trucks during World War II. Yet, today, there are only a few companies manufacturing gasifier systems. The authors have spent more than 20 years working with various gasifier systems. In this book they describe how to run a carbureted, gasoline engine on wood chips, sawdust, and other burnable biomass.

Magazines

Home Power Magazine

Price: \$22.50/year to U.S. Zip Codes via 2nd Class U.S. Mail

\$30.00 International Surface Mail

Ordering info: PO Box 920, Ashland, OR 97520

Phone: 800-707-6585 or 530-475-3179

Fax: 530-475-0941

Email: hp@homepower.com

Website: <http://www.homepower.com>

Description: Simply the best resource for information on alternative technology and renewable energy. This is a real hands-on magazine for do-it-yourselfers. Each issue contains full color schematics, wiring diagrams, photos, and step-by-step instructions. Topics covered include: solar power, micro-hydro power, wind power, electric vehicles, hydrogen production, alternative transportation, energy politics, and water purification. Each issue is offered in electronic Adobe Acrobat format on the Home Power website free of charge.

ReNew Magazine

Price: Australian \$40 (includes membership to the Alternative Technology Association)

Ordering info: The Alternative Technology Association, PO Box 2001, Lygon St North, Brunswick East, Victoria 3057, Australia

Phone: 61-39-388-9311

Fax: 61-39-388-9322

Email: altec@netspace.net.au

Website: <http://www.ata.org.au>

Description: *ReNew Magazine* is Australia's number one resource for information on renewable energy and alternative technology. The magazine covers similar topics to *Home Power* with a distinctly Down Under flare. Each issue contains great photos, innovative and useful articles, and advertisements from Australian renewable energy product manufacturers and distributors.

Diesel Car Magazine

Price: U.K. subscriptions £28.00 for 12 issues

E.U. subscriptions £41.00 for 12 issues

International subscriptions £62.00 for 12 issues

Phone: 0-458-271-149 or 44-1458-271-149 outside the U.K.

Website: <http://www.totalcar.co.uk>

Description: The definitive monthly guide to the world of Diesel-engine cars in the U.K. and Europe. *Diesel Car* offers road tests, news of new vehicles, and independent reviews of new and used cars, including the gasoline equivalents of the different models. Each issue contains technical spec listings, used car prices, a maintenance section, and reviews of all the latest cars and products.

I N D E X

A

Advanced Maintenance Technology 32
 Africa 26, 49
 Alaska 11, 14, 127
 alcohol/catalyst mixing tank 82, 83, 84, 86
 algae 52, 53, 54, 55
 Amsoil 31, 123
 animal fat 31, 40, 124
 anti-gel formula 31, 123
 Asia 26, 50
 ASTM 31, 71, 72, 75, 119
 Audi 27
 Australia 26, 62, 127
 Austria 43

B

B20 36, 39, 45
 bacteria 33, 69
 barrels of oil 12
 Bean Buses 42, 43
 Better World Workshop 51, 100, 130, 131
 Bielenberg, Carl 51, 130, 131
 BioCar 99, 100
 biocide 33, 87, 123
 biodegradability 37
 biodiesel mixing tank 76, 82, 83, 84, 85, 86, 120
 biofuels 19, 21, 45
 Biomass Energy Foundation 125
 BioRabbit 129, 130
 biostat 33, 123

C

Canada 43, 49, 50
 Canadian Alternative Fuels Act 43
 canola 49, 53, 118, 126, 127, 128
 carbon cycle 16
 carbon dioxide 16, 17, 20, 37, 38, 45, 53, 54
 carbon monoxide 37, 38, 126
 Caspian Sea 13
 catalytic converter 38, 126
 chem-mix tank 76, 77, 82, 83, 84, 85
 chemical mixer 76, 77, 78, 79, 82, 83, 84, 85, 86
 Chesapeake Bay 42
 cloud point 31, 72
 coal 16, 23, 45, 59

coconut 47, 48, 125
 cold weather 31, 32, 72, 123, 126, 130
 combustion chamber 24, 25
 combustion temperature 38
 compressed natural gas 12, 45
 compression ignition 24
 conical bottom 76, 77, 78, 79, 80, 84, 85
 consumption of oil 12
 corn 50, 127
 crop adjuvant 46
 Cummins 26, 27, 39, 40, 125, 126
 Czech Republic 43

D

Deer Valley School District 42
 Department of Energy 13, 34
 Detroit Diesel 39
 diesel #1 31, 89
 diesel #2 31, 72
 Diesel generator 28, 47, 51, 100, 125, 127
 Diesel, Rudolf 23
 Dieseltherm 32, 105
 diester 43
 direct injection 24, 25, 27, 34, 100, 128
 Dodge 26, 27, 125, 126
 DOE 13, 14, 21, 53, 55, 125

E

economic growth 40, 41
 electric cars 45
 Elsbett 100
 emissions
 20, 29, 34, 36, 37, 38, 47, 54, 72, 99, 125, 126
 energy balance ratio 36
 energy content 37
 Energy Policy Act 44
 engine coolant
 29, 32, 99, 101, 104, 115, 126, 130, 131
 engine timing 38
 engine warranties 39
 England 23, 131
 ethanol
 19, 21, 22, 39, 44, 50, 59, 60, 61, 63, 64, 66,
 67, 68, 69, 70, 118, 119, 120, 121, 126
 ethanol industry 21, 22
 Europe 23, 26, 34, 38, 39, 43, 49, 52

F

fallow land 40, 41
 farm commodity programs 41
 farm income 21, 22, 40, 41
 farming equipment 35, 104
 fatty acids 31, 50, 61, 64, 66, 80, 86, 118
 filler cap 33, 92, 93, 106
 filler pipe 33, 107
 firewall 93, 108, 111, 130
 flashpoint 37, 71
 fleets 36, 45
 flouroelastomer 39, 122
 flow-improver additive 31
 food production 41, 52
 Ford 26, 27, 34, 39, 125
 Fort McCoy 42
 fossil fuel
 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 22,
 36, 41, 43, 45, 52
 France 23, 43, 100
 fuel consumption 37, 130
 fuel filter pre-heater 104, 105, 106
 fuel heating accessory 32, 90
 fuel lines
 31, 33, 39, 89, 90, 92, 93, 94, 95, 97, 99, 101,
 122, 126, 128
 fuel pickup pipe 93, 94, 102, 106
 fuel return loop 102
 fuel tank filter 32

G

gas chromatography 72
 gasoline 9, 10, 11, 15, 16, 17, 19, 21, 23, 24, 26,
 28, 34, 38, 45, 52, 63, 69, 87, 92, 101, 123
 gel point 31, 72
 General Motors 32
 Germany 34, 42, 43, 49
 global warming 16, 17, 20, 125
 glow plugs 24, 31, 46, 131
 glycerin 76, 80, 83, 84, 86, 87, 118, 119, 120, 127
 Greasy Gretta 89, 90
 green Diesels 34
 Green Grease Machine 75
 greenhouse effect 17
 greenhouse gases 17
 gross business volume 41

H

halogens 37
 heater hoses 29, 101, 103, 104, 106, 108, 111
 hemp 50
 HEVs 34

high efficiency farming 52
 home heating oil 33, 42, 46
 Home Power Magazine 127, 128, 129, 131
 hose within a hose 103, 104, 106, 108, 109, 111, 112
 hybrid vehicles 34
 hydrocarbons 16, 19, 20, 24, 37, 38, 126
 hydrometer 73, 118, 119
 hydropower 19

I

India 48, 50
 indirect injection 24, 25, 100, 128
 injector coking 72, 99, 101
 injector pump
 25, 33, 90, 95, 97, 99, 100, 101, 102, 112, 113,
 114, 122, 131
 injector tester 122
 injectors 25, 39, 99, 101, 115, 119, 122, 128, 130
 intercooler 24
 internal combustion engine 16, 17, 20, 38
 Iran 11
 Iraq 11, 15
 Ireland 43
 isopropyl alcohol 63, 64, 66
 Italy 42, 43

J

Japan 26, 27, 43
 jatropha 48, 49, 51, 130, 131
 JC Whitney 102, 105, 114
 jet fuel 89

K

kerosene
 29, 30, 31, 46, 89, 90, 92, 97, 99, 123, 128
 Kinematic viscosity 72
 KOH 60, 62, 69, 70, 121
 Kuwait 11

L

life-cycle analysis 38
 litmus paper 62, 66
 Lockheed Martin 34
 Lohmann, Georg 100
 lubricity 35, 42
 Lupo 34
 lye
 60, 61, 62, 63, 64, 66, 67, 68, 69, 70, 76, 77, 82,
 83, 84, 85, 92, 103, 106, 108, 109, 118, 120, 121, 127

M

maize 50
 Malaysia 43
 marine environments 37
 Maui 75
 measuring stick 79, 82
 Mercedes Benz 26, 125
 metal fuel tank 89, 92, 99, 102
 methane 13
 methanol
 39, 44, 59, 60, 61, 63, 64, 66, 67, 68, 69, 70,
 118, 119, 120, 121
 Middle East 11, 12, 13, 14, 15, 45
 military 14, 15, 28, 42, 76, 82
 mini batch 70, 80, 86, 117, 118, 120
 model aircraft 28, 46
 MSDS 37

N

National Biodiesel Board 45
 national debt 21
 National Renewable Energy Laboratory 53
 NATO 15
 natural gas 12, 13, 15, 45, 59
 Navistar 34
 Nicaragua 43
 nitrous oxide 38, 45
 North America 49
 North Sea 11, 14
 Norway 43

O

oil distillation 10
 oil extraction 11, 53, 54, 55
 oil press 51, 130
 oil production 11, 13, 14, 50, 52
 oil screen filter 95
 oil shock 11, 13, 14, 26
 oil spills 46
 oil-producing plants 20, 47
 OPEC 11
 oxygenated fuel 39, 123

P

P2000 34
 palm 47, 48
 particulates 37
 peanut 23, 47, 48, 49, 128, 131
 Persian Gulf 13, 14, 15
 petroleum imports 21
 pH 48, 60, 61, 62, 66, 71, 87, 118, 120
 Philippines 125

photovoltaics 19
 Poland 43
 polycyclic aromatic hydrocarbons 38
 potassium hydroxide 60, 62, 69
 pour point 31
 prechamber 25
 producer gas 19

R

Racor 32, 33, 95, 104, 105, 106, 119
 ram press 51
 rapeseed 38, 49, 52, 127
 Renault 100
 renewable fuel 13, 14, 19, 20, 21, 22, 45, 53
 restaurant fryer filters 64, 90
 Russia 49, 50

S

safety wear 62
 safflower 50
 saponification 121
 Saudi Arabia 11
 screw press 51
 second fuel tank
 89, 90, 92, 93, 94, 95, 97, 102, 115, 128
 set-aside land 43
 sight tube 82, 83
 Slovakia 43
 soap
 48, 49, 60, 62, 68, 69, 71, 72, 118, 119, 120, 121,
 124, 127
 sock filter 32, 87
 sodium hydroxide 60, 62
 solar panels 19, 28, 34
 solenoid valve
 90, 92, 94, 95, 96, 97, 102, 103, 105, 106, 109,
 112, 113, 114, 115, 123, 129
 soot 15, 24, 38
 South America 48, 49
 soybean 42, 43, 47, 48, 49, 50, 54
 spark ignition 24
 specific gravity 72, 73, 87, 118, 119
 splash lid 85
 steam kettle 75, 76
 straight vegetable oil
 23, 29, 30, 45, 51, 92, 99, 100, 101, 102, 106, 108,
 115, 117, 123
 subsidies 14, 44, 125
 sulfur 35, 37, 38
 sunflower 41, 47, 49
 Sunrider 42
 Sweden 43, 51
 Synergy 2010 34
 synthetic hoses 39

T

tax writeoffs 14
TDI 25, 26, 34
thermoswitch 105, 106, 114, 115
titration 64, 66, 69, 70, 80, 86, 118, 120, 127
Titusville, Pennsylvania 10
toggle switch 89, 90, 96, 97, 112, 113, 114, 115
torque 37
toxicity 37
Toyota 27
tractor 28, 49, 127, 131
trade deficit 21, 22, 40
transesterification 120, 124
transport industry 26
turbocharger 24

U

U.S. Plastic Corp 75, 76, 77, 82
Ultra-Low Emissions Vehicle 34
United Arab Emirates 11
University of Georgia 45, 49
University of Graz 42
University of Idaho 42, 52
University of Missouri 42
University of North Dakota 41
UPS 34, 37

V

Veggie Van 42, 43, 129
viscosity 24, 29, 59, 72, 99, 100
Viton 39, 122
Volkswagen 25, 26, 27, 32, 34, 89, 92, 128, 129

W

waste cooking oil 40, 125
water wash 70, 71, 119
wind turbines 19, 28
winterizing agent 31, 123
World Exhibition 23, 49

Y

Yellowstone National Park 126