Evaluating the Potential for Large-Scale Biodiesel Deployments in a Global Context

by

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Abstract

This thesis conducts a national-level evaluation of potential biodiesel volumes, replicated across all countries, to answer the following questions:

1. *Which countries have the highest absolute biodiesel potential?*
2. *Which countries can profit the most from biodiesel exports?*
3. *Which countries can profitably offset petrol-diesel imports with biodiesel?*
4. *What is the cost of self-sufficiency from petroleum-diesel imports?*

In answering these questions, data from a multitude of sources was used, with exported vegetable oil and animal fat volumes from the Food and Agriculture Organization (FAO) of the United Nations forming the foundation of the calculations. This study is unique in the level of detail retained throughout the calculations, allowing the results to be useful to a variety of audiences – both to international institutions such as the World Bank and the United Nations for country comparisons, as well as to individual countries as a first-order assessment of potential and a basis for further in-depth analyses and strategic planning.

The results of this thesis highlight the vast untapped potential for large-scale production of biodiesel, especially in developing and less-developed countries. With a commitment to growth through yield increases, biodiesel can potentially supply over 400 billion liters fuels -- essentially erasing all new petroleum demand from China, India, the US and the EU for the next 15 years -- while continuing to meet demands for human and animal foods.

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Chapter I: Introduction

Petroleum is the largest single source of energy consumed by the world's population, exceeding coal, natural gas, nuclear, hydro and renewables (EIA 2006). In addition to powering the vast majority of mechanized transportation -- from commercial and personal transport, to aviation, rail and the military -- oil is a critical component in the production of fertilizers, plastics and chemicals. Although most experts predict global oil production will peak sometime between 2007 and 2025, demand will continue to rise another 40% during the same period (EIA 2005; Hirsch 2005). Supply concerns in the near-future will be exacerbated as the *security* of supply also becomes a greater risk due to more and more of the remaining oil reserves being concentrated in the Middle East and North Africa (IEA 2005). The expected 52% rise in world CO_2 emissions by 2030 further highlights the risk of reliance on a single commodity for so much of the world's energy needs -- especially with the emissions of fossil fuels (including petroleum) already linked to global climate change. Whether due to shrinking supply, national security concerns, or global climate change, the price of petroleum products will continue to increase, affecting all aspects of the global economy.

The transportation sector will be particularly vulnerable with few alternatives readily available, *even* at a cost premium -- unlike electricity generation, space heating or industrial uses which have more distributed options. Over the last 100 years, our transportation infrastructure has become almost totally reliant on a few varieties of liquid, hydro-carbon fuels compatible with internal combustion, or gas turbine engines. Any alternative transportation fuels must either meet the strict specifications of the existing infrastructure or replace it wholesale, as many hope hydrogen fuel-cells will do. However, while hydrogen fuel has many advantages over petroleum fuels (including emissions and flexibility of production), the technology needed to distribute and store hydrogen, not to mention the sheer cost of replacing trillions of dollars infrastructure, preclude it from being a viable alternative in the immediate future.

Liquid biofuels, renewable fuels derived from biomass, are arguably one of the best transition fuels for the near-term and have made a recent resurgence in response to rising oil prices. However, the use of biofuels as a quick-fix to petroleum supply problems has been one of the most visible examples of our lack of fortitude and long-term planning. As the historical review later in this chapter will show, all major efforts at implementing biofuels on a wide-scale have been triggered by supply problems linked to our dependency, both on oil itself and the few countries capable of exporting it in sufficient quantities. In each case, development efforts in biofuels waned as petroleum supply problems eased and the massive financial losses, economic disturbances, social upheaval and accompanying political fallouts were all but forgotten. This dependence on a finite energy source controlled by dangerously few, often politically unstable countries, has unfortunately led to a cycle of crisis followed by complacency in an industry which can take decades to fully embrace new supply options.

To break this cycle, biofuels – including biodiesel, the focus of this study – must be used as a strategic tool to pre-empt crises. More directed efforts at planned biofuels growth, and their eventual successes, will help create a larger foothold, maturing biofuel technologies and ultimately legitimizing their use in ever larger markets. Although the technical details of biodiesel have been thoroughly studied, there has been little focus on what constitutes a strategic deployment. Therefore, while the following chapter covers some of the prerequisite details of biodiesel – including a technical overview, a brief history and the benefits and drawbacks of its use – the chapters which follow focus on the more tactical aspects of building out the biodiesel industry. Many questions remain to be answered before the burgeoning biodiesel industry will be embraced globally: Which countries hold the most potential for profitable exports? Which countries can use biodiesel to become self-sufficient from petroleum diesel imports? Which feedstocks are best suited for biodiesel production? To answer these questions, this thesis conducts consistent, biodiesel potential assessments, using all feedstocks for all countries. By ranking the results, this study can be used to aid individual countries and world-bodies, such as the United Nations (UN) and the World Bank, in long-term planning and decision making – ultimately leading to a more robust, optimally deployed biodiesel industry which can better weather competition and fluctuating petroleum prices.

It is important to note that while this analysis could be useful for many different types of renewable energy technologies, this study purposely focuses only on biodiesel. Biodiesel was chosen because of the diesel engine's wide range of applications, the diesel-cycle's inherent combustion efficiency advantage over Otto-Cycle engines (powered by gasoline) and its existing wide-spread use around the globe. Additionally, because biodiesel can be refined under atmospheric temperatures and pressures (unlike many other liquid fuels), it can be produced economically and is well suited for production in a variety of sites and scales, from urban to rural, from small to commercial.

A. Biodiesel Basics

Biodiesel, formally known as either methyl-ester or ethyl-ester, is a natural occurring vegetable oil or animal fat which has been chemically modified to run in a diesel engine (Brown 2003). Biodiesel's many advantages compared to petroleum diesel include its renewable nature, superior emissions properties, support for domestic agriculture, compatibility with existing engines and distribution infrastructure, and ease of manufacture (NREL et al. 1998). In response to growing dependence on foreign sources of petroleum fuels, stricter emissions standards and concern for human linked climate change, the biodiesel industry has grown significantly over the last 15 years. World-wide biodiesel capacity has grown to over 2.2 billion liters since commercial production began in the early 1990's (WI 2005).

Biodiesel can be produced from a variety of lipid feedstocks, catalysts and alcohols using several possible conversion processes, making it difficult to define biodiesel in any singular way. Over the last 100 years of biodiesel research and manufacture, refining processes have matured, new feedstock sources have been tested and engine technology has been continuously optimized. All of the fuels developed during this time can be generally defined as biodiesel, even though they may differ significantly in their ultimate chemical make-up. Today, biodiesel has much stricter definitions in the form of quality standards, established to gain wider acceptance from engine manufacturers, distributors, retailers and end users. In 1991, Austria introduced the first quality standard, ON C 1990, with other European countries following-suit (Körbitz 1997). The European Union (EU) eventually established the biodiesel standard EN 14214 in 2003, which superseded individual country standards (DIN 2003). Similarly, the US passed American Society for Testing and Materials (ASTM) D 6751 in 2001 which regulates 14 fuel properties including flash point, water content, cetane and cloud point (ASTM 2001).

i. History

Rudolf Diesel invented the diesel engine in 1891. Intending to compete with coal-powered steam engines in manufacturing applications, Diesel's first models were large – the prototype was two stories tall and had a 3 meter cylinder. In fact, the diesel engine was not made sufficiently small enough to work in on-road vehicles until 1924 when it was used in a large truck by MAN Group[1] and not until 1936 for a passenger vehicle by Daimler-Benz (Nitske 1965). The diesel engine was reduced in size over the years following its invention, evolving from manufacturing to marine to locomotive to trucking and eventually personal transportation applications. During that time, the petroleum industry worked with diesel manufacturers to optimize the engines for use with petroleum diesel. This optimization of the engine (based on a thinner fuel) introduced compatibility complications for the more viscous, lipid-based diesel fuels -- a legacy which has persisted to this day.

Petroleum diesel's dominance over vegetable oil alternatives were not a foregone conclusion during the early period surrounding the engine's invention. Rudolf Diesel had designed his engine to be very flexible, running off a variety of low grade fuels including kerosene and coal dust in early tests (Nitske 1965). Contrary to popular belief, he did not originally plan for the use of lipid-based diesel fuels in his engine. However, after the French Otto Company demonstrated a more compact version of his engine at the 1900 Paris Exposition using straight peanut oil, he quickly became a proponent of biofuel use for their renewable nature and support of local agriculture (Knothe 2001). Rudolf Diesel went on to

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[1] The MAN Group, founded in 1758, is one of Europe's leading manufacturers of vehicles, engines and mechanical engineering equipment.

modify the fuel atomizers[2] to improve the performance of lipid diesel fuels in his engine. However, the slight exposure and support these fuels had quickly eroded with Diesel's death in 1913.

At the base of all the lipid diesel fuel experimentation which continues through today was the realization that, given the evolution of the diesel engine towards petroleum diesel fuel, straight vegetable oil was too viscous for the fuel injectors to handle properly. Prolonged use of vegetable oil in a stock diesel engine will lead to carbon deposits in the combustion chamber, 'valve sticking' on seats and stems and eventual leakage of fuel into the lubricating oil causing irreparable engine damage (Bari et al. 2002). This viscosity problem left two options: modify the vegetable oil fuels or modify the diesel engine. Even though the alterations necessary to the fuel injectors were small and relatively inexpensive, with tens of thousands of engines already in use, early experimentation focused on reducing the viscosity of the vegetable oil fuels. Motivated by increasing profits from their colonies, several European countries began researching ways to thin vegetable oils for use in diesel buses in 1920's. This experimental research led to the first recorded production of a biodiesel-like fuel in the form of a 1937 Belgian patent for an ethyl-ester made from West-African palm oil by G. Chavanne at the University of Brussels (Knothe 2001). Early experiments using vegetable oils in

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[2] The fuel atomizer was the precursor to fuel injectors in a modern diesel engine and is still the main area of compatibility with using straight vegetable oil.

heavy farming equipment also occurred in South Africa in the 1930's, but they were abandoned in favor of coal-to-liquid-fuel research (Demirbas 2002).

From the 1930's through the end of the war, limited domestic resources and disruptions to global petroleum supplies spurred new research and experimentation with biofuels. Brazil, China, South Africa, India and Argentina all used vegetable oil as a fuel during the war. With only very small domestic petroleum reserves and imported supplies essentially cut off, both Germany and Japan began rapid and large scale programs in alternative fuels including biofuels, coal-to-oil and even steam-powered vehicles. Japan, lacking the coal resources of Germany, was more focused on biofuels, culminating with the use of refined soybean oil in their battleship *Yamamoto* (Knothe 2001). While world petroleum reserves were not in question, supply problems during WWII highlighted the vulnerability countries would face when overly dependent on cheap, readily available petroleum. That said, with the return of cheap, readily available petroleum after the war, almost all lipid diesel development programs and research were terminated.

Interest in transportation fuel self-sufficiency was renewed by a series of supply crises in the 1970's. Between the Organization of Petroleum Exporting Countries (OPEC) oil embargo to the West in 1973 and the Iranian Revolution in 1979, the academic, scientific and business communities were once again emboldened to research and deploy large-scale alternative energy technologies and projects[3]. Three research teams began independent experimentations on the transesterification of vegetable oils to remove the thicker glycerin component beginning in Austria in 1973, in Idaho in 1979 and in South Africa in 1980; South Africa had additional impetus for energy independence after international embargoes protesting Apartheid significantly reduced their petroleum imports (Knothe 2001). Following these early lipid experiments, a wave of government and academic biodiesel research was funded, examining everything from the pollution properties, feasibility, oil feedstock comparisons, and the economics of deployment, as well as actual on-road testing in government vehicles. However, research and funding was scaled back significantly with falling petroleum prices in the 1980's and early 1990's. During this time biodiesel gained somewhat of a cult following amongst scientists, academics, tinkerers and treehuggers as much for its logistic properties -- ease of manufacture, readily available *free* feedstock in waste cooking oil, and great compatibility with existing engines -- as for its more idealistic properties, being a less polluting, more distributed, domestically produced, renewable fuel.

This continued groundswell of support made possible the most recent biodiesel revival which began in Europe in the early 1990's. Spurred by mandatory alternative fuel use legislation and a liquid fuel market dominated by

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[3] The 1970's also witnessed the first major attempts to understand the effects of pollution on human health, ecosystems, global climate change and the environment, further exemplifying the many *costs* of dependence on petroleum and other fossil fuels. The *Clean Air Act (1970)*, the *Endangered Species Act (1973)*, the *Safe Drinking Water Act (1974)*, the *Energy Policy and Conservation Act (1975)* and the *National Energy Act (1977)*, among others, were all passed during this time period.

diesel fuel (66% of demand), Europe's biodiesel production capacity has grown to over 2.0 billion liters today, spread across almost every country on the continent (IEA 2004; WI 2005). The biodiesel industry in the United States is not as mature as Europe with a current production of 100 million liters – less than Germany, France and Italy each (WI 2005). Many other countries have also begun to research and commercially produce biodiesel due to the low cost, relative simplicity and scalable nature of the infrastructure requirements. Today Canada, Australia, South Africa, Japan, China, India, Brazil, Thailand, Malaysia and Indonesia all have commercial biodiesel programs and many more are still in the research phase (Pahl 2005).

ii. Biodiesel Processing Overview

The conversion of lipids into biodiesel fuel requires several simple processes which differ depending on the feedstocks and type of transesterification method used. First, the oil (or fat) from the nut or seed bearing plant (or animal) must be extracted and processed. Then, transesterifying the oil (or fat) with an alcohol in the presence of a catalyst will yield biodiesel and glycerol.

Lipid Extraction and Processing

In extracting oils from plants, the primary goal is to disrupt the cell walls, thereby liberating as much oil as possible. *Physical* oil extraction technology has existed for thousands of years and involves simple mechanical presses.

Traditionally, screw presses were used, but today hydraulic presses improve efficiency. Most large-scale vegetable oil processing facilities, however, use hexane in a *chemical* extraction for its higher rate of recovery. Before the raw, extracted vegetable oil can be consumed or traded as a commodity, it must be de-gummed and de-acidified to qualify for the *food-grade* classification (Van Gerpen et al. 2004).

Animal fats must be processed before they can be used to make biodiesel, but they are desirable as a feedstock for their low cost. "*Rendering*," the process of extracting animal fats, can be used with lard, tallow, fat and whale blubber. Similar to vegetable oils, there are multiple rendering methods to extract fats. The simple method, in use for many years, involves chopping fatty tissues into fine pieces and boiling them in vats or steam digesters, allowing the pure fats to be skimmed off the surface. Today, more efficient temperature-controlled centrifuges are used to render fats on a commercial scale (Van Gerpen et al. 2004).

Transesterification

Transesterification, the exchange of the alkoxy group of an ester compound with an alcohol, is chemical process which has been has known about as early as 1853 (Demirbas 2002). The Colgate Company first patented the process in the United States in 1940 -- although not to produce biodiesel as a war-time fuel. Instead, transesterification was used to produce glycerol for use in explosives manufacturing (Van Gerpen 2003). While, more efficient methods of producing glycerol have been developed since, transesterification is still used commercially, most notably in the production of polyester and biodiesel. Transesterification methods, including those used to produce biodiesel, are primarily differentiated by the processing infrastructure and catalyst selected. Batch processing is an easy method that produces small quantities of biodiesel; however, most large-scale production uses continuous-flow processors due to lower per liter refining costs. Both acid and base-catalyzed transesterification processes are used in large-scale biodiesel production depending on the desired by-products – with base-catalyzed being the more common of the two (Van Gerpen et al. 2004).

Biodiesel Co-Products & By-Products

The added-value products of biodiesel production can be divided into two categories – the co-products, made from unused feedstock materials, and the by-products, additional outputs of the transesterification process. Both types of products are important to take into account when producing biodiesel as they will greatly influence the final cost per liter.

The co-products of the feedstock lipids vary depending on the crop and can often be more sought after than the biodiesel. From the perspective of a biodiesel producer, soybean meal would be considered a co-product of soybean oil production, as it is the pulpy vegetation left after oil extraction. In the United States, demand for soybean meal animal feed far outpaces that of the accompanying soybean vegetable oil. The commercial biodiesel industry in the

United States was founded by soybean farmers and processors searching for a higher-value, alternative outlet for soybean oil which had an oversaturated market (Pahl 2005). Similar market dynamics must be factored into any decision on feedstocks, as oilseed crop co-products are used for everything from human food, animal feed, raw building materials, to charcoal for heating.

The by-products of the transesterification process include glycerol and un-reacted catalyst and alcohol. In efficient, continuous-flow refineries, the un-reacted raw materials are recaptured and reused. Glycerol, also known as glycerin and glycerine, is a sugar alcohol commonly used in the manufacture of soap, cosmetics & creams, foods & beverages and pharmaceuticals. These by-products of biodiesel production, if re-used and sold, can also affect the final cost per liter of the resulting biodiesel.

iii. Benefits and Drawbacks of Biodiesel vs. Petroleum Diesel

Biodiesel has been touted as a drop-in replacement for petroleum diesel. While this is generally true, there are a few distinct differences that should be noted – some which make switching to biodiesel easier, some more difficult and others which have both positive *and* negative attributes. Biodiesels themselves can also differ from one another depending on the feedstocks used for production. These differences are particularly important to this global study which includes all commercially traded varieties of processed lipids.

Table 1.1: B100 Emissions vs. Petrol-Diesel

Effluent	Reduction
CO_2	-78%
CO	-43%
NO_x	+13%
SO_2	-100%
PM_{10}	-32%
VOC	-63%

Biodiesel improves on petroleum diesel in a variety of ways which make it safer to store and handle. Unlike petroleum diesel, biodiesel is not classified as a hazardous liquid due to properties which make it much safer to handle and store. Biodiesel has a higher flash point, is less toxic and is more biodegradable than petroleum diesel. These factors, along with biodiesel's natural solvent properties, reduce the environmental risk of spills – biodiesel breaks down naturally while petroleum products tend to coat surfaces in the event of a spill. Biodiesel also has much better overall combustion emissions compared to petroleum diesel, as seen in Table 1.1. Nitrogen oxides (NO_x) are the only effluent which increases and that can be tweaked to equal petroleum diesel emissions by retarding the ignition timing. Carbon dioxide (CO_2), which has been linked to global climate-change, is reduced by 78% and could be made totally carbon neutral if biodiesel were used in the production and transportation of the fuel as well. Petroleum diesel retains an overall power advantage over biodiesel, although it is only the equivalent of about 5-7% and is rarely noticeable by the end user (NREL et al. 1998; Strong et al. 2004). Petroleum diesel has a higher gel-point, the temperature which the fuel begins to gel, than gasoline making it less desirable in cold climates without modifications to the fuel or engine. Biodiesel has an even higher gel-point than petroleum diesel which can affect users in all countries but the most consistently warm (NREL et al. 1998).

In addition to the positives and negatives, there are several differences which contain elements of both. Because biodiesel is a natural solvent, overall engine-life will be extended but maintenance will increase initially. Biodiesel has been shown to dislodge petroleum-diesel deposits in the engine, requiring more frequent filter changes for several months after switching fuels (Strong et al. 2004). Similarly, biodiesel's solvent properties can degrade natural rubber seals, requiring additional upfront maintenance to replace them with synthetic rubber varieties. Engine seals are rarely an issue, however, as most modern diesel vehicles already use synthetic rubber seals. The last comparison property between petroleum diesel and biodiesel is in regards to the fuel distribution infrastructure and is neither positive nor negative. Biodiesel, having been chemically modified to resemble petroleum diesel, can utilize the existing distribution infrastructure including pipelines, tanker trucks and filling stations. While this compatibility is not an *advantage* biodiesel has over petroleum diesel, it is often considered a benefit of biodiesel nonetheless, as it will make transition and adoption easier.

For this study, several of these differentiating factors must be examined in closer detail as they are responsible for the largest discrepancies in biodiesel potential between countries. The most influential of these factors, is the *choice* of lipid feedstock used to manufacture biodiesel. The feedstock options available to a country are theoretically only limited by growing conditions. However, realistically, lipids available for biodiesel production are often dictated by entrenched national agricultural crops with strategic value and uses above and beyond those offered by biodiesel. When choice of feedstock crops is available, oil yield per hectare can be a very important differentiator as few countries in the world have excess farmland. Deciding between oilseed crops entails balancing climate conditions and individual crops' soil, fertilizer and water requirements, with the land use priority a country puts on biofuels. For instance, in the United States, canola can be grown in the same climate regions as soybeans and yield more than double the oil per acre [Table 1.2]. However, because soy products are in higher demand and have more end uses – whole beans, oil, meal and plastics among others – canola is only grown on 1/88th as much land area as soy (FAOSTAT 2005). Table 1.2 lists the oil yields per hectare of some of the most common oilseed feedstock crops referenced in the study (Duke 2001; NewCROP 2006).

The technical properties of biodiesels made from different feedstock oils and fats can vary in a multitude of ways including cetane number, flash point, ash content, density, iodine value and electrical conductivity. Most are close enough not to be noticeable to end users or affect compliance with ASTM or EU standards (Kinast 2003). However, biodiesel cold-flow related properties such as viscosity, pour-point and cloud-point can vary significantly

Table 1.2: Ave. Oilseed Crop Yields

Oilseed Crop	Liters/Hectare
Cotton	160
Soybean	320
Hemp	440
Opium Poppy	500
Mustard	570
Linseed (Flax)	700
Safflower	780
Rapeseed/Canola	800
Groundnuts (Peanuts)	800
Sunflower	850
Sesame	1,200
Coconut	1,750
Castor Beans	2,000
Palm Oil	3,800

depending on the oilseed feedstock and can introduce incompatibilities with fuel specifications. In particular, the gel-points of biodiesels made from most tropical oilseed crops, such as palm and coconut, as well as from animal fats, are significantly higher than those made from more temperate oilseed varietals. Table 1.3 lists the gel-points of the most widely available lipid feedstocks (Kinast 2003). While tropical biodiesels were not included in that particular test, the properties of palm-based biodiesel tracks closely with that of lard biodiesel and coconut splitting the difference between soy and palm. Depending on where the finished biodiesels are used, these gel-point differences become more, or less, important. Biodiesel made from tropical oils will pose few problems if used in those same countries as temperatures are almost always warm. If the goal is to export the fuel to colder climates, thinning additives must be mixed with the biodiesel, which increase costs per liter. Cold-flow concerns are significant for this study as the European Union and the United States are currently the largest importers of biofuels – both of which have temperate climates with cold winters.

The emissions properties of biodiesels made from different oilseed feedstocks are all similar and, therefore, will compare favorably to petroleum diesel across the study. However, while

Table 1.3: NREL Study of Cold-Flow Properties of Various Biodiesels and Petrol-Diesel

Fuel	Viscosity	Pour-point (ºC)	Cloud-point (ºC)
Petroleum Diesel	2.45	-27	-18
Canola Biodiesel	4.63	-4	-3
Soy Biodiesel	4.546	-1	2
Yellow Grease Biodiesel	4.66	8	8
Lard Biodiesel	4.85	11	14
Edible Tallow Biodiesel	4.908	13	20
Inedible Tallow Biodiesel	4.93	8	23

technical properties of biodiesel emissions are consistent, the economic priorities and incentives placed on the reduction of emissions (and greenhouse gases) may vary considerably across countries. Strict environmental regulations and alternative fuel mandates put price premiums on biofuels and contribute to their high demand in Europe and North America. These variations between countries on how emissions reductions are incentivized can make certain feedstock crops profitable for use in biodiesel production when they would not normally be otherwise.

B. Literature Review

Despite biodiesel's relatively recent commercialization, it has already amassed a large body of technical research. Research began as far back as the 1970's, however, the majority of publications have only come out after the early 1990's. Since that time, over 700 peer reviewed articles and countless other grey literature[4] have been published on biodiesel which generally address one of three categories, 1) research on the technical properties of biodiesel fuel, 2) impact studies of implementing large-scale biodiesel refineries, or 3) assessment of biodiesel potential for a region or regions.

Existing research on biodiesel is heavily weighted toward the first category -- the technical properties of the fuel, its production and its combustion. Research

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[4] Grey literature is the term often used to describe semi or not formally published material, for example internal reports or commissioned studies.

has been published on everything from optimal transesterification processes (Demirbas 2002; Van Gerpen 2003; Van Gerpen et al. 2004), to power content (Kinast 2003; IEA 2004), to effects on engine life (NREL et al. 1998; Strong et al. 2004; EERE 2006), and combustion emissions (NREL et al. 1998; Lapuerta et al. 2003; NREL 2003; Powlson et al. 2005). Because all of these properties can vary according to feedstock, however slightly, much of the research has been repeated for multiple oilseed or animal fat varietals (Bari et al. 2002; Kinast 2003). As new oilseed feedstocks continue to be assessed, research has become less and less centered on the Europe and the United States (Kheshgi et al. 2000; Francis et al. 2005; Holm 2005; Kojima et al. 2005). While some lipid feedstocks are less desirable than others, assuming a choice exists, *all* oil and fat feedstocks can be made into biodiesel and new studies continue around the globe. In the case of sub-optimal varieties, research attempts to address the particular shortcomings, either compared to other feedstocks or compared to petroleum diesel, including the costs which must be incurred to overcome them (additional oil processing, additional catalyst, thinning agents, etc).

The second most prevalent body of publications addresses the impacts of implementing biodiesel refining plants. These studies and reports cover either biodiesel's macro-impacts, quantifying the economic or environmental effects of massive country or state-wide biodiesel initiatives, or micro-impacts, quantifying the costs and benefits of an individual refining plant on the state, region or city (Babiker et al. 2000; Austin et al. 2003; Kammen et al. 2004; Assmann et al. 2005;

Domac et al. 2005; Kojima et al. 2005). As biodiesel's cost per liter exceeds that of petroleum diesel in most markets, these studies encourage development of biodiesel by attempting to quantify its benefits: the support of rural development, support of domestic agriculture, emissions reductions and job creation. Many of the smaller-scale impact assessments specific to certain regions are released not as peer reviewed publications, but as commissioned, grey studies by state or local governments.

The last category of biodiesel research, the assessment of potential biodiesel volumes, is by far the least published. A country or region's biodiesel potential is defined as the volume of biodiesel which can be produced from domestic feedstocks. The first two categories of research, the technical feasibility of biodiesel and quantification of its impacts, demonstrate biodiesel to be a beneficial alternative to petroleum diesel. Less common are studies which calculate biodiesel potential and assess which regions or countries can best take advantage of it, either to offset imported petroleum diesel imports or to export profitably. In performing a literature review for this thesis study, only thirteen publications were identified that assess biodiesel potential in one form or another [Table 1.4]. The thirteen studies generally differ by type of study, geographical scope, feedstocks and level of detail.

The format of the thirteen studies identified incorporates both peer reviewed articles as well as grey literature from state, federal and international groups. Much like the implementation studies, potential assessments in the grey reports are specific to local conditions, laws and incentives. An effort was made to include all

Table 1.4: Publications Which Assess Biodiesel Potential

No.	Author, Year	Type of Study	Focus	Geographic Scope	Feedstocks Included	Volume Estimates	Econ/Envir. Impacts	Addresses Self-Sufficiency
1	Cadenas and Cabezudo 1998	Peer reviewed	Biofuel opportunities for less-developed countries	Europe	All Available Feedstocks	Yes	No	Yes
2	Wörgetter 1998	IEA Bioenergy	Compilation of biodiesel studies	Austria, France, Italy and European Commission	Rapeseed, Sunflower	Yes	Yes	No
3	Poitrat 1999	Peer reviewed	Liquid biofuels potential	France	Rapeseed, Sunflower	Yes	Yes	Yes
4	Raneses, Glaser et al. 1999	Peer reviewed	Econ. effects of biodiesel on agriculture sector	United States	Soybean	Yes	Yes	No
5	Kheshgi, Prince, Marland, 2000	Peer reviewed	Biomass fuels and climate change	United States	Soybean, Algae	Yes	No	Yes
6	Schöpe 2002	Grey study	Biodiesel from rapeseed	Germany	Rapeseed	Yes	Yes	Yes
7	Althoff 2003	Grey study	Biodiesel legislation review for the state of Indiana	Focus: Indiana Context: United States	All Available Feedstocks	No	Yes	No
8	Boyd 2004	Grey study	Biodiesel feasibility study	British Columbia	All Available Feedstocks	Yes	Yes	No
9	IEA 2004	IEA Bioenergy	Biofuels for transport	United States and Europe	Soybean, Rapeseed	Yes	Yes	Yes
10	SEI 2004	Grey study	Liquid biofuels strategy	Ireland	All Available Feedstocks	Yes	Yes	Yes
11	Cloin 2005	Grey study	Coconut oil study	Pacific Island Countries	Coconut	Yes	No	Yes
12	Powlson, Riche et al. 2005	Peer reviewed	Decreasing emissions through agriculture	United Kingdom	Rapeseed, Sunflower	Yes	No	Yes
13	Subramanian, Singal et al. 2005	Peer reviewed	Liquid biofuels potential	India	Jatropha	Yes	Yes	Yes

related peer-reviewed journal articles. However, additional location-specific studies presumably exist, but were not circulated enough to be identified in this literature review.

In terms of geographic scope, only four of the thirteen publications identified attempt to calculate potential across multiple countries. Three of the studies target Europe and/or the United States (Cadenas et al. 1998; Wörgetter 1998; IEA 2004). However, the above studies calculate the entire region or regions potential as opposed to separating out countries for comparison sake. The final regional study does compare potentials among Pacific Island Countries and is one of the most in-depth of all the publications identified in this literature review (Cloin 2005). The results cannot be compared to the following thesis study, however, as the analysis was centered on a single feedstock – coconut. None of the existing publications perform truly *global* analyses of biodiesel potential, something this study aims to address.

The majority of the publications limit their assessments to specific countries or states. Three of the studies target the United States as a whole or individual states there-in (Raneses et al. 1999; Kheshgi et al. 2000; Althoff 2003). Four European countries, France, Germany, Ireland and the United Kingdom, have individual potential assessments as well (Poitrat 1999; Schöpe 2002; SEI 2004; Powlson et al. 2005). The remaining two country or region-specific studies target British Columbia and India respectively (Boyd 2004; Subramanian et al. 2005). However, because each study was undertaken independently of each other, individual analyses are of little use for cross-country comparisons that determine optimal deployments of biodiesel. Similarly, the results of these assessments cannot be directly compared to the results of this thesis due how feedstocks were calculated or included.

Feedstock selection was one of the primary differentiators of the studies, with the majority only analyzing select feedstocks from the region being researched, typically the one or two most common varieties. Cadenas, Althoff, Boyd and the SEI perform their analyses using *all* the available feedstocks from the region or regions. However, these studies chose a more theoretical approach – examining potential from *all* feedstocks quantities regardless of impacts to a country's human or animal food needs. Powlson's study remains even more abstract, calculating the energy in the biomass without attempting to covert the figures to more comparable units such as liters or tons of biodiesel. Unfortunately, these methods of assessing feedstock potential preclude them from comparison with this study which assumes only exported vegetable oil and animal fats as viable feedstocks.

All of the thirteen studies recognize that biodiesel generally costs more per liter than petroleum diesel. While a strict economic analysis would only consider the use of biodiesel if it were cheaper per liter than petroleum diesel, self-sufficiency in transportation fuels is addressed in the majority of the publications (9 of 13). The benefits of biodiesel are not always quantified explicitly; however, they hold enough value with the authors to merit calculating the cost of energy independence (self-sufficiency). Of the studies which did not address national self-sufficiency. Only one of the four was published in a peer-reviewed journal and its thesis primarily addressed the economic impacts of biofuels to the agricultural industry as opposed to transportation (Raneses et al. 1999). The other three were all grey literature -- one a compilation of regional analyses and the rest, limited in geographical scope to states or territories such that national self-sufficiency would not be relevant (Wörgetter 1998; Althoff 2003; Boyd 2004).

C. Goals of this Thesis Study

The primary goal of this thesis is to conduct a consistent, national-level, evaluation of potential biodiesel volumes, replicated across all countries in the world, to answer the following questions:

Primary Thesis Questions:

1. Which countries have the highest absolute biodiesel potential?
2. Which countries can profit the most from biodiesel exports, thereby increasing their trade balances?
3. Which countries can profitably offset petroleum-diesel imports with biodiesel?
4. What is the cost of self-sufficiency from petroleum-diesel imports?

This study only uses exported vegetable oils and animal fats in potential calculations to give a more accurate representation of a country's short-term biodiesel production. By using existing commodity crop data, all of the results presented could be achievable as soon as the refining infrastructure is constructed. Additionally, this study of potentials is unique in the level of detail retained throughout the calculations, allowing the results to be useful to a variety of audiences – both at the national and international levels. By preserving volume and price data for individual biodiesel feedstock crops, it is not only possible to calculate more accurate bioenergy potentials (in actual liters), but also to evaluate each one economically in a variety of growth strategies. Furthermore, the inclusion of national petroleum diesel consumption statistics allows this study to address the topic of self-sufficiency more explicitly than previous publications.

This study is intended to be useful in global-level country comparisons. Institutions such as the World Bank and the United Nations, as well as member nations of the Kyoto Protocol can use the results of this thesis to compare countries' potentials against one another. By using a consistent assessment procedure across all countries, this study allows for the possibility to maximize the economic development and environmental impacts of foreign aid and foreign investment dollars committed to renewable energy technologies. This study may also be used strategically within individual countries as a first-order assessment of potential and a basis for further in-depth analyses.

Since the basis for this study is a national-level assessment of export potential, not all of the global implications of realizing these potentials are evaluated. This study does not address impacts on global food supply or long term sustainability of world agriculture production, among others, as these concerns would not be included in a national study. Local impacts on domestic demand are included, however, by examining only potential export volumes. Additionally, this study analyzes only existing farm land already dedicated to oilseed crops, thereby mitigating some of the concerns related to local, unsustainable agricultural growth. That is to say, while this thesis is set in a global context and can be useful for comparisons between countries, it should not be read as a global impact analysis.

Chapter II: Data Sources and Calculations

The previous chapter served as an introduction to both the benefits of replacing petroleum diesel with biodiesel, and to the existing body of research which aids in biodiesel's development. This thesis study attempts to build on that prior research, to complete a more in-depth, global analysis of biodiesel potential. This evaluation is organized around a database which incorporates data from a variety of sources spanning all countries and all feedstocks. In addition to raw cost and volume savings, this study calculates the percent reduction in petroleum demand, effects on job creation and trade balances, as well as air quality and greenhouse gas reductions. The database also incorporates country specific information such as population and economic trends, receptiveness to foreign aid and investment, general safety and climate and environmental sensitivities.

This chapter details the data sources used in this study and includes information on why they were chosen, how they were used to create indicators relative to biofuels potential development scenarios and some of the limitations inherent in the calculations. All of the data used in this assessment were taken from publicly available online sources. By providing a detailed overview of the data sources and how they were used, this work may be independently updated as newer, more complete data sets become available. Unless otherwise noted, all of the sources below were converted to metric units and United States dollars (US$).

A. Assessing Biofuel Volume and Cost Potential

Potential can be defined in many ways, especially when speaking on the subject of energy. Comparisons of energy content, volumes, cost-differential and environmental impact (among others) are all valid approaches to determining the potential of one energy source over another. In the context of this thesis, *biodiesel potential* is defined specifically as how much of a country's existing petroleum demand (based on energy content) can be met by biodiesel produced from domestic lipid feedstocks. This study only considers land already used in oilseed cultivation and assumes only exported fats, oils and oilseed crops can contribute to a country's biodiesel potential to ensure domestic lipid demand is accounted for. Because this is a global assessment of biodiesel potential, the scope includes all lipid feedstocks and all farmland for all countries for which data exists.

Biodiesel is a very flexible fuel in that it can be made from many different lipid sources, including both plant oils and animal fats. Assessing the total volume of lipids which can be utilized, however, remains difficult as there are over 350 species of oilseed plants, many of which are very unique to specific locations and climates (Demirbas 2002). Similarly, the fats from essentially any animal species can be used as a feedstock in biodiesel production. To research all the highly specific sources of lipids that exist world-wide would be time-prohibitive and contribute little to overall volumes, which are dominated by few commercial sources in each country. By limiting the assessment to large-volume, commodity crops, oils and fats, it is possible to assess volume and value using readily available data sources. The U.S. Department of Agriculture and the E.U. Agriculture Commission both have statistics on oilseed crops but the most complete source, with regards to number of feedstocks and countries included, is the Food and Agriculture Organizations of the United Nations (FAO)[5]. The FAO's statistics division, FAOSTAT[6], has the most extensive statistics on *processed* oils and fats as well as *primary* oilseed crops (FAOSTAT 2005). Using the data from FAOSTAT, this study calculates the total lipid volumes across three growth (investment) strategies -- each requiring additional investments in agriculture or processing infrastructure than the last. Figure 2.1 details how lipid volumes available for conversion into biodiesel are calculated across the three growth strategies including the infrastructure required. Table 2.1 lists all the variables used in the biodiesel potential calculations.

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[5] FAO, founded in 1945, serves both developed and developing countries, acting as a neutral forum where all nations meet as equals to negotiate agreements, debate policy, and share knowledge relating to agriculture, fisheries, forestry and sustainable development.

[6] FAOSTAT is an online and multilingual database currently containing over 3 million time-series records covering international statistics in the following areas of: production, trade, food balance sheets, producer prices, forestry trade flow, land use and irrigation, forest products, fishery products, population, codex alimentarius food quality control, fertilizer and pesticides, agricultural machinery, food aid shipments and exports by destination.

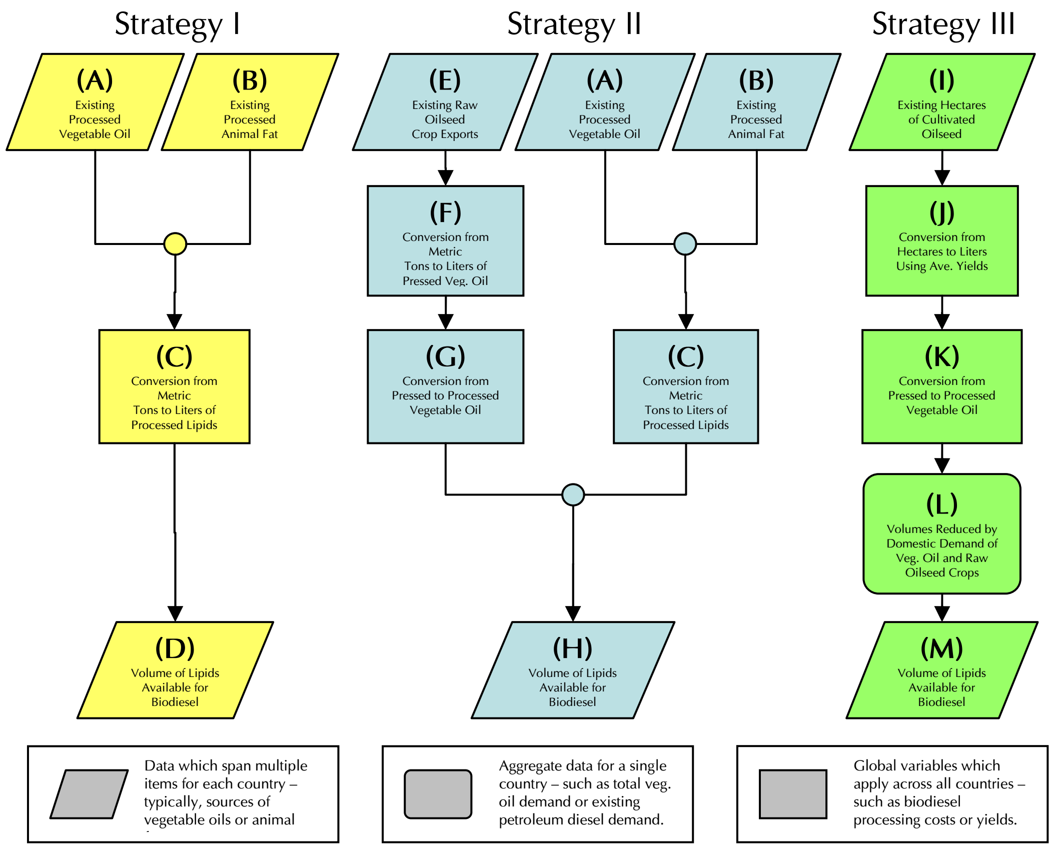
Table 2.1: Table of Variables

Variable Name	Description	Source	Comments
EO_{ij}	Exported, processed vegetable oil for feedstock i, country j	FAO 2005	Units = metric tons
EF_{ij}	Exported, processed animal fats for feedstock i, country j	FAO 2005	Units = metric tons
LD	Average lipid density	Walker 2005	Units = kilograms per liter
$LV1_{ij}$	Potential lipid volumes for development scenario 1, feedstock i, country j	N/A	Calculated by this study, units = liters
EC_{ij}	Exported, whole oilseed crop for feedstock i, country j	FAO 2005	Units = metric tons
OC_i	Oil content of crops for feedstock i	NewCROP 2006	% oil of nuts/seeds
CV_{ij}	Crude, vegetable oil volumes for feedstock i, country j	N/A	Calculated by this study, units = liters
PR	Vegetable oil processing ratio	Van Gerpen, Shanks et al. 2004	% of processed to crude vegetable oil
$LV2_{ij}$	Potential lipid volumes for development scenario 2, feedstock i, country j	N/A	Calculated by this study, units = liters
LU_{ij}	Land use for feedstock i, country j	FAO 2005	Units = hectares
OY_i	Oil yield for feedstock i	NewCROP 2006, Duke 2001	Liters of oil per hectare
AD_j	Aggregate veg oil & whole seed demand for country j	FAO 2005	Units = metric tons
CD_{ij}	Crop-specific veg oil & whole seed demand for feedstock i, country j	N/A	Calculated by this study, units = liters
CP_{ij}	Crop-specific veg oil & whole seed demand for feedstock i, country j	FAO 2005	Units = metric tons
AP_j	Aggregate veg oil & whole seed production for country j	FAO 2005	Units = metric tons
$LV3_{ij}$	Potential lipid volumes for development scenario 3, feedstock i, country j	N/A	Calculated by this study, units = liters
LV_{ijk}	Lipid volume for feedstock i, country j, growth strategy k	N/A	Calculated by this study, units = liters
LC_{ijk}	Lipid costs for feedstock i, country j, growth strategy k	N/A	Calculated by this study, units = liters
RC	Biodiesel refining costs	Kojima and Johnson 2005	Units = US$ per liter
RR	Biodiesel refining ratio	Van Gerpen, Shanks et al. 2004	% of biodiesel to lipid feedstock
BV_{ijk}	Biodiesel volume for feedstock i, country j, growth strategy k	N/A	Calculated by this study, units = liters
ER	Energy content ratio	EERE 2006	% energy content difference of biodiesel to petrol diesel
AV_{ijk}	Energy content adjusted biodiesel volume for feedstock i, country j, growth strategy k	N/A	Calculated by this study, units = liters
GP	Glycerol production per liter biodiesel	Kojima and Johnson 2005	Units = kilograms
GV	Glycerol value (technical grade)	Radich 2004	Units = US$ per kilogram
AC_{ijk}	Cost adjusted biodiesel for feedstock i, country j, growth strategy k	N/A	Calculated by this study, units = US$ per liter

i. Growth Strategy I: Exported Vegetable Oil & Animal Fat Potential

Volumes of exported, commercially traded, processed plant oils, EO_{ij} [Figure 2.1.A], and animals fats, EF_{ij} [Figure 2.1.B], form the basis for calculating the biodiesel potential in the first growth strategy (GS1). This study presumes exported lipids are required for domestic consumption, thereby assuring domestic demand remains fulfilled. Converting these lipids sources into biodiesel to offset petroleum diesel imports would require minimal investment, as no additional lipid processing infrastructure would be needed –only biodiesel refining infrastructure would be needed. These vegetable oils and animal fats, currently exported for use

Figure 2.1: Calculating Potential Vegetable Oil Volumes



in human or animal food, are listed in metric tons by the FAOSTAT database and must first be converted into liters. The densities of vegetable oils are all very close, so an average value of 0.9242 kg/liter, *LD* [Figure 2.1.C], was used to convert the figures to liters, $LV1_{ij}$ (feedstock i, country j) [Figure 2.1.D], for later comparisons (Walker 2005). This approach introduces an error of no more than 1% for vegetable oils, the maximum density difference between sunflower oil (the lightest oil) and linseed oils (the heaviest) and 2% for animal fats. In addition to mass, the FAOSTAT database also tracks the value of all import and export commodities making it possible to determine the current price per liter of each individual feedstock and assess its competitiveness with petroleum fuels.

$$(EO_{ij} * LD) + (EF_{ij} * LD) = LV1_{ij}$$

ii. Growth Strategy II: Exported Whole Oilseed Crop Potential

Whole oilseed crop exports, EC_{ij} [Figure 2.1.E], can also be used in making biodiesel, but the oils must first be extracted, requiring additional investment in processing capacity. The biodiesel potential in the second growth strategy (GS2) [Figure 2.1.H], is based on a combination of these processed vegetable oil volumes from exported, whole oilseed crops and the existing exported vegetable oil and animal fat volumes from $LV1_{ij}$. The FAOSTAT database includes data on whole oilseed crop exports, but to be useful to this study, they required conversion from metric tons of seeds/nuts to liters of vegetable oil. Oil content data from the

NewCROP database[7], OC_i, ranging from cotton seed at 13% to coconut at 62%, were used to calculate how much vegetable oil (in metric tons) could be extracted from the whole oilseed crop exports (NewCROP 2006). Then, the same average vegetable oil density figure of 0.9242 kg/liter, *LD* [Figure 2.1.C], from GS1 was used to convert the metric tons of vegetable oil to liters, CV_{ij} [Figure 2.1.F] (Walker 2005). The vegetable oil volumes resulting from these calculations, however, remain in terms of raw, pressed vegetable oil. Before this oil can be made available for refining into biodiesel, it must first be processed into a food-grade vegetable oil which will reduce the overall volume. This processing includes filtering to remove non-oil particles, de-gumming and de-acidifying the vegetable oil. For this study, the overall volume was adjusted downward to 96.22% -- the industry average efficiency of soybean oil processing, *PR* [Figure 2.1.G] (Van Gerpen et al. 2004). The value per liter of this newly processed vegetable oil was assumed to be equal to existing crop-specific, export prices from the FAOSTAT database. These new volumes added to the lipid volumes from GS1, $LV1_{ij}$, were the total lipid volumes available for later biodiesel refining in GS2, $LV2_{ij}$ [Figure 2.1.H].

$$EC_{ij} * OC_i * LD = CV_{ij}$$

$$LV1_{ij} + (CV_{ij} * PR) = LV2_{ij}$$

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[7] The NewCROP database, started in 1995, is a compilation of agricultural crop data and statistics. NewCROP is a project of the Purdue University Center for New Crops and Plant Products and is associated with the New Crop Diversification project and the Jefferson Institute.

iii. Growth Strategy III: Maximum Cultivated Land Potential

In addition to exported commodity crops, the FAOSTAT database also tracks primary agriculture statistics including land use (in hectares) and production volumes (in metric tons) for a variety of crops, including oilseeds. The third growth strategy (GS3) calculates the *best-practices* vegetable oil potential – based on the expected yield from a well managed, modernized farm -- from existing land used for oilseed cultivation. Considering these yields are often equal to or greater than those recorded in the FAOSTAT database, GS3 reflects a theoretical, yet still achievable, upper bound on production. The yields for a single feedstock crop can vary greatly across countries (or even within countries) depending on the climate, soil fertility, and chemicals and machinery used. By combining specific crop data on total areas cultivated from the FAOSTAT database, LU_{ij} [Figure 2.1.I], with world-wide, *best practice* oil yields, OY_i [Figure 2.1.J], it is possible to identify the potential for a given country if more intensive forms of agriculture were used (Duke 2001) (NewCROP 2006). It is important to note that different average oil yields were used in GS2 (percentage oil in seeds/nuts) and GS3 (liters/hectare). The oil contents of specific crops used in GS2 have much less regional variation than the potential volumes of vegetable oil per hectare -- dependent on such factors as growth rate, insolation, irrigation, climate, and soil quality -- further contributing to the theoretical nature of the GS3 calculations. Like the potential from existing oilseed crops in GS2, the oil volumes were reduced to 96.22% of the raw vegetable oil volumes, *PR* [Figure 2.1.K] to account for processing into a form suitable for refining into biodiesel (Van Gerpen et al. 2004).

Unlike the portion of the FAOSTAT database which tracks exported oilseed crops and processed oils, the primary crop section from which land use data was taken includes *all* production, including domestic requirements. To adjust the maximum vegetable oil potentials from GS3 to include domestic demand, FAOSTAT's aggregate statistics for demand of both whole oilseed crops and processed vegetable oil were used. To retain crop specific data for later calculations, this aggregate demand, AD_j, was converted to approximate, crop-specific demand, CD_{ij} [Figure 2.1.L], which after converting to liters, could be exclude from the overall potential, $LV3_{ij}$ [Figure 2.1.M]. These crop-specific demands were calculated by attributing the same percentage which a specific crop's production, CP_{ij}, contributes to a country's total oilseed production, AP_j, to the total oilseed demand, AD_j. While only approximations, by retaining potential data at the crop level, it is possible to separate out volumes and prices to later determine which, if any, can be profitably refined into biodiesel.

$$(CP_{ij} / AP_j) * AD_j * LD = CD_{ij}$$

$$(LU_{ij} * OY_i) - CD_{ij} = LV3_{ij}$$

B. Petroleum Fuel Demand and Pricing

Before the profitability of biodiesel made from individual feedstocks can be assessed, an understanding of the existing petroleum fuels market is required to determine both the baseline competitive price and the ultimate size of the fuel market in each country. The U.S. government's Energy Information Administration[8] (EIA) has the most complete data on import, export and total domestic consumption of liquid fuels – covering over 230 countries, territories and protectorates (EIA 2005). The EIA does not track country-specific petroleum fuels pricing information directly, but provides a link on their website to an organization which does, Deutsche Gesellschaft für Technische Zusammenarbeit[9] (GTZ). GTZ biennially publishes the International Fuel Prices guide which has pricing information on 172 countries (GTZ 2005). Particularly of interest to this assessment, are the extensive reporting on retail fuel prices, taxes and subsidies, set in the context of baseline average wholesale prices of both refined fuels and crude oil.

While GTZ was the most inclusive source of fuel price data available, there were noticeable gaps in the country coverage when compared to agricultural and fuel consumption figures, especially among many Pacific Islands. To help fill in this data gap, retail fuel pricing information for both gasoline and diesel was added

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[8] The Energy Information Administration (EIA), created by the Congress in 1977, is a statistical agency of the U.S. Department of Energy. They provide policy-independent data, forecasts, and analyses to promote sound policy making, efficient markets, and public understanding regarding energy and its interaction with the economy and the environment.

[9] Deutsche Gesellschaft für Technische Zusammenarbeit is a private sustainable development company owned by the German government whose activities are geared to improving people's living conditions and prospects on a sustainable basis. Working in cooperation with the World Bank, German embassies and consulates and their world-wide offices, GTZ provides forward-looking data and solutions for political, economic, ecological and social development in a globalised world.

from the Pacific Islands Forum Secretariat's[10] quarterly "Pacific Fuel Price Monitor" (PFPM) reports (PIFS 2005). The last source of liquid fuel pricing data came from the World Bank[11] (WB 2002). The statistics section on the World Bank's website includes country profiles for 152 nations, many of which overlap with the GTZ study. However, the few unique entries were added to the master fuel price list, making it complete enough to allow for detailed, world-wide biofuels comparisons.

C. Calculating Biodiesel Conversion Costs

To compare diesel fuel and vegetable oil costs associated with each of the three growth strategies, lipid volumes, LV_{ijk} (feedstock i, country j, growth strategy k), and costs, LC_{ijk} [Figure 2.2.D], [Figure 2.2.H], [Figure 2.2.M], must first be adjusted based on biodiesel refining costs, conversion ratios and for the energy content of the fuel itself. Additionally, the main by-product of biodiesel refining, glycerol, is a valuable commodity and must factor into the final cost of the fuel production.

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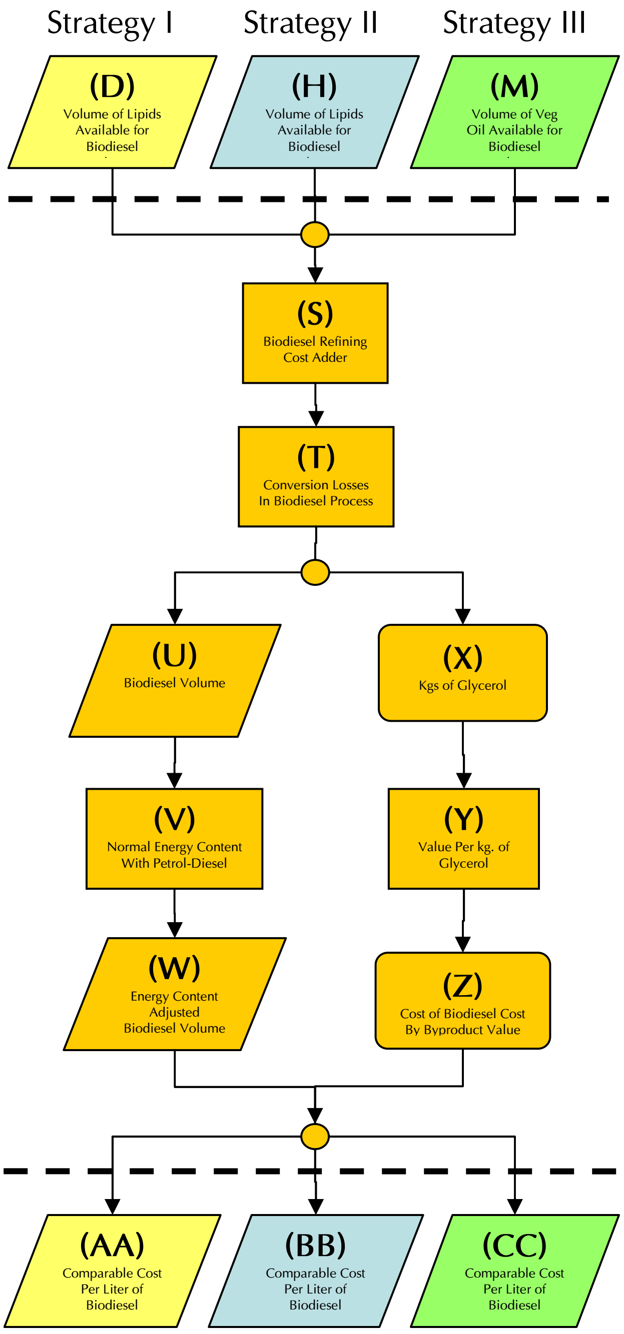
[10] The Pacific Islands Forum Secretariat is a cooperative group of 16 countries committed to improving the economic and social well-being of peoples of the south pacific. Member nations include: Australia, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Republic of the Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu.

[11] The World Bank is not a bank in the common sense, but made up of two development institutions owned by 184 member countries—the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA). Together the World Bank provides low-interest loans, interest-free credit and grants to developing countries for education, health, infrastructure, communications and many other purposes.

To determine the cost of refining the vegetable oil into biodiesel, average, commercial-scale production costs of $0.12 per liter, *RC* [Figure 2.2.S], were applied to the cost of the processed vegetable oil volumes (Kojima et al. 2005). While biodiesel conversion costs can vary considerably based on the scale, process and labor costs, a fixed average was chosen for consistency and ease of calculation. This fixed cost figure embodies all raw material and energy inputs of biodiesel refining including ethyl/methyl alcohol, catalysts, water, heat, electricity and labor. The estimate used in these

Figure 2.2: Biodiesel Refining Costs



calculations was taken from an Energy Sector Management Assistance Program[12] (ESMAP) analysis of five publications, performed between 2002 and 2005 and which ranged from \$0.08 and \$0.16 per liter.

Volumes of biodiesel were adjusted downward to reflect the efficiency of the process -- refining vegetable oil into biodiesel is not a one to one conversion. On average, using current refining equipment setup in a continuous flow process, the conversion from processed vegetable oil to refined biodiesel is approximately 98%, *RR* [Figure 2.2.T] (Van Gerpen et al. 2004). This resulting figure from this adjustment represents the total volume of biodiesel which can be produced from the vegetable oil, BV_{ijk} [Figure 2.2.U]. However, before the biodiesel volumes can be directly compared to petroleum diesel, the volume must be "scaled" to reflect the energy content difference of the two fuel types. When compared to petroleum diesel, biodiesels have higher cetane numbers[13] and oxygen contents which increase engine combustion efficiency. However, biodiesel fuel also has less overall energy content, which when combined, these differences work out to a net decrease in torque, power and fuel economy of 8%, *ER* [Figure 2.2.V] (EERE 2006). While the difference is rarely noticeable to the end user, biodiesel volumes are

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[12] The ESMAP is a special global technical assistance partnership sponsored by the UNDP, the World Bank and bi-lateral official donors. Established in 1983, the ESMAP's mission is to promote the role of energy in poverty reduction and economic growth in an environmentally responsible manner.

[13] Cetane number measures ignition quality. Higher cetane numbers indicate higher ignition rates, which tend to reduce carbon and lacquer formation and engine deposits, and decrease engine roughness.

adjusted downward in this study for a more technically accurate comparison to petroleum diesel, AV_{ijk} [Figure 2.2.W].

The final price of biodiesel must also include the sale value of the main by-product of refining, glycerol, which is used in a variety of products including soap, cosmetics and food. In a typical continuous-flow process, glycerol, $C_3H_8O_3$, is produced at a rate of approximately 0.0832 kilograms per liter of biodiesel refined, GP [Figure 2.2.X] (Kojima et al. 2005). Glycerol resulting from biodiesel production is approximately 88% pure and is considered a *technical-grade*. It is possible to further refine glycerol to a *pharmaceutical-grade*, >99.7% pure, which increases its value but at the expense of additional processing infrastructure (Pahl 2005). For this assessment, the more conservative estimate of technical-grade glycerol was chosen, which currently ranges in value from $0.05 to $0.10 per liter of biodiesel produced (Kojima et al. 2005). However, most assessments of large-scale biodiesel production assume a drop in value due to increased supply and availability. The long-term value estimate for technical-grade glycerol of $0.04 per liter of biodiesel produced, estimated by an EIA-sponsored study, was chosen for these calculations, GV [Figure 2.2.Y] (Radich 2004). The cost of refined biodiesel after the value of the glycerol has been subtracted, AC_{ijk} [Figure 2.2.Z], and adjusted biodiesel volumes, AV_{ijk}, are used in the three growth strategies for later comparisons [Figures 2.2.AA, 2.2.BB and 2.2.CC].

$$LV_{ijk} * RR = BV_{ijk}$$

$$BV_{ijk} * ER = AV_{ijk}$$

$$LC_{ijk} - RC - (GP * GV) = AC_{ijk}$$

D. Assessing the Impacts of Large-Scale Biofuel Operations

The decision to significantly increase the biodiesel refining capacity on a national-scale necessitates an understanding of economic and environmental impacts. This study uses a combination of existing indicators as well as calculated impacts (on a per liter basis) to determine which countries are best suited to achieve their biodiesel volume potentials. Country specific indicators such as human development, corruption perception, and foreign debt are used to establish the likelihood of successfully implementing large-scale infrastructure projects. The calculated impacts of biodiesel production on unemployment, emissions reductions and GDP per capita reveal the national impacts of large-scale investment in biodiesel – useful both to national governments as well as to global lending and development institutions to compare projects. Due to the highly varied financial situations and living conditions across countries, associated costs for these factors are less accurate than vegetable oil productions statistics and calculations. Still, these data are valuable contextually, helping to frame how a biofuel program could potentially impact the social, environmental and economic conditions of a country beyond strict fuel price comparisons.

i. Country Specific Indicators

Ranking countries based on their biodiesel potential helps decision-makers determine what volumes can theoretically be produced. However, country profiles which establish current social and economic conditions are also needed to determine which countries have the best chance of realizing their potential. Six unique indicators are used to narrow the resulting country lists to those most favorable to large-scale infrastructure investments, whether domestic or foreign. Aside from normalization so they may be ranked, no calculations are performed on the indicators chosen for this study and there is no set formula for their application. The following chapters will describe how each indicator is employed in calculations. This section simply identifies background information on the indicators and their sources.

The first indictor used by this study is the Human Development Index (HDI), calculated by the United Nations Development Programme[14] (UNDP) as part of the Human Development Report encompassing 177 countries. The HDI is a summary composite index that measures a country's average achievements in three basic aspects of human development: longevity, knowledge, and standard of living (Fukuda-Parr et al. 2003). The second indicator, GDP per capita, is factored into the HDI index but was also used independently for this analysis, both as a measure

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[14] The UNDP is the UN's global development network, an organization advocating for change and connecting countries to knowledge, experience and resources to help people build a better life. The UNDP publishes the most extensive information on human development and is primary body which tracks progress of the Millennium Development Goals, most notably of which is to cut poverty in half by 2015.

of average well-being and in later calculations on economic impacts of biodiesel production (Fukuda-Parr et al. 2003). The third index used by this study, provided by Transparency International[15] (TI), ranks countries by their perception of graft, a practice which can discourage investments and increase operating costs. The *Corruption Perceptions Index* (CPI) annually ranks over 150 countries by their perceived levels of corruption, as determined by expert assessments and opinion surveys (TI 2005). The fourth indicator was constructed by normalizing the amount of foreign direct investment (FDI) for 199 countries, territories and protectorates. Tracked by the United Nations Conference on Trade and Development[16] (UNCTAD), FDI is an important gauge of the confidence and willingness of the international community to invest in domestic projects (UNCTAD 2004). The fifth indicator selected to compare economic conditions between countries is the debt status as classified by the World Bank. The World Bank classifies all member countries (184), and all other economies with populations of more than 30,000 (208 total) according to region, income levels and current debt status – listed as either *Severely Indebted*, *Moderately Indebted*, *Less Indebted* or *Debt Not Classified* (WB 2005). The sixth and final indicator of a country's economic

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[15] Transparency International is the leading global civil society organization whose aim is to end the devastating impact of corruption on men, women and children around the world. TI does not undertake investigations of alleged corruption or expose individual cases, but at times will work in coalition with organizations that do.

[16] Established in 1964, UNCTAD promotes the development-friendly integration of developing countries into the world economy. UNCTAD is an authoritative knowledge-based institution whose work aims to help shape current policy debates and thinking on development, with a particular focus on ensuring that domestic policies and international action are mutually supportive in bringing about sustainable development.

condition used by this study, lack of travel safety, can be either actual or perceived and can be a limiting factor in business development. The U.S. Bureau of Consular Affairs'[17] (CA) current travel warnings website was used to identify countries which have excessive crime, areas of instability, or military activity which could impede infrastructure development (CA 2006).

ii. Assessing Economic Impact

Normally, to assess the economic impacts of shifting large fuel expenditures from foreign to domestic sources, a sophisticated Input-Output[18] (I-O) analysis model would be constructed. However, due to the extensive, region-specific data I-O models that require for usable results, they are not practically applied in a global context. In place of these more detailed models, this study prioritized three calculations -- change in GDP per capita, jobs created per liter of biodiesel produced, and change in national unemployment -- which could be performed consistently for all countries to estimate economic impacts of large-scale biodiesel development projects. All economic impacts calculated by this study are listed as a percentage so that *relative* impacts may be compared across countries of varying populations.

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[17] The U.S. Bureau of Consular Affairs (CA), an office within the U.S. Department of State, oversees foreign U.S. consular responsibilities including Passport Services (PPT), Visa Services (VO), Overseas Citizens Services (OCS) and the Fraud Prevention Program (FPP).

[18] Input-output analysis is an analytical tool to analyze inter-industry relations in an economy. These relations depict how the output of one industry goes to another industry where it serves as an input, and thereby makes one industry dependent on another both as customer of output and as supplier of inputs. An input-output model is a specific formulation of input-output analysis.

This study assumes all biodiesel potential, if realized, would be produced domestically, replacing imported petroleum diesel fuel. The Worldwatch Institute[19] (WI) estimates the number of jobs created per liter of biodiesel produced, from both direct and indirect sources[20], in their Renewables 2005: Global Status Report. This annual report concludes that the job creation associated with biodiesel production is half that associated with ethanol production due to its fewer processing requirements. Global direct jobs from ethanol production were estimated by applying the Brazilian employment coefficient of 33 direct jobs per million liters of production to the major world-wide sources; the 32 billion liters of ethanol production capacity are currently distributed between Brazil (14 billion liters), China (2 billion liters), the United States (14 billion liters) and others (2 billion liters). The U.S. production was discounted 30% due to the less-labor-intensive processes employed. Together the WI estimated 902,000 direct jobs resulting from the 32 billion liters of existing ethanol production and 31,000 direct

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[19] The Worldwatch Institute is an independent research organization which provides accessible, fact-based analyses of critical global issues to work for an environmentally sustainable and socially just society. The Worldwatch Institute focuses on the underlying causes of and practical solutions to the world's problems, in order to inspire people to demand new policies, investment patterns and lifestyle choices.

[20] Direct jobs are typically defined to be those related to the manufacture, construction, installation, operation, maintenance, and fuel collection of biodiesel refining plants. Indirect jobs are those created as a result of increased economic activity brought about by the biodiesel refining plants, sometimes referred to as economic or employment multiplier effects. These added domestic economic benefits can include, but are not limited to: Increased agriculture employment due to higher crop values and increased farm revenues; increased non-farm, agriculture-related jobs through the manufacture and sale of seed, fertilizer, pesticides and herbicides, and purchases and repair of machinery; a decreased budget deficit due to increased income tax revenues; a significant improvement in the foreign trade balance; and a variety of other benefits realized by keeping transportation fuel expenditure dollars in country.

jobs from the 2.2 billion liters of biodiesel production, or one job for every 71,000 liters of biodiesel produced annually (WI 2005).

By identifying a fixed ratio of jobs created to biodiesel produced -- one job per 71,000 liters of annual biodiesel production, or 0.00001408 jobs per liter – this study estimates the total number of new jobs as well as their impacts on national unemployment. The total number of jobs created was found by simply multiplying a country's biodiesel potential (in liters) times the job creation coefficient. The U.S. Central Intelligence Agency (CIA) publishes the most complete national unemployment estimates as part of their annual The Worldfact Book[21] report (CIA 2006). By multiplying this figure with population statistics from the UNDP's human development indicators, this study calculates the total number of unemployed citizens as well as the percentage impact jobs created through biodiesel production will have on national unemployment.

Impacts on GDP per capita were also calculated with the aid of UNDP's population statistics. Total national savings vs. imported petroleum diesel (or costs if the required biodiesel build-out is not profitable) was divided by population to determine economic impacts on a per-person level. Percentage impacts to the

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[21] *The World Factbook* is prepared by the Central Intelligence Agency for the use of US Government officials but is also made available in the public domain. Information is provided by Antarctic Information Program (National Science Foundation), Bureau of the Census (Department of Commerce), Bureau of Labor Statistics (Department of Labor), Central Intelligence Agency, Council of Managers of National Antarctic Programs, Defense Intelligence Agency (Department of Defense), Department of State, Fish and Wildlife Service (Department of the Interior), National Geospatial-Intelligence Agency (Department of Defense), Naval Facilities Engineering Command (Department of Defense), Office of Insular Affairs (Department of the Interior), US Board on Geographic Names (Department of the Interior), and other public and private sources.

existing GDP per capita were then calculated allowing for normalized comparisons between countries.

iii. Assessing Environmental Impact

National studies normally use a cost-benefit analysis (CBA) to quantify the environmental benefits of changing to a less polluting fuel--in this case, from petroleum diesel to biodiesel. CBAs calculate and assign costs to environmental side-effects which impact human health (mortality and morbidity), and economic loss due to building and agriculture damage. However, similar to the complex I-O analyses used to calculate economic impacts, the detailed data necessary for a CBA can vary significantly across countries depending on local economic conditions, environmental regulations and the monetary values associated with the *value of life*[22]. Therefore, to reliably calculate and compare environmental impacts among countries, this study estimates the total emissions reduced (in tons) resulting from the implementation of the potential biodiesel infrastructure. The emissions calculated by this study fall into two categories: 1) those which impact air quality including CO, NO_x, SO_x, VOCs, and PM_{10}, and 2) CO_2 which impacts global climate change. Absolute quantity reductions were chosen instead of percentage impacts, as emissions trading markets already assign standard values to

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[22] Certain economic theories calculate the value of a human life based on earning potential, a figure which can vary greatly around the world and is highly correlated with the national economic conditions. While seemingly insensitive, without performing these calculations no value would be assigned.

different effluents. These values are useful even if an individual country is not a participant in the cap-and-trade framework; member countries can often pay for improvements in non-member countries to count the emissions reductions towards their own targets.

However, estimating national emissions globally, through a single calculation is complicated by the varying mile per gallon (mpg) averages, fuel standards, and mandated emissions control technologies of individual countries. For example, according to the International Fuel Quality Center[23] (IFQC), new legislation in the United States limits the sulfur content of diesel fuel to only 15 ppm, while countries such as Brazil, Turkey, Saudi Arabia and South Africa all have sulfur contents in excess of 3000 ppm (IFQC 2002). To account for this overall lack of comparable information between countries, this study extrapolated detailed historical diesel emissions data from the United States, published by the U.S. Environmental Protection Agency[24] (EPA), to the rest of the world -- this study used U.S. data from 1990 for less developed countries, 1995 data for developing countries and 2000 data for developed countries[25].

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[23] The IFQC is an informational arm of the private Hart Energy Consulting company. IFQC's mission is to make changing policies and regulations of global fuels and their influence on refining and automotive industries more available and understood.

[24] The mission of the EPA is to protect human health and the environment through: developing and enforcing regulations, offering financial assistance, furthering environmental education, sponsoring voluntary partnerships and programs, and performing and publishing environmental research.

[25] World Bank income groups closely correspond to the more common economic classifications of individual countries with low-income countries generally equating *less developed countries*, lower-middle and upper-middle income countries equating *developing countries* and high income countries closely matching countries classified as *developed*. A Complete list of these parallel classifications was not available, however, so the World Bank groups were used in their place.

The EPA records composite diesel emissions data (in kg) for the following effluents: CO_2, CO, PM_{10}, NO_x and SO_x (EPA 2005). To estimate fixed *emissions per liter*, these figures were divided by the total diesel fuel consumed in the corresponding year -- the same EIA source data used for petroleum diesel imports [Table 2.2]. Finally, total emissions reductions attributed to a country's biodiesel potential were calculated by multiplying these total estimated emissions by the reductions of biodiesel over petroleum diesel from Table 1.1 (NREL et al. 1998).

Table 2.2: US Diesel Emissions

Effluent	1990 (kg/lt.)	1995 (kg/lt.)	2000 (kg/lt.)
CO_2	0.43188	0.47991	0.47464
CO	0.01695	0.01507	0.01091
NO_x	0.03800	0.04039	0.03602
SO_2	0.00387	0.00282	0.00226
PM_{10}	0.00312	0.00254	0.00177
VOC	0.00410	0.00337	0.00236

E. Data Limitations

To arrive at comparable data for all countries in the world, many limitations had to be made concerning which data would be included and how it would ultimately be used. These limitations fall into three categories: infrastructure complexities, data source limitations, and unexplored broader impacts.

i. Infrastructure Complexities

The production, processing, importing and exporting of both petroleum diesel and vegetable oil are similar in that they often do not happen within the same country. When examining the difference between crude oil and refined diesel fuel production, consumption, import and export data, certain anomalies were identified. Singapore, for example, has very few domestic petroleum reserves. However, due to their large refining capacity and convenient location on major shipping routes, the data shows that Singapore is a net importer of crude petroleum but a net exporter of refined diesel fuel – sometimes sending it back to the countries which initially supplied the crude oil. Only utilizing the data for refined petroleum fuels, as this study does, incorrectly gives Singapore the appearance of having domestic petroleum reserves with which to make transportation fuels. Similar cases are likely to exist in oilseed producing nations which may export large quantities of whole oilseed crops yet import processed vegetable oil. These anomaly countries can only be identified through individual comparisons to supplemental data sources which are beyond the scope of this assessment.

Potential changes to the agricultural infrastructure not explored in this global study were the options of altering types of oilseed feedstock crops and/or the amount of farm land. There are many possibilities to further increase biodiesel potential by substituting existing feedstock crops for higher yielding varieties, increasing total farm land cultivated or growing certain hearty species, such as jatropha, on marginal or overused land (Subramanian et al. 2005). Assessing the potential of these strategies is not feasible without more detailed and unique information about the individual countries and was therefore excluded from this study.

Additionally, the one-time capital costs of vegetable oil processing and biodiesel refining infrastructure were not included in this assessment. Determining the added cost per liter would depend on many country-specific factors including the discount rate, the profitability of the resulting fuel and the overall time frames of the investments.

ii. Data Source Limitations

Due to the diverse array of source information included in this study, not all countries had complete data sets. The "N/A" symbol was used to designate calculations with incomplete results. Countries were eliminated from the study if biodiesel volume potential could not be fully calculated. However, countries were still included in the case of indicators or impacts being incomplete, there were simply noted as such. An additional limitation of using data from such comprehensive, global sources was that, in many cases, the primary data is not tracked annually. In all cases, data from the most recent, complete years were used – all of which were between 2000 and 2006.

iii. Broader Impacts

The scope of the assessment is limited to specific impacts which do not include how refining large volumes of vegetable oil into biodiesel will affect food supplies, feedstock by-products and the sustainability of agriculture practices. This study calculates a country's biodiesel potential based on vegetable oil exports --

without considering the impacts on the larger vegetable oil market or those of the feedstock by-products. The current world market for vegetable oil is almost 120 billion liters annually, the majority of which goes towards food for either human or animal consumption (USDA 2006). While the vegetable oil volumes used for biodiesel are still small by comparison (<2%), if enough volumes were removed from the overall market, food shortages or unsustainable expansion of farm lands could potentially result[26]. Sustainable vegetable oil production is a very real concern, especially in developing countries where natural forests are being increasingly razed in favor of mono-cropping oilseed plants.

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[26] If oilseed agriculture expands to meet future biodiesel demands, vegetable oil and meal prices are expected to decrease with added supply, however, the overall economic impact for farmers is expected to be positive Raneses, A. R., L. K. Glaser, et al. (1999). "Potential biodiesel markets and their economic effects on the agricultural sector of the United States." Industrial Crops and Products **9**(2): 151-162.

Chapter III: Calculating Biodiesel Potential

In the previous chapter, data sets were assembled to evaluate national biodiesel potentials and compare their impacts globally. The cornerstone of this analysis merges statistics on oilseed agriculture, biodiesel refining and petroleum diesel consumption. These statistics were used to calculate the biodiesel export potentials of individual countries across three growth strategies, each requiring varying amounts of new capital investment in processing and refining infrastructure. To supplement this evaluation of export potentials, this study assembled contextual, development-specific information including foreign direct investment, Corruption Perception ranking, Human Development ranking and current travel warnings. While more uncertain and more qualitative in nature, this second, contextual set of information is equally critical – it was used in evaluating an individual country's chance for successful large-scale deployments. Finally, by calculating the impacts of the biodiesel potentials on country specific indicators, the expected economic and environmental impacts can be compared between countries which often compete for the same aid and development dollars.

This chapter answers the first of four questions originally posed in the introduction: Which countries have the highest absolute biodiesel potential? The large amount of data and number of sources included this study allows for many possible analyses. In addressing the question, the following chapter serves as a walk-through of how potentials are calculated and assessed across the growth strategies. This same process is then used in the next chapter (Chapter IV) to compare the profitability of biodiesel export potential to that of energy independence.

The method used in this study sorts all 226 countries, territories and protectorates to find those with the highest biodiesel potentials. Then using more contextual, development-specific indicators, countries with the most potentials are ranked by their chance of realizing their potential. Finally, the economic and environmental impacts are analyzed over the three growth strategies to better compare the top candidates. This study includes comprehensive information and calculations for every country with complete source data, from volume potentials and concluding with impacts. However, in calculating absolute biodiesel potential for this chapter, neither the filtering step nor the economic and environmental impacts are assessed -- none of the resulting volume potentials are assumed to be implementable without further cost comparisons.

A. Which Countries Have the Most Absolute Biodiesel Potential?

In the context of this thesis, potentials can refer to both *volumes* of biodiesel (in liters) as well as *costs* of production (in $/liter). These base values can be used to calculate potential export revenues, reduced petroleum diesel imports and the cost of self-sufficiency. In all cases, these potential volumes (PV) can be broken down by specific feedstock crops allowing for more detailed comparisons and inclusion of only profitable varietals. Potential costs (PC) are also only calculated based on *exported* processed vegetable oil to assure domestic demand will be accounted for.

i. Potential Biodiesel Volumes: Top 25 Countries

Table 3.1 below lists the top 25 countries, ranked by their potential biodiesel volumes, in liters. The presence of the top five countries on this list, Malaysia, Indonesia, Argentina, the United States and Brazil, are not unexpected as they are among the top palm and soybean growers; the two most prevalent oilseed crops in the world (USDA 2006). Collectively, they account for over 70% of the total biodiesel volume potential. However, the source data shows that several of the countries represented in the top 25 list are not large vegetable oil producing countries and would use *imported* vegetable oil to produce biodiesel. Imported vegetable

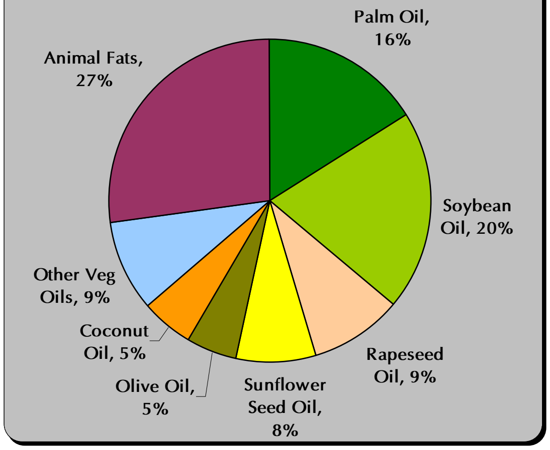
Table 3.1: Highest Volume Potential

Rank	Country Name	Volume Potential (lts.)
1	Malaysia	14,540,561,000
2	Indonesia	7,595,073,000
3	Argentina	5,255,341,000
4	United States	3,212,392,000
5	Brazil	2,566,633,000
6	Netherlands	2,495,807,000
7	Germany	2,023,526,000
8	Philippines	1,233,893,000
9	Belgium	1,212,740,000
10	Spain	1,073,453,000
11	France	934,376,000
12	Ukraine	924,570,000
13	Canada	829,611,000
14	Italy	658,323,000
15	U.K.	511,305,000
16	Australia	468,512,000
17	Papua New Guinea	383,349,000
18	Singapore	367,380,000
19	Thailand	344,094,000
20	Sweden	258,395,000
21	India	250,427,000
22	Bolivia	228,976,000
23	Denmark	214,523,000
24	Paraguay	183,558,000
25	Turkey	176,036,000

oil even inflates the positions of some countries in Table 3.1 which already have sizable oilseed crop agriculture. Some importing countries, such as Singapore, are easy to spot because their limited land area for oilseed cultivation precludes them from producing the necessary volumes; however, identifying *all* of these countries is difficult without country-specific analysis. These countries are what can be called *processing-stopover countries*, importing raw oilseed crops or unprocessed oils, only to process them domestically for later export.

These processing-stopover countries are most easily recognized by looking at the distribution of oilseed feedstocks among the countries in the top 25 shown in Figure 3.1[27]. Based on the distribution, the most prominent oilseed crops in terms of world-wide exports are palm and soy oils, jointly accounting for 36% of the biodiesel potential of the top 25 countries. A high-ranking country such as the Netherlands becomes suspect as it only grows poppy seed, rapeseed and linseed in large, commercial quantities, as seen in Figure 3.2 (FAOSTAT 2005). When comparing oilseed production to the feedstock distribution of the

Figure 3.1: Feedstock Distribution
Top 25 Countries' Volume Potential



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[27] This distribution chart in Figure 3.1, as well as the ones which follow in the remainder of the chapter, shows which feedstock crops are used most commonly by the top countries -- assuming *equal weight* for each country. The distribution charts do not calculate distribution percentage based on the total volume of all countries as the top few would overshadow the remainder.

Figure 3.2: Feedstock Distribution Netherlands' Oilseed Crop Production

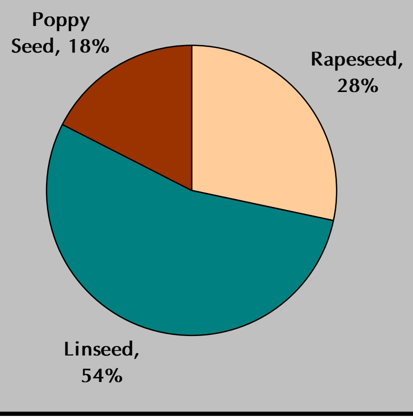
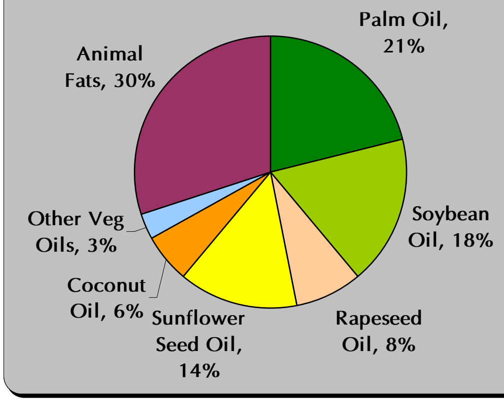


Figure 3.3: Feedstock Distribution Netherlands' Biodiesel Volume Potential



Netherlands' biodiesel volume potential, shown in Figure 3.3, its role as a processing-stopover country becomes more apparent. More than 59% of the Netherlands' potential comes from oilseed feedstocks which it does not produce domestically. Other countries in the top 25 fulfilling similar import, processing and redistribution roles, include Belgium, Singapore and to a lesser extent, Sweden and Denmark. These countries are important to identify since without guaranteed domestic supply, large-scale production will not be as profitable in the long-term without subsidies or other market controls. However, aside from obvious cases with small land mass or temperate countries using tropical oils, processing-stop-over countries are difficult to identify without country-specific analyses which are beyond the scope of this assessment.

Also of interest in the list of top 25 countries, is the large role which processed animal fats can potentially play in biodiesel production in western countries. Processed animal fats are a by-product of the animal slaughter industry and, with few competing commercial uses, can contribute to low-cost biodiesel production. The biodiesel potentials from the United States, Germany, Belgium, France, Australia, Sweden and Denmark all consist of over 40% animal fats. Australia's top 25 position, in particular, is almost entirely due to animal fats which make up 93% of its potential. While requiring additional processing as compared to vegetable oils due to their higher free fatty acid content, animal fats are often inexpensive and hold much potential for future biodiesel production (Kinast 2003).

Based on how volume potentials are assessed in this first growth strategy which assesses exported lipids, the countries with the most biodiesel volume potential all have at least one common trait – large lipid *processing* capacities. Production, which is dominated by a small group of countries at the top, turned out not to be a requirement for inclusion on the list. Domestic supplies, however, will reduce the risk of large-scale investments into biodiesel infrastructure becoming unprofitable.

ii. Cost of Production: Top 25 Countries

The cost potentials listed in Table 3.2 use the same country list from Table 3.1 above, but ranked by lowest production cost per liter instead of by total volume. This list has been limited by volume, however, to only include countries with total annual production exceeding one million liters of potential, the volume throughput of an efficient large-scale, continuous flow biodiesel reactor. While refining costs generally scale linearly with volume for each processor type, continuous-flow reactors have lower overall costs of production than batch-reactors due to their higher overall efficiency and throughput (Van Gerpen et al. 2004). By limiting volumes to this threshold amount required for cost-effective, continuous-flow processing, comparisons between countries will be consistent and more accurate by focusing on differences in feedstocks – the most influential component in biodiesel cost.

Table 3.2: Lowest Cost Potential

Rank	Country Name	Production Cost Potential ($/lt.)
1	Papua New Guinea	$ 0.47
2	Samoa	$ 0.48
3	Myanmar	$ 0.49
4	Indonesia	$ 0.49
5	Panama	$ 0.50
6	Uruguay	$ 0.50
7	Swaziland	$ 0.51
8	Vanuatu	$ 0.51
9	Nepal	$ 0.52
10	Ghana	$ 0.52
11	Poland	$ 0.52
12	French Polynesia	$ 0.52
13	Philippines	$ 0.53
14	Niger	$ 0.53
15	Malaysia	$ 0.53
16	Burkina Faso	$ 0.54
17	Algeria	$ 0.54
18	Australia	$ 0.54
19	Colombia	$ 0.54
20	Honduras	$ 0.56
21	Micronesia	$ 0.56
22	Thailand	$ 0.56
23	Hong Kong, China	$ 0.57
24	Mozambique	$ 0.58
25	Fiji Islands	$ 0.58

Figure 3.4 shows the feedstock distribution of the countries with the lowest cost biodiesel production potential in Table 3.2. Tropical oilseed crops, including palm and coconut, are consistently produce some of the lowest cost commodity oils due to their high yields and long growing seasons. This advantage in the vegetable oil market translates directly into low cost biodiesel potential -- tropical oils dominate the top 25 low cost producer list with 68% of the countries relying on them. Only five of the top twenty-five countries rely on a feedstock other than tropical oilseeds for their largest single source: Uruguay, Nepal, Poland, Algeria and Australia – all of which rely of animal fats as their primary biodiesel feedstock.

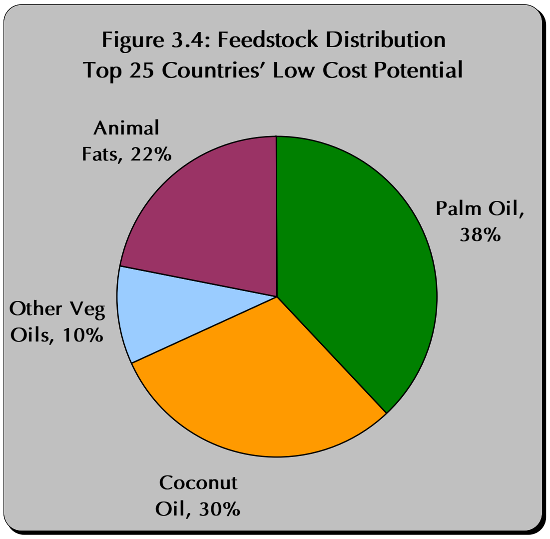


Figure 3.4: Feedstock Distribution
Top 25 Countries' Low Cost Potential

With palm oil being used by 38% of top 25 countries and coconut oil 30% -- assuming *equal weight* for each country [see: footnote 26] -- the two appear close in terms of their attractiveness as a commodity oilseed crop.[28] However, when looking the feedstock distribution of the total production *volume* of the top 25 countries, palm oil increases to 81% and coconut drops to only 7%. The prevalence of palm oil compared to coconut oil is a relatively recent phenomenon. Over the last 25 years, Malaysia and Indonesia, the two primary growers of West African Palm, have increased their production capacity by over 500% and 1600% respectively (FAOSTAT 2005). While most of that growth can be attributed to growing food and raw materials markets[29], palm has also replaced a significant portion of the coconut crop during the same period due to a more than double oil yield for the same cultivated land area (Duke 2001). Nevertheless, with a growing, world-wide demand for biodiesel, coconut-producing countries can still profit from their low cost of production and unrealized capacity.

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[28] Palm and coconut are both species of from the same sub-family and require similar growing climates. NewCROP (2006). New Crops Resource Online Program, Center for New Crops & Plant Products - Purdue University.

[29] Palm oil, as well as other vegetable oils, are used in the production of margarine, cooking oils, ice cream, mayonnaise, baked goods as well as soaps, candles, lubricants and detergents. Duke, J. A. (2001). Handbook of Nuts. Boca Raton, CRC Press LLC.

By focusing on lowest cost of production, processing-stopover countries have been all but eliminated from the list [Table 3.2]. The data shows it is difficult to rank among the lowest cost biodiesel producers without also being among the lowest cost oilseed growers. Hong Kong (China), the exception, managed to retain a spot towards the bottom of the list, even with zero commercial oilseed agriculture (FAOSTAT 2005).

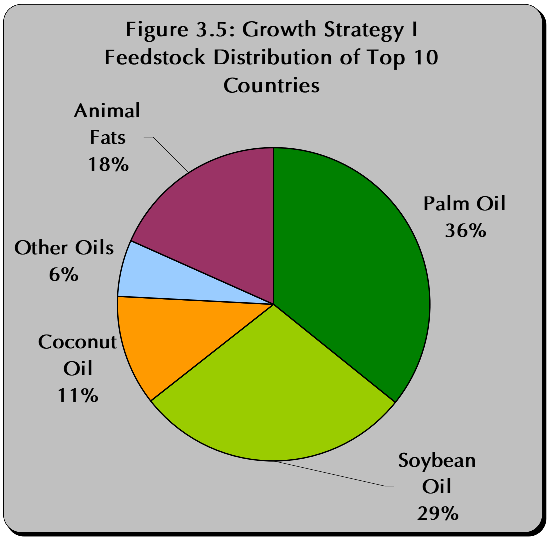
iii. Highest Biodiesel Potential: Top 10 Countries

In determining the top 10 best-positioned countries, this study requires a combination of both high potential volume and low production potential cost. The majority of countries on the top 10 list were identified simply by their presence on both of the top 25 lists, Table 3.1 and 3.2. For the few remaining cases in which there was no direct overlapping between the two tables, countries were chosen subjectively, giving priority to countries with high volume potential and cost potentials which did not exceed those in Table 3.2 by more than a few cents. Table 3.3 lists the top 10 countries found to have the best combination of high volume

Table 3.3: Growth Strategy I
Existing Vegetable Oil Exports

Rank	Country	Production Cost Potential ($/lts.)	Volume Potential (lts.)
1	Malaysia	$ 0.53	14,540,561,000
2	Indonesia	$ 0.49	7,595,073,000
3	Argentina	$ 0.62	5,255,341,000
4	Brazil	$ 0.62	2,566,633,000
5	Philippines	$ 0.53	1,233,893,000
6	Australia	$ 0.54	468,512,000
7	Papua New Guinea	$ 0.47	383,349,000
8	Thailand	$ 0.56	344,094,000
9	Paraguay	$ 0.60	183,558,000
10	Hong Kong, China	$ 0.57	166,831,000

potential and low production costs.



As compared to the original feedstock distribution based solely on potential volume in Figure 3.1, the distribution from the "top 10 overall" countries in Figure 3.5 shows most temperate oilseed crops, as well as some of the animal fat potential has been replaced by palm, coconut and soy. Additionally, while soybean oils were almost completely absent from the lowest cost feedstocks distribution as seen in Figure 3.4, Brazil and Argentina are among the largest and lowest-cost producers of soybeans in the world. Even though the average cost of production in these countries is a few cents per liter higher than their palm or coconut oil based competitors, their considerable volumes and processing capacity give them some of the best biodiesel potentials in the world. Brazil and Argentina also hold an advantage over many tropical oil producers in that biodiesel made from soybean oil, along with other temperate oilseed crops such as rape, sunflower, safflower and mustard, have much lower gel points making them more suitable for exports to countries with colder climates. Palm and coconut based biodiesels can also be exported to these countries, but usually require a thinning additive which can eliminate their cost advantage.

Once again, Hong Kong, even without domestic oilseed agriculture, retained its position on the top 10 list of countries with the best combination of potential volumes and prices. If Hong Kong is able to secure long-term supply contracts at favorable prices, there is no reason why they cannot also benefit from large-scale biodiesel refining operations. However, as mentioned previously, without guaranteed, low-cost domestic oilseed production, they could be at risk of their suppliers eventually building out their own processing and refining capacity.

The overall volume potential exhibited by the top 10 countries is large, at over 32 billion liters, almost 15 times larger than what is currently produced today. However, it is unlikely that all, or even one of these countries, could fully dedicate their exported vegetable oil to biodiesel production without significantly affecting commodity prices. The vegetable oil market for food use is relatively inelastic and dwarfs that of the biodiesel market. Any large reductions in global supply would increase feedstock costs, potentially putting them out of reach for biodiesel production. There is still room for significant growth in biodiesel production in the immediate-term, however, which depending on if it is used domestically or exported, may provide a more valuable end commodity.

iv. Alternative Growth Strategies

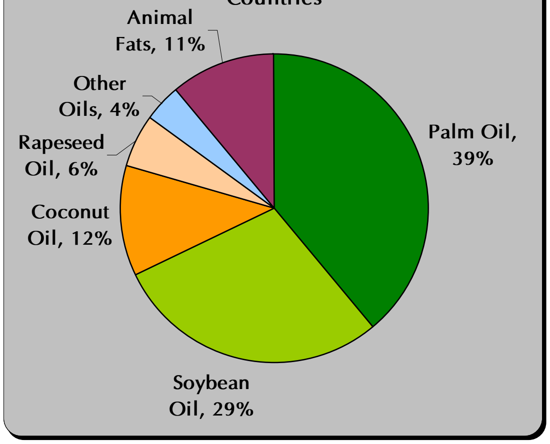
The final step in analyzing the data compares the previous growth (or investment) strategy, assuming only existing exported lipids, with the remaining two, primarily differentiated by increasing scale. Each strategy considers a larger required investment in new infrastructure, resulting in more annual biodiesel production. Table 3.4 shows the results from Growth Strategy II which assumes both exported lipids *and* exported whole oilseed crops can be used in biodiesel production. Therefore, the list of the "top 10 overall" countries in Table 3.4 is similar to Table 3.3, but with small additions attributed to processed vegetable oil volumes which were previously exported whole.

Table 3.4: Growth Strategy II
Existing Vegetable Oil Exports

Rank	Country	Production Cost Potential ($/lt.)	Volume Potential (lts.)
1	Malaysia	$ 0.53	14,546,047,000
2	Indonesia	$ 0.49	7,639,120,000
3	Argentina	$ 0.62	6,193,920,000
4	Brazil	$ 0.61	5,224,512,000
5	Philippines	$ 0.53	1,234,288,000
6	Australia	$ 0.65	934,749,000
7	Paraguay	$ 0.64	555,274,000
8	Papua New Guinea	$ 0.47	399,183,000
9	Hong Kong, China	$ 0.59	170,514,000
10	Colombia	$ 0.54	155,887,000

The most notable differences between the two growth strategies were Thailand's removal from the list and Columbia's addition. Thailand did not make the top 10 list for the second growth strategy due to its average cost of production *increasing* to $0.76 per liter -- a result of this first analysis looking at total potential volume, using *all* feedstocks regardless of profitability. Columbia's addition to the list did not come as much from increased volumes, as it did from its existing low production cost potential as seen in Figure 3.2. Brazil and Argentina, however, both had significant volume boosts from newly crushed soybean oils, of which a large portion of production had previous been exported whole. The countries that primarily grow palm oil (or import it in the case of Hong Kong) made comparatively small gains due to whole palm fruits having few uses outside oil production. Australia was the exception on the list, whose volume doubled due to expanded rapeseed oil production, albeit at an increased average cost. Australia was able to remain competitive with the tropical oil and soybean producing-countries because it averaged down with low cost animal fats which made up the remainder of its potential. These changes are visible in the distribution chart in Figure 3.6.

Figure 3.6: Growth Strategy II Feedstock Distribution of Top 10 Countries



Growth Strategy III is based on countries achieving *best-practices* oil yields per hectare (based on individual crops) for all of their existing cultivated land. This strategy does not include animal fats and relies on aggregate domestic vegetable oil demand. Previously, if a vegetable oil was exported, domestic demand for that crop was assumed to be met. However, as there are no statistics on domestic demand for individual oilseed crops, the third strategy estimates demand based on aggregate domestic demand statistics tracked by FAOSTAT. If the calculated vegetable oil volumes do not exceed the FAOSTAT's recorded aggregate demand, these countries are assumed to require all vegetable oils domestically and are not included in the study.

The top 10 countries which exhibited the most biodiesel potential based on Strategy III are shown in Table 3.5. While more theoretical in nature, this last scenario highlights palm oil production's huge remaining growth possibilities from better plantation management and more intensive agriculture. The countries which produce palm oil all increased volume by a factor of ten or more. Palm oil yields depend on many factors including climate and soil quality. However, they are particularly susceptible to plantation management practices and extraction methods with palm fruit production ranging from as little as 1.2MT per hectare to over 38MT per hectare (NewCROP 2006). Palm's recent explosive growth in South East Asia has often come at the expense of intact rainforests and its biodiversity – a continuing trend with volume expected to double again by the year 2020 (Hai 2002). While current farming practices are unlikely to change quickly, this untapped potential from increasing oil yields per hectare is promising news for proponents of sustainable palm production: the expected doubling of export volumes by 2020 can be attained simply by using land already under cultivation.

As observed in the feedstock distribution under this assumed average-yield strategy [Figure 3.7], the low-cost biodiesel potential from palm oil has almost completely eliminated countries using other oilseed crops from the from the top 10. The Philippines remain the lone holdout, receiving its primary biodiesel potential from coconuts. Like palm, coconut yields are also highly variable ranging from 200kg per hectare to as much as 8,000kg per hectare, again leaving much room for growth using only existing lands.

Table 3.5: Growth Strategy III
Existing Vegetable Oil Exports

Rank	Country	Production Cost Potential ($/lts.)	Volume Potential (lts.)
1	Malaysia	$ 0.53	241,317,618,000
2	Indonesia	$ 0.51	211,944,118,000
3	Nigeria	$ 0.55	40,136,517,000
4	Thailand	$ 0.48	16,143,437,000
5	Colombia	$ 0.54	10,176,065,000
6	Ecuador	$ 0.54	5,452,297,000
7	Philippines	$ 0.53	5,272,422,000
8	Cote d'Ivoire	$ 0.52	5,002,302,000
9	Papua New Guinea	$ 0.43	4,705,252,000
10	Honduras	$ 0.53	3,808,044,000

This final growth strategy highlights the huge remaining potential from increased yields, which, if achieved, could easily meet food demand and in addition to contributing to global fuel supplies. Interestingly, most of the large soybean growers including Brazil, the United States and Argentina, saw little growth from increasing yields. These countries' soybean farms have apparently already optimized their production to achieve some of the highest oil volumes per acre possible. If sustainable growth is the ultimate goal, the tropical oils will have more spare capacity to increase production without increasing land requirements.

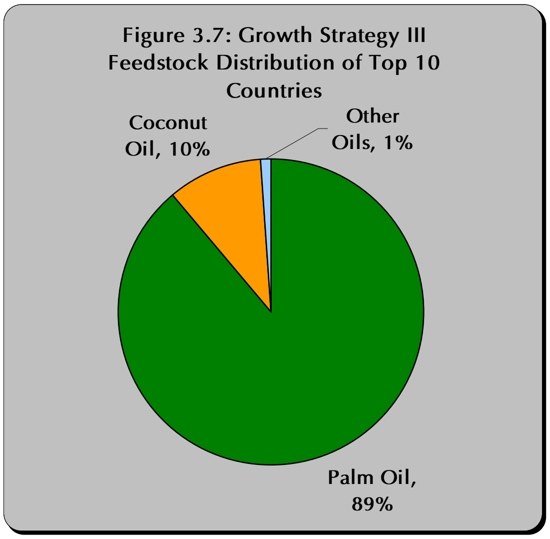


Figure 3.7: Growth Strategy III Feedstock Distribution of Top 10 Countries

Chapter IV: Global Comparison of Biodiesel Potential for Export or Offset

This chapter will examine biodiesel potentials and their roles in both increasing trade balances through exports and helping to achieve energy independence. It is not only possible to identify the most profitable development options, but also to calculate the price of self-sufficiency in situations where it is not the more cost-effective alternative outright. Using the contextual data set as a filter, this chapter identifies the best positioned countries to profitably export biodiesel, to profitably use biodiesel to offset petroleum diesel imports and to achieve energy independence regardless of cost -- ranked by their likelihood of deploying successful, large-scale biodiesel programs.

A. Which Countries Can Profit the Most from Biodiesel Exports?

To determine which countries are currently positioned to profit the most by exporting biodiesel, it was first necessary to establish a world-wide, baseline price for imported biodiesel that could be used for comparison. As described in chapter 2, the European Union is the largest market for biodiesel – even with over 90% of world-wide biodiesel production, they cannot meet demand due to favorable subsidies and aggressive renewable fuel targets (WI 2005). The current import price for biodiesel that meets EU quality standard EN14214 is €73.00 per 100 liters, or $0.88 per liter[30], excluding VAT (Oleoline 2006). The only oilseed feedstocks used to answer this question are those that can be refined into biodiesel with a total production cost of less than the EU import price. The import price of biodiesel is highly variable, depending on such factors as current domestic biodiesel production levels, petroleum diesel prices, agricultural yields and new environmental legislation, and this study does not attempt to forecast future import prices. Rather, the European price is used as a convenient baseline, limiting the results to only today's most profitable feedstocks and countries. In identifying those top candidates for increasing their trade balances through biodiesel exports, it is once again necessary to find countries which have the best combination of high volumes and low production costs.

i. Highest Absolute Profits from Biodiesel Exports: Top 25 Countries

Table 4.1 shows the top 25 countries in terms of highest profits. This list of countries also represents the maximum impact these biodiesel investments can have on a country's trade balance. While every country on this list can produce biodiesel profitably, some clearly have much lower production costs than others – whether due to better management practices, more favorable growing conditions

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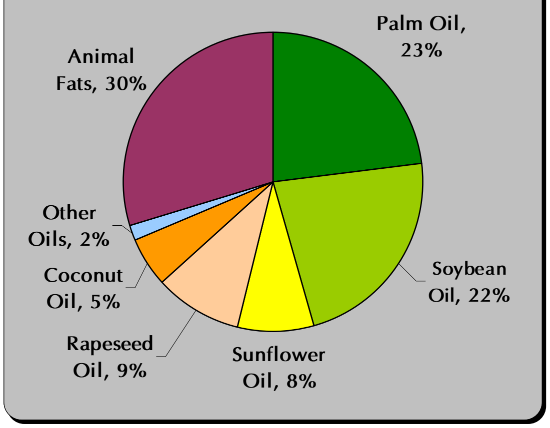
[30] Exchange rate on March 21, 2006

or higher yielding feedstocks. The top 2 countries in Table 4.1, Malaysia and Indonesia, both realize the majority of their production potential from West African palm oil. However, because of its lower growing and processing costs per liter, Indonesia exhibited almost two-thirds as much profit potential from biodiesel exports as Malaysia with just over half the volume required. Four other countries also rely on palm oil for the majority of their biodiesel potential, highlighting palm's low cost and suitability for export. When looking at the complete distribution of oilseed feedstock crops used by the top 25 countries in Figure 4.1, however, it is clear that palm is no longer the dominant low-cost feedstock. Even though overall production volumes are still greater for palm,

Table 4.1: Highest Absolute Profit Potential from Exports

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)
1	Malaysia	14,506,487,000	$ 5,065,059,000
2	Indonesia	7,593,280,000	$ 2,967,235,000
3	Argentina	5,235,021,000	$ 1,382,878,000
4	United States	2,835,579,000	$ 710,985,000
5	Brazil	2,511,075,000	$ 695,891,000
6	Philippines	1,233,369,000	$ 432,697,000
7	Netherlands	2,415,009,000	$ 371,282,000
8	Germany	1,450,985,000	$ 263,669,000
9	France	860,565,000	$ 188,426,000
10	Belgium	941,109,000	$ 171,618,000
11	Australia	454,233,000	$ 171,427,000
12	Ukraine	924,238,000	$ 170,958,000
13	Canada	733,190,000	$ 163,633,000
14	Papua New Guinea	383,065,000	$ 158,503,000
15	Thailand	341,721,000	$ 109,911,000
16	Spain	499,828,000	$ 96,724,000
17	U.K.	417,449,000	$ 61,058,000
18	Bolivia	228,938,000	$ 56,242,000
19	Hong Kong, China	155,709,000	$ 55,904,000
20	New Zealand	135,147,000	$ 55,331,000
21	Singapore	277,829,000	$ 54,387,000
22	Colombia	154,557,000	$ 52,220,000
23	Paraguay	181,105,000	$ 51,813,000
24	Italy	194,437,000	$ 44,958,000
25	Austria	112,065,000	$ 40,811,000

Figure 4.1: Feedstock Distribution
Top 25 Higest Total Profit Exporters



animal fat's low costs[31] and consequent added profit per liter give it the most potential in refining biodiesel for export. The position of soybeans has grown considerably, being used by 22% of the top 25 countries now that the focus is only on feedstocks which can be refined into biodiesel *profitably*. Brazil, Argentina, Bolivia and Paraguay, all rely almost entirely on soybeans for their positions on Table 4.1 in which the focus has shifted to profitability. With a total of almost 45 billion profitable liters of biodiesel, the top 25 countries clearly show that the potential for commercialized large-scale biodiesel export exists. Next, this study will examine which of the countries can profit with the least required infrastructure per liter.

ii. Lowest Biodiesel Production Costs: Top 25 Countries

Because cost of production plays such a large part in overall profit calculations, Table 4.2 shows the country results from the same strategy assessment as above, re-sorted to highlight the lowest production cost countries. Countries

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[31] The use of animal fats in food products typically have more restrictions than do vegetable oils, given them lower commodity value. For example, one of the largest markets for animal fats is as an animal feed for bovine, swine and poultry; however, recent restrictions on the use of animal fats as a bovine feed in response to mad-cow disease have depressed prices even further.

with high total profit potential but low profitability per liter would have to make much larger infrastructure investments to realize gains than countries with high profitability per liter. Additionally, countries with low profitability would have a high risk of becoming unprofitable with only small shifts in feedstock or biodiesel import prices – potentially forcing that large infrastructure base to sit idle. Once again, a threshold volume of 1,000,000 liters of annual production was used to limit the results to countries with production large enough to benefit from large-scale, continuous flow biodiesel refining. As shown by the feedstock distribution chart [Figure 4.2], processed animal fats are clearly the lowest cost feedstock, with 14 of the top 25 countries almost completely relying on them for their biodiesel potential. The remaining 11 countries with high profitability per liter all rely on palm oil or coconut oil for the majority of their potential. Soybean, rapeseed, sunflower, sesame, and cottonseed oils each form a small part of the potential for various countries, however, none of them amount to more than a percent or two of the total distribution.

Table 4.2: Lowest Cost Potential

Rank	Country Name	Production Cost Potential ($/lt.)
1	Syrian Arab Republic	$ 0.22
2	Switzerland	$ 0.29
3	Tunisia	$ 0.31
4	Cyprus	$ 0.35
5	Algeria	$ 0.37
6	Botswana	$ 0.41
7	Burkina Faso	$ 0.43
8	Uruguay	$ 0.45
9	Ghana	$ 0.45
10	Saudi Arabia	$ 0.46
11	Papua New Guinea	$ 0.47
12	New Zealand	$ 0.47
13	Samoa	$ 0.48
14	Myanmar	$ 0.49
15	Indonesia	$ 0.49
16	Chile	$ 0.50
17	Panama	$ 0.50
18	Viet Nam	$ 0.50
19	Australia	$ 0.50
20	Ireland	$ 0.50
21	French Polynesia	$ 0.51
22	Swaziland	$ 0.51
23	Poland	$ 0.51
24	Vanuatu	$ 0.51
25	Croatia	$ 0.51

While many of the overall volumes of the countries on this list are small by comparison to the volumes in Table 4.1, there is clearly much potential for investments in these smaller-scale projects which still offer high profitability per liter and quick returns.

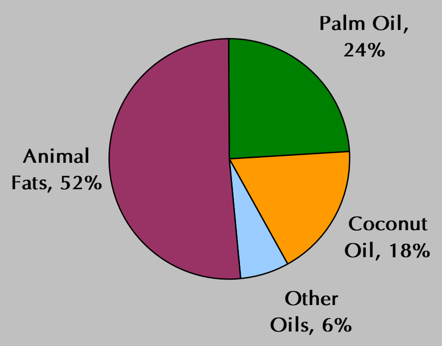


Figure 4.2: Feedstock Distribution Top 25 Most Profitable Exporters per Liter

iii. Most Potential Profit from Biodiesel Exports: Top 10 Countries

To discover which countries have the best potential for biodiesel export, this study selects countries that best balance volume potential, high total profits and high profitability per liter. The method used to identify these top 10 export countries seen in Table 4.3, was similar to that in the previous chapter – when

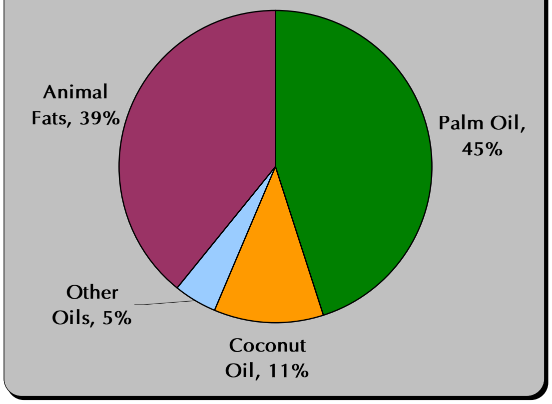
Table 4.3: Top 10 Highest Profit Potential from Biodiesel Exports

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	HDI Rank	GDP/ cap	Corr. Rank	FDI Rank	WB Debt	Trvl Warn
1	Malaysia	14,506,487,000	$ 5,065,059,000	66%	65%	75%	82%	Mod.	No
2	Indonesia	7,593,280,000	$ 2,967,235,000	38%	34%	13%	68%	Severe	Yes
3	Philippines	1,233,369,000	$ 432,697,000	53%	41%	26%	70%	Mod.	Yes
4	Australia	454,233,000	$ 171,427,000	98%	94%	94%	95%	N/A	No
5	Papua New Guinea	383,065,000	$ 158,503,000	23%	31%	18%	48%	Mod.	No
6	Thailand	341,721,000	$ 109,911,000	59%	61%	63%	82%	Less	No
7	Hong Kong, China	155,709,000	$ 55,904,000	88%	90%	91%	98%	N/A	No
8	New Zealand	135,147,000	$ 55,331,000	89%	87%	99%	83%	N/A	No
9	Colombia	154,557,000	$ 52,220,000	61%	55%	65%	76%	Mod.	Yes
10	Ireland	65,995,000	$ 24,863,000	95%	99%	88%	94%	N/A	No

possible using countries which appear on both Tables 4.1 and 4.2 as well as subjectively picking the remainder which only deviate in price per liter by a few cents. All of the selected countries had production costs of $0.56 per liter or less giving them all profit margins in excess of 50% to encourage large-scale investment. As can be seen in Figure 4.3, once again, volumes from tropical oils and animal fat feedstocks dominate the top 10 with all countries utilizing them for the majority of their potential biodiesel export.

The ten countries in Table 4.3 have the most potential for profitably increasing their trade balances by encouraging large-scale biodiesel exports. The question then becomes: Which countries have the best chance of realizing these export volumes? Before large capital infrastructure projects can be approved, investors will need assurance that risks will be minimal, that the likelihood of a profitable venture is high and most importantly, that there are not better investments for their money. This caution does not mean investments will not be approved on higher risk projects or in less favorable locations, they simply require higher estimated returns to justify the risks of doing business in those situations.

Figure 4.3: Feedstock Distribution
Top 10 Most Profitable Exporters



Color coding was added to better visualize the difference in how the countries compare to one another – green signifies the country is in the top 1/3 of all countries, yellow the middle 1/3 and red the bottom 1/3. There is no single method of narrowing the list of countries in Table 4.3. However, Indonesia, Papua New Guinea and the Philippines all stand out from the group due to their high perception of corruption, low human development rating and low GDP per capita. Additionally, Thailand and Columbia, while not as lowest, also have poor scores in corruption perception, human development and GDP per capita compared to the rest of the countries on the list. Indonesia, Columbia and the Philippines all appear on the CIA's current travel warnings list, indicating increased safety concerns and decreased attractiveness of foreign investment. Considering that the average return per liter of all the countries on the 10 top list are within a few cents of each other, the increased risk of investment in biodiesel in Indonesia, Papua New Guinea, Philippines, Columbia and Thailand do not yield enough of an increased return on investment and both can be eliminated. That said, if investments were come from within those countries, with all competing projects having similar risks, these countries do hold excellent potential for profiting from biodiesel exports.

Of the five enduring countries, the risk for shareholders investing in Malaysia, Australia, and Ireland is lower as they already have mature domestic biofuels markets as a backup to exports. Additionally, Ireland, New Zealand and Australia all have strict, well enforced environmental laws and high dependency on imported petroleum fuels, which can contribute to premiums on the cost of domestic biodiesel as an alternative, reducing the overall risk of investment in refining capacity.

iv. Most Profit Potential from Biodiesel Exports: Top 10 Developing Countries

One of the primary goals of this study is to identify countries that can benefit the most from international development aid and investment. As the narrowed list of countries which are most favorable for development from Table 4.3 above would not be competing for these funds, it was necessary to develop an alternate top 10 list, one that compared the top countries with developing economies. Table 4.4 lists the top countries using the same criteria as above, with the added limitation that their economies *not* be ranked as "High Income" by the World Bank. By focusing only on developing economies, Figure 4.4 shows that palm oil is again the dominant feedstock, with animal fats being next most widely used.

Table 4.4: Highest Profit Potential from Biodiesel Exports – Developing Countries Only

Rank	Country	Biodiesel Potential (lts.)	Total Export Profits ($)	HDI Rank	GDP/ cap	Corr Rank	FDI Rank	WB Debt	Trvl Warn
1	Malaysia	14,506,487,000	$ 5,065,059,000	66%	65%	75%	82%	Mod.	No
2	Indonesia	7,593,280,000	$ 2,967,235,000	38%	34%	13%	68%	Severe	Yes
3	Philippines	1,233,369,000	$ 432,697,000	53%	41%	26%	70%	Mod.	Yes
4	Papua New Guinea	383,065,000	$ 158,503,000	23%	31%	18%	48%	Mod.	No
5	Thailand	341,721,000	$ 109,911,000	59%	61%	63%	82%	Less	No
6	Colombia	154,557,000	$ 52,220,000	61%	55%	65%	76%	Mod.	Yes
7	Honduras	123,760,000	$ 40,287,000	34%	32%	32%	49%	Mod.	No
8	Nepal	49,041,000	$ 17,909,000	23%	14%	26%	12%	Less	Yes
9	Uruguay	40,089,000	$ 17,388,000	74%	63%	80%	45%	Severe	No
10	Ghana	40,415,000	$ 17,302,000	22%	27%	59%	44%	Less	No

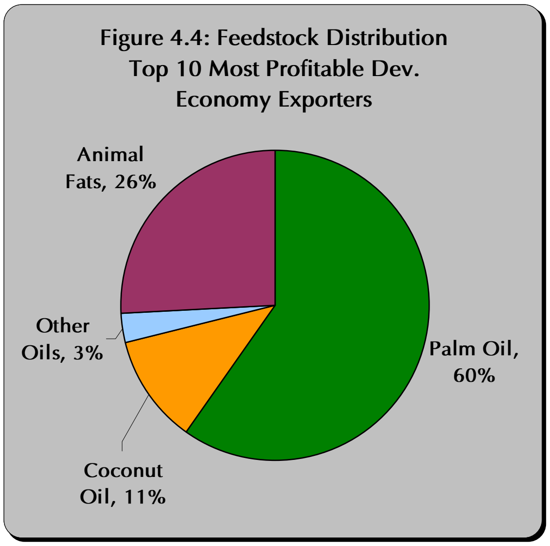


Figure 4.4: Feedstock Distribution Top 10 Most Profitable Dev. Economy Exporters

Before determining what impacts the development funds can have on these countries, it is again possible to use these data to narrow the list to only those countries with the best chance of realizing their biodiesel export potential. All of the countries in the top 10 have one or more factors which could preclude successful implementation of a large-scale infrastructure project, so this study attempts to identify those with the best combination of economic and social indicators to arrive at the top 5 candidates.

Corruption Perception should be heavily weighted as graft can quickly eliminate profitability from development projects, negating the very impetus behind their implementation -- increased economic stability. In addition to a high perception of corruption, Indonesia, Papua New Guinea, Honduras and Nepal, all rank among the lowest countries in terms of human development and GDP per capita -- both possible reflections of how well infrastructure and distribution of resources are managed -- and can therefore be eliminated from further assessment. Deciding between the remaining 6 countries is difficult as none of the countries provide optimal investment conditions. The Philippines and Columbia both have excellent volume potential but also share CIA travel warnings. Of the two, the Philippines was eliminated due to a much higher perception of corruption and lower overall human development, GDP per capita and foreign investment. Thus the top 5 chosen for further comparison were: Malaysia, Thailand, Columbia, Uruguay and Ghana.

v. Economic and Environmental Impacts: Top 5 Countries

Two of the largest criteria for aid or investment funds from institutions such as the World Bank and the United Nations, are the economic and environmental impacts of development projects. These impacts are shown in Tables 4.5 and 4.6 for all countries and for developing economy countries respectively. Countries with more mature economies, such as the majority in Table 4.5, will likely be developed as privately funded ventures. If this is the case, the potential for financial returns will presumably overshadow economic and environmental indicators as a means of comparison between projects. However, they are still considered by local governments in distributing permits and for loans and are therefore worth including in this assessment.

Table 4.5: Growth Strategy I - Top 5 Countries Overall with Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	14,506,487,000	$ 5,065,059,000	2.34971%	25.0440%	204,317	5,461,499
2	Australia	454,233,000	$ 171,427,000	0.02960%	0.62941%	6,398	169,135
3	Hong Kong, China	155,709,000	$ 55,904,000	0.02816%	0.51776%	2,193	57,979
4	New Zealand	135,147,000	$ 55,331,000	0.06270%	1.21768%	1,903	50,322
5	Ireland	65,995,000	$ 24,863,000	0.01697%	0.56995%	930	24,573

Malaysia, which is the number one country on both lists, stands out from the others by the incredible amount of feedstock volume which can be profitably refined into biodiesel and exported. When combining biodiesel's higher commodity value as compared to vegetable oil, with the sheer volume Malaysia can export, the potential economic and environmental impacts are very large. Malaysia currently has a very low unemployment rate at only 3.6%. By building-out biodiesel refining capacity, they could potentially reduce that figure by a quarter, down to 2.7%. Similarly, the proportional rise in GDP per capita, number of jobs created and CO_2 reduced all dwarf the gains by the remaining countries on both Tables 4.5 and 4.6. At a $32.64 per ton of CO2[32], Malaysia's potential biodiesel exports have over $170 million in trading credits alone.

While the gains look small comparatively, the other countries in Table 4.6 can also benefit economically by developing their biodiesel refining and export infrastructure. Uruguay and Thailand could significantly impact both unemployment and GDP per capita by pursuing biodiesel exports. The impact on GDP per capita in Ghana could potentially be the 3rd biggest of the countries from both tables – which would be welcome given Ghana's unique position of having

Table 4.6: Growth Strategy I - Top 5 Developing Economies with Biodiesel Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	14,506,487,000	$ 5,065,059,000	2.34971%	25.0440%	204,317	5,461,499
2	Thailand	341,721,000	$ 109,911,000	0.02274%	0.54016%	4,813	128,653
3	Columbia	154,557,000	$ 52,220,000	0.01900%	0.04499%	2,177	58,188
4	Uruguay	40,089,000	$ 17,388,000	0.06200%	0.13892%	565	15,093
5	Ghana	40,415,000	$ 17,302,000	0.03834%	0.01412%	569	13,693

low debt, perception of corruption and high foreign investment but low human development and GDP per capita.

Also of interest in both Tables 4.5 and 4.6, are that 68% and 31% of the two feedstock potentials respectively come from processed animal fats. Any projects developing biodiesel infrastructure will likely be done in close cooperation with and proximity to the farms providing these feedstocks. Large factory farms and slaughterhouses do not typically have positive ecological effects so investments in *environmentally-friendly* biodiesel would be viewed favorably. If the proposed biodiesel were to be consumed domestically, additional environmental benefits would include the reductions of emissions corresponding to the volumes of petroleum-diesel offset.

vi. Alternative Growth Strategy Impacts on Profitable Export Potential

This section examines how the two alternative growth strategies affect overall biodiesel export potential and the impacts of their development. Examining these strategies would be of little use for countries not deemed likely to realize their potential from Growth Strategy I (existing vegetable oil exports only), so the following section only assess the top 5 countries from Tables 4.5 and 4.6.

Growth Strategy II, the results of which are shown in Tables 4.7 and 4.8, adds new volumes of vegetable oils resulting from the extraction and processing of whole oilseed crop exports, to those in Tables 4.5 and 4.6. The most notable comparison among the set of tables, is how similar they are. The aggregate volume

Table 4.7: Growth Strategy II - Top 5 Countries Overall with Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	14,509,012,000	5,065,559,000	2.34994%	25.0483%	204,352	5,462,450
2	Australia	887,568,000	233,808,000	0.04037%	1.22987%	12,501	330,489
3	Hong Kong, China	157,507,000	56,221,000	0.02832%	0.52373%	2,218	58,648
4	New Zealand	135,147,000	55,331,000	0.06270%	1.21768%	1,903	50,322
5	Ireland	67,779,000	25,113,000	0.01714%	0.58536%	955	25,238

Table 4.8: Growth Strategy II - Top 5 Developing Economies with Biodiesel Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	14,509,012,000	5,065,559,000	2.34994%	25.04833%	204,352	5,462,450
2	Thailand	343,206,000	110,498,000	0.02286%	0.54251%	4,834	129,213
3	Colombia	155,216,000	52,434,000	0.01908%	0.04518%	2,186	58,437
4	Uruguay	129,599,000	29,019,000	0.10347%	0.44910%	1,825	48,792
5	Ghana	41,662,000	17,696,000	0.03922%	0.01455%	587	14,115

increases between Tables 4.5 and 4.7, and between Tables 4.6 and 4.8 are only 3% and 1% respectively. However, the combination Malaysia's dominant volumes and only modest growth, hides some larger increases from individual countries. As Table 4.7 shows, Australia realized the largest volume increase, adding over 400 million liters of export capacity through the processing of previously exported rapeseed. The remaining countries in Table 4.7 only saw modest increases of between 2 – 3 million liters. Table 4.8 again shows a single country realized the majority of the gains. Uruguay had the largest proportional increase in volume, more than tripling its volumes from 40 million liters to almost 130 million liters. These gains came from huge increases in soybean and sunflower oil production, each of which went from almost nothing to over 40 million liters. Based on these increases, it is clear that Uruguay has considerable soybean and sunflower agriculture, but very little oil processing infrastructure -- instead exporting them whole. Depending on the market prices and demand for whole soybeans and sunflower seeds vs. their vegetable oil counterparts, Uruguay might benefit from building its processing infrastructure even if it does not pursue biodiesel production.

As might be expected, the most interesting economic and environmental changes resulting from the second growth strategy occur in Australia and Uruguay which realized the two largest volume changes. As can be seen in Table 4.7, Australia increased its impact on unemployment, moving into second place in front of New Zealand. The large proportional volume increase by Uruguay, shown in Table 4.8, is most easily visible when compared to Ghana. In Table 4.6, the two countries previously had very close volume potentials, while in the second growth strategy, Uruguay moved ahead in the number of jobs created, and further increased its impacts on GDP per capita, unemployment and tons of CO_2 reduced.

Growth Strategy III calculates lipid volumes using a method unrelated to the previous growth strategies. Volumes are limited to vegetable oils only, and are calculated based on achieving average oil yields per hectares for land currently under cultivation. This final growth strategy does not include animal fats or countries in which total vegetable oil production is less than aggregate demand -- as detailed in the previous section.

Because of the limitations on how domestic demand is accounted for in Growth Strategy III, on two countries, Malaysia and Australia, remain in Table 4.9 compared with GS2. Hong Kong has been eliminated due to not having any domestic land under oilseed cultivation. Hong Kong imports all of its potential which is not included when calculating volumes based on agricultural yields. New Zealand and Ireland previously relied almost entirely on animal fats for their potential, which are not included in the third growth strategy. The two countries small vegetable oil volumes did increase enough to exceed domestic demand so they were dropped from the results table entirely.

Malaysia, which holds its top spot in Tables 4.9 and 4.10, once again stands out from the group, having increased its total volumes over 17 fold. While this yield-based growth strategy is more theoretical than previous strategies, Malaysia alone has the export potential to increase world biodiesel production over 100

Table 4.9: Growth Strategy III - Top 2 Countries Overall with Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	241,317,376,000	83,411,154,000	38.6950%	416.610%	3,398,836	90,852,779
2	Australia	642,854,000	94,788,000	0.01636%	0.89078%	9,054	239,369

Table 4.10: Growth Strategy III - Top 5 Developing Economies with Biodiesel Export Potential

Rank	Country	Volume Potential (lts.)	Total Export Profits ($)	Rise in GDP/cap.	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	241,317,376,000	83,411,154,000	38.69493%	416.61%	3,398,836	90,852,779
2	Thailand	15,996,055,000	6,602,329,000	1.36586%	25.285%	225,297	6,022,302
3	Colombia	10,171,928,000	3,511,231,000	1.27757%	2.9607%	143,267	3,829,595
4	Uruguay	110,722,000	20,550,000	0.07328%	0.3837%	1,559	41,685
5	Ghana	3,795,911,000	1,310,283,000	2.90369%	1.3258%	53,464	1,286,091

times from its current 2.2 billion liters (WI 2005). In the process, it could completely eliminate unemployment, increase GDP per capita by over 40% and earn almost $3 billion in CO_2 credits (again based on $32.64 per ton reduced).

The remaining developing economy countries in Table 4.10 also increase export potential, mainly through increases in the palm and coconut yields. Thailand, Columbia and Ghana all increase their volumes, 46, 65 and 91 fold respectively. Interestingly, Uruguay's volume potential *decreases* from Growth Strategy II to Growth Strategy III. Ghana's soybean and sunflower production remains roughly equal, while the majority of the decrease is attributed to animal fats removal. This leveling off of oilseed production shows Uruguay as already having reached best-practice yields for its soybean and sunflower production. While small gains in efficiency may still be possible for Uruguay, as it works towards further increasing crop yields, the gains will not be nearly as dramatic as those possible by palm and coconut producers.

Overall, the results of Growth Strategy III, for only these 6 countries, emphasize the enormous potential which remains for existing cultivated land – and this based on *average* oil yields per hectare, not the maximum yields more often reported by biodiesel enthusiasts. Average tropical oilseed crops such as palm and coconut do appear more difficult to achieve, however, with so much potential remaining untapped.

B. Which Countries Can Profitably Offset Petroleum-Diesel Imports?

In a strict economic sense, the question of whether to use biodiesel to offset imported petroleum diesel would actually be a sub-question of how best to increase a country's trade balance. If a country can produce biodiesel profitably, it will choose to export it over using it domestically in order to be more self-reliant if the profits were greater. However, economics is only one of many factors which must be weighed in the decision to implement a large-scale biofuels program. Environmental regulations, rural development, support for domestic agriculture and national security are only a few of the driving reasons behind the growth in biofuels. In fact, the majority of countries with large biodiesel and ethanol industries have chosen to encourage and support their growth for these reasons *over* strict economic profitability making the fuels more costly at the pump. While profits may be greater in exporting biodiesel, many countries place enough value on self-sufficiency in transportation fuels to outweigh the difference.

The following section evaluates which countries can profitably offset petroleum diesel imports. Profitability is defined differently for each country and is based on biodiesel which would be made for less than their petroleum diesel costs. Only profitable oilseed feedstocks are used in the following assessment, unlike the final question, examined in section C, which calculates self-sufficiency regardless of cost.

i. Largest Reduction in Imported Petroleum Diesel: Top 25 Countries

Table 4.11 lists the top 25 countries, ranked by the percent in which they can reduce their petroleum diesel imports through domestic biodiesel production. To calculate this reduction, the cost of biodiesel made from each feedstock available to a given country was compared against the retail cost of petroleum diesel, less $0.10 per liter to estimate the after tax, import cost[33] (GTZ 2005). It is important to note that excise fuel taxes are assumed to be included in the GTZ pump prices, although the country specific cost is not tracked. Therefore comparisons in this study are between biodiesel with no tax and petroleum diesel with tax. This precedence has been established by all major biodiesel producing and

Table 4.11: Most Potential for Profitable Self-Sufficiency

Rank	Country	Volume Potential (lts.)	% of Imports
1	Malaysia	1,638,221,000	96%
2	Cote d'Ivoire	101,491,000	93%
3	Papua New Guinea	383,065,000	60%
4	Canada	177,396,000	43%
5	Australia	454,233,000	33%
6	Vanuatu	7,533,000	30%
7	Italy	332,693,000	29%
8	Lithuania	15,263,000	23%
9	Romania	57,889,000	22%
10	Portugal	126,402,000	18%
11	Netherlands	2,448,758,000	16%
12	Belgium	1,186,233,000	16%
13	Bulgaria	20,692,000	15%
14	Slovakia	47,764,000	14%
15	U.K.	493,215,000	13%
16	Benin	23,549,000	13%
17	Honduras	123,730,000	12%
18	Togo	16,700,000	12%
19	Germany	2,006,262,000	12%
20	Ghana	39,687,000	11%
21	Uruguay	39,906,000	11%
22	Sweden	252,160,000	11%
23	Hungary	113,334,000	10%
24	Samoa	2,490,000	10%
25	Denmark	205,984,000	9%

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[33] GTZ only aggregates data on global, at-the-pump prices. To estimate after tax, import prices, GTZ assumes a $0.10 per liter cost attributable to in-country distribution and retail profits by using United States average as a baseline. Excise taxes (or subsidies) can be estimated if a world-wide whole sale price could be established. However, before tax import prices can vary significantly depending on location, volume and historical contracts making this exercise difficult to perform on a global scale.

consuming countries. Excise taxes on biodiesel have been eliminated in both the EU and the US, which recently offered an excise tax credit which exceeds the tax on petroleum diesel, effectively subsidizing the cost of production. Fuel taxes can be a significant revenue stream, however, especially for developing economy countries. Any decision to eliminate or reduce excise taxes on biodiesel would have to balance the benefits biodiesel brings to the domestic economy from rural development, agricultural support and reduced dependency on foreign oil, with the effects on operating budgets of the government.

The number of countries with the potential to offset petroleum diesel *profitably* is surprisingly high, given how many countries in the world currently utilize biodiesel which is priced above petroleum diesel. Nine countries were found capable of offsetting over 20% of their imports with Cote d'Ivoire and Malaysia almost achieving independence from imports at 93% and 96% respectively. Notably missing from this list, however, are the some of countries previously identified as the top volume producers of vegetable oil in the world. Indonesia, Brazil, Argentina and the United States are all missing due to their primary feedstocks, palm oil and soybean oil, not being competitively priced vs. their petroleum diesel costs. Not surprisingly, all of these countries also have large domestic petroleum industries, giving them lower costs of diesel fuel to compete against.

Because self-sufficiency in petroleum diesel *imports* is the current focus, a list measuring offset percentage will be comprised of both countries with large

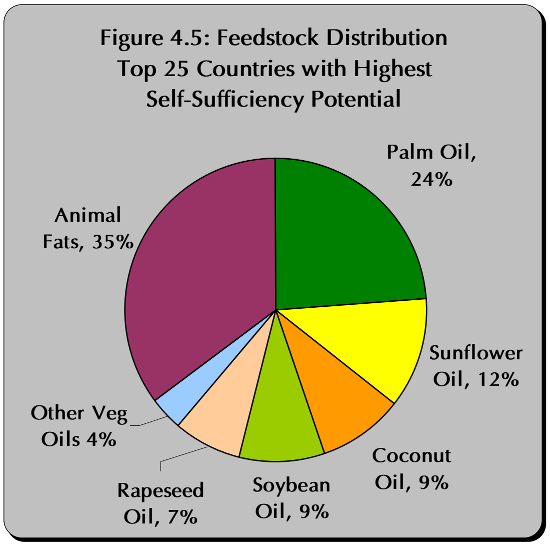


Figure 4.5: Feedstock Distribution Top 25 Countries with Highest Self-Sufficiency Potential

agriculture production, and countries with relatively small petrol-diesel imports. Five of the countries in the top 25, Papua New Guinea, Canada, the United Kingdom, Denmark and Norway, are all net exporters of refined petroleum products. Their reasons for importing petroleum products such as diesel fuel is most likely entirely economic, and based on very specific refining capacity, logistic or transportation situations. In effect, these countries are already self-sufficient in petroleum product imports and would not place as large a premium on the implementation of biofuels to offset these specific importing situations.

Figure 4.5 shows the distribution of feedstock crops used by the countries with the most potential for independence from diesel imports. The distribution of the variety of feedstocks is larger because profitability is defined in this instance by each country internally, relative to their cost of petroleum diesel imports. Most notably, sunflower and rapeseed's shares of the distribution grew considerably in this table, mainly from European countries such as Romania, Lithuania, Germany, the United Kingdom, Sweden and Denmark.

ii. Most Profitable Reduction of Imports: Top 25 Countries

Table 4.12 lists the top 25 countries, ranked by how profitably they offset the cost of petroleum diesel imports. Whereas the previous table ranked countries based on the percentage volume of petroleum diesel offset, Table 4.12 ranks countries by the price differential between biodiesel and petroleum diesel. Whether due to high taxation or cost of remote transportation, the cost of diesel fuel in these countries becomes the overriding factor in the makeup of this list. The common factors leading to a country's high ranking are significant volumes of low cost biodiesel feedstocks along with high diesel prices. Both European and African countries have comparatively high taxes, and as such, comprise of 22 of the top 25 countries. Vanuatu and French Polynesia, ranked 10th and 12th, have higher transportation costs due to remoteness in addition to higher than average excise taxes. Because Table 4.12 is ranked by

Table 4.12: Most Potential for Profitability per Liter, Self-Sufficiency

Rank	Country	Volume Potential (lts.)	Price Diff. ($/lt.)
1	Switzerland	3,933,000	$ 0.91
2	Norway	50,589,000	$ 0.83
3	U.K.	493,215,000	$ 0.81
4	Ireland	66,112,000	$ 0.79
5	Cyprus	2,434,000	$ 0.59
6	Poland	33,048,000	$ 0.58
7	France	891,610,000	$ 0.58
8	Austria	135,796,000	$ 0.58
9	Finland	103,151,000	$ 0.55
10	Vanuatu	7,533,000	$ 0.54
11	Germany	2,006,262,000	$ 0.52
12	French Polynesia	4,899,000	$ 0.51
13	Burkina Faso	1,920,000	$ 0.51
14	Netherlands	2,448,758,000	$ 0.50
15	Sweden	252,160,000	$ 0.48
16	Slovakia	47,764,000	$ 0.48
17	Hong Kong, China	159,378,000	$ 0.47
18	Italy	332,693,000	$ 0.46
19	Slovenia	13,383,000	$ 0.46
20	Hungary	113,334,000	$ 0.44
21	Greece	73,379,000	$ 0.44
22	Spain	501,404,000	$ 0.41
23	Czech Republic	58,638,000	$ 0.40
24	Swaziland	5,050,000	$ 0.40
25	Niger	2,794,000	$ 0.39

profitability vs. petroleum diesel prices, again, the feedstock distribution seen in Figure 4.6 shows a higher variety of feedstocks than previously charts. Still, animal fats, due to their low costs and wide regional distribution, are the largest at 40%.

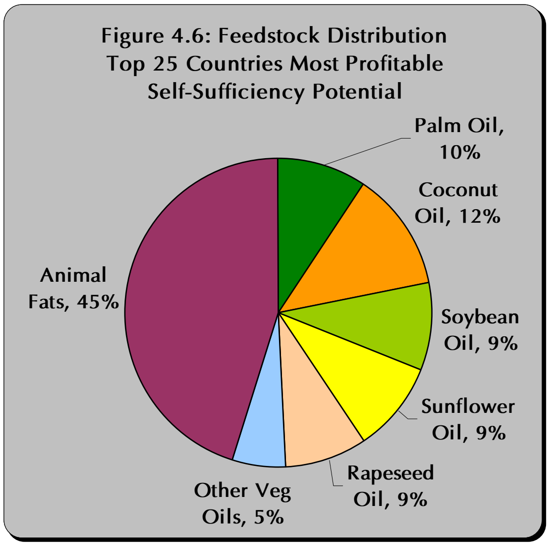


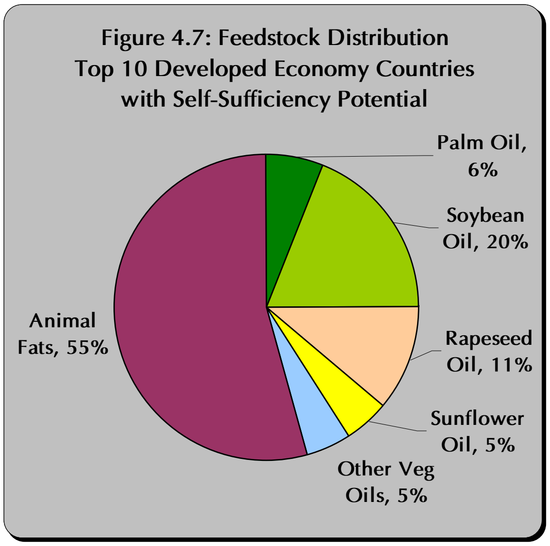
Figure 4.6: Feedstock Distribution
Top 25 Countries Most Profitable
Self-Sufficiency Potential

iii. Largest, Profitable Reductions of Imports: Top 10 Developed Countries

Disparities in the viability of investments (for less developed or developing economies compared to more developed economies) necessitate a different top 10 list for both categories of development. Table 4.13 lists the developed economies with the most potential to profitably reduce imported petroleum diesel. As in previous sections, countries on this top 10 list were identified by overlaps between

Table 4.13: Most Potential for Profitable Self-Sufficiency – Developed Countries Only

Rank	Country	Potential Biodiesel (lts.)	Total Savings vs. Diesel	% of Diesel Imports	HDI Rank	GDP / cap	Corr Rank	FDI Rank	WB Debt	Trvl Wrn
1	Canada	177,396,000	$ 42,607,000	43%	97%	96%	91%	96%	N/A	No
2	Australia	454,233,000	$ 148,715,000	33%	98%	94%	94%	95%	N/A	No
3	Italy	332,693,000	$ 154,371,000	29%	90%	89%	75%	93%	N/A	No
4	Portugal	126,402,000	$ 47,296,000	18%	85%	81%	84%	88%	N/A	No
5	Netherlands	2,448,758,000	$ 1,222,673,000	16%	93%	93%	93%	97%	N/A	No
6	Belgium	1,186,233,000	$ 369,855,000	16%	95%	93%	88%	95%	N/A	No
7	U.K.	493,215,000	$ 401,555,000	13%	92%	89%	93%	99%	N/A	No
8	Germany	2,006,262,000	$ 1,045,954,000	12%	89%	92%	90%	97%	N/A	No
9	Sweden	252,160,000	$ 121,729,000	11%	97%	88%	96%	91%	N/A	No
10	Norway	50,589,000	$ 41,885,000	8%	99%	98%	95%	83%	N/A	No



Tables 4.11 and 4.12, as well as subjectively selecting the remainder from countries which showed a good balance of attributes but just missed overlapping directly. With the exception of Australia, all of the countries on the top 10 list are located in Western Europe and all have very high petroleum diesel prices due to taxation. Due to the regional make-up of the countries in Table 4.13, the use of palm oil as a primary feedstock in achieving independence has greatly diminished as compared with previous evaluations in this study, comprising of only 6% [Figure 4.7]. However, palm oil is still used by all countries except Canada, Australia and Norway for between 1% and 21% of profitable biodiesel potential used towards self-sufficiency, even though it is not grown domestically. If self-reliance is the ultimate goal, trading a dependency on imported petroleum for a dependency on imported vegetable oil would not be terribly useful.

Narrowing the top 10 list of countries which can best offset petroleum diesel down to those which have the highest probability of achieving their self-sufficiency potential is challenging as all have very high social and economic ratings. It is possible to prioritize the countries either by total savings potential or by cost-savings per liter, in which the countries sometimes vary greatly. However, because this question concerns self-reliance, investments would most likely come from domestic sources, reducing the need for cross-country comparisons. For this reason, the impacts on all 10 developed countries, as well as the top 10 developing countries in the next section, are assessed.

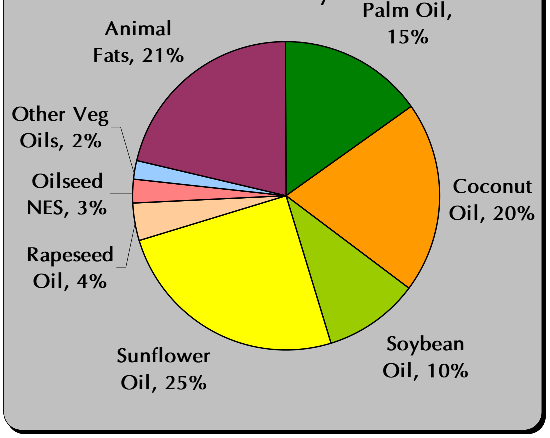
iv. Largest, Profitable Reductions of Imports: Top 10 Developing Countries

Table 4.14 lists the top 10 developing countries in terms of potential for profitable self-sufficiency in diesel transportation fuel imports. The prominent change in Table 4.14 is the lowered overall volume and savings potentials as compared to the developed countries in Table 4.13. Aggregate volumes and savings both dropped by almost 95%. However, although the countries in Table 4.14 have less volume potential, they actually have more potential for self-sufficiency. This is due in large part to the tables being ranked by percentage of imports offsets, allowing countries with lower vegetable oil and animal fat volumes to still rank highly if they have correspondingly low diesel imports.

Table 4.14: Most Potential for Profitable Self-Sufficiency – Developing Countries Only

Rank	Country	Potential Biodiesel (lts.)	Savings vs. Diesel	% of Diesel Imports	HDI Rank	GDP/ cap	Corr Rank	FDI Rank	WB Debt	Trvl Wrn
1	Cote d'Ivoire	101,491,000	$ 28,797,000	93%	8%	15%	4%	54%	Severe	Yes
2	Vanuatu	7,533,000	$ 4,077,000	30%	33%	33%	N/A	21%	Less	No
3	Lithuania	15,263,000	$ 3,821,000	23%	78%	72%	72%	62%	Mod.	No
4	Romania	57,889,000	$ 15,772,000	22%	64%	60%	46%	74%	Less	No
5	Bulgaria	20,692,000	$ 4,256,000	15%	69%	61%	65%	64%	Severe	No
6	Slovakia	47,764,000	$ 22,916,000	14%	76%	74%	70%	72%	Mod.	No
7	Togo	16,700,000	$ 4,808,000	12%	19%	17%	N/A	25%	Severe	No
8	Uruguay	39,906,000	$ 10,603,000	11%	74%	63%	80%	45%	Severe	No
9	Hungary	113,334,000	$ 50,190,000	10%	80%	76%	75%	86%	Mod.	No
10	Swaziland	5,050,000	$ 2,006,000	6%	17%	43%	35%	31%	Less	No

Figure 4.8: Feedstock Distribution
Top 10 Developing Economy Countries
with Self-Sufficiency Potential



The feedstock distribution of these top 10 developing countries comes largely from coconut and sunflower, which for first time exceed palm oil in the degree countries utilize those feedstocks [Figure 4.8]. Rapeseed is widely grown in Europe and is the most common existing vegetable oil feedstock for biodiesel. The rapeseed potential, as well as that of sunflower, comes entirely from the five Eastern European countries on the list, Lithuania, Romania, Bulgaria, Slovakia and Hungary. These countries also rely to a large degree on processed animal fats. With the exception the "severe" debt of Bulgaria, these Eastern European countries also rank the lowest in corruption perception and highest in human development, GDP per capita and foreign direct investment making them clear favorites in terms of realizing their potential. Vegetable oilseeds NES[34] also make their first appearance on these charts, being used by both Togo and Uruguay to meet 24% and 2% of their respective potential. Overall, Table 4.14 shows significant potential for these countries to become more self-sufficient, in total,

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[34] FAOSTAT code 0339 defines Vegetable Oilseeds NES to be: Other oilseeds, oleaginous fruits and nuts that are not identified separately because of their minor relevance at the international level. Because of their limited local importance, some countries report commodities under this heading that are classified individually by FAO. Also included under this code are tea seeds, grape pips and tomato seeds from which oil is extracted.

freeing up over 425 million liters of petroleum diesel annually from the world markets.

v. Economic and Environmental Impacts: Top 10 Countries

Tables 4.15 and 4.16 show the impacts of realizing the developed economy and developing economy potentials respectively. Table 4.15 shows the impacts on developed countries in achieving their self-sufficiency potential. Canada, Australia, Italy and Portugal can reduce their imports the most through large-scale biodiesel programs. However, the Netherlands can reduce their *overall* petroleum demand the most as they import 100% of their petroleum diesel fuel in addition to having the largest potential biodiesel volumes. The Netherlands, along with Belgium, also have the largest potential impacts on GDP per capita and unemployment, albeit in part by using imported vegetable oils. Due to their large overall volumes, the Netherlands, Germany, Belgium and the United Kingdom

Table 4.15: Growth Strategy I – Top 10 Dev'd Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Potential Biodiesel (lts.)	Savings Vs. Diesel	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO$_2$ Reduced
1	Canada	177,396,000	$ 42,607,000	43%	0.00435%	0.115%	2,499	66,054
2	Australia	454,233,000	$ 148,715,000	33%	0.02568%	0.629%	6,398	169,135
3	Italy	332,693,000	$ 154,371,000	29%	0.00983%	0.102%	4,686	123,879
4	Portugal	126,402,000	$ 47,296,000	18%	0.02588%	0.242%	1,780	47,066
5	Netherlands	2,448,758,000	$ 1,222,673,000	16%	0.25908%	3.204%	34,490	911,803
6	Belgium	1,186,233,000	$ 369,855,000	16%	0.12704%	2.140%	16,708	441,698
7	U.K.	493,215,000	$ 401,555,000	13%	0.02469%	0.247%	6,947	183,650
8	Germany	2,006,262,000	$1,045,954,000	12%	0.04576%	0.296%	28,257	747,038
9	Sweden	252,160,000	$ 121,729,000	11%	0.05126%	0.667%	3,552	93,892
10	Norway	50,589,000	$ 41,885,000	8%	0.02457%	0.375%	713	18,837

hold the most potential for reductions in CO_2 emissions.

Among the developing countries in Table 4.16, Vanuatu shows the best potential, proportionally, to impact its economy by increasing GDP per capita [Table 4.16, column 6]. While a somewhat riskier investment due to its current economic and social conditions, Vanuatu also the smallest and therefore most accessible of all the projects in terms of overall volumes requiring refining. Cote d'Ivoire holds the most potential for self-sufficiency from imports as well as holding the next highest rise in GDP per capita potential. However, the size of the investment required to reach its full potential combined with the current travel warnings and low social and economic rating may preclude it from receiving large enough outside assistance. In terms of impacts on unemployment, Hungary, Uruguay and Slovakia benefit the most proportionally, with 0.22%, 0.14% and 0.11% decreases in number of unemployed citizens respectively. Overall, the percentage changes in the number of unemployed people in Table 4.16 are much

Table 4.16: Growth Strategy I – Top 10 Dev'ing Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Potential Biodiesel (lts.)	Savings vs. Diesel	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Cote d'Ivoire	101,491,000	$ 28,797,000	93%	0.1175%	0.0663%	1,429	34,386
2	Vanuatu	7,533,000	$ 4,077,000	30%	0.7065%	N/A	106	2,836
3	Lithuania	15,263,000	$ 3,821,000	23%	0.0091%	0.1126%	215	5,746
4	Romania	57,889,000	$ 15,772,000	22%	0.0098%	0.0562%	815	21,794
5	Bulgaria	20,692,000	$ 4,256,000	15%	0.0072%	0.0333%	291	7,790
6	Slovakia	47,764,000	$ 22,916,000	14%	0.0313%	0.1079%	673	17,982
7	Togo	16,700,000	$ 4,808,000	12%	0.0535%	N/A	235	5,658
8	Uruguay	39,906,000	$ 10,603,000	11%	0.0378%	0.1383%	562	15,024
9	Hungary	113,334,000	$ 50,190,000	10%	0.0342%	0.2232%	1,596	42,669
10	Swaziland	5,050,000	$ 2,006,000	6%	0.0369%	0.0155%	71	1,901

less than those in the developed countries listed on Table 4.15, primarily due to those countries already having much lower populations of unemployed citizens.

The remaining countries on the top 10 list all have similar impacts of a few tenths of a percent or less, on GDP per capita and unemployment. While not having as large of an impact on the national level as some of the mother countries examined in this thesis study, each of these opportunities has the potential to generate multiple millions of dollars in revenue, create several hundred jobs and reduce thousands of tons of CO_2 annually.

vi. Alternative Growth Strategy Impacts on Profitable Self-Sufficiency Potential

When calculating export potential, the previous growth strategies limited the countries in the analyses to only those on the narrowed list -- pre-qualified through the use of economic indicators as being more likely to realize their export potential. As this section did not narrow the country list, assuming the percentage to which a country can be profitably self-sufficient is an important enough motivator for internal investment, all countries were considered for inclusion in these final analyses. As such, the results from Growth Strategy II, shown in Tables 4.17 and 4.18, and Growth Strategy III, shown in Tables 4.19 and 4.20, are not limited to countries from the original growth strategy which looked only at exported vegetable oil.

The volume gains by adding crushed and processed whole oilseed crop exports to a country's self-sufficiency potential were, comparably, much larger than those in the previous section examining exports. When assessing profitable exports, gains of only a few percent were realized. However, in this section which compares profitability based on internal petroleum prices, Growth Strategy II shows much more noticeable volume increases – a 30% gain for developed countries

Table 4.17: Growth Strategy II – Top 10 Dev'd Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Volume Potential (lts.)	Savings vs. Diesel ($)	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Canada	177,396,000	$ 24,868,000	43%	0.0025%	0.1152%	2,499	66,054
2	Australia	454,233,000	$ 103,292,000	33%	0.0178%	0.6294%	6,398	169,135
3	Italy	338,185,000	$ 122,574,000	29%	0.0078%	0.1041%	4,763	125,924
4	Portugal	128,152,000	$ 34,982,000	19%	0.0191%	0.2452%	1,805	47,718
5	Nether-lands	2,712,380,000	$1,081,137,000	18%	0.2291%	3.5486%	38,203	1,009,963
6	Belgium	1,255,344,000	$ 261,403,000	17%	0.0898%	2.2642%	17,681	467,431
7	U.K.	544,277,000	$ 384,266,000	15%	0.0236%	0.2722%	7,666	202,663
8	Germany	2,226,883,000	$ 941,911,000	13%	0.0412%	0.3283%	31,365	829,187
9	Sweden	253,103,000	$ 96,807,000	11%	0.0408%	0.6693%	3,565	94,244
10	France	1,628,879,000	$ 728,305,000	10%	0.0440%	0.3828%	22,942	606,518

Table 4.18: Growth Strategy II – Top 10 Dev'ing Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Volume Potential (lts.)	Savings vs. Diesel ($)	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Cote d'Ivoire	112,969,000	$ 20,576,000	103%	0.0840%	0.0737%	1,591	38,275
2	Bulgaria	116,439,000	$ 14,011,000	86%	0.0238%	0.1871%	1,640	43,838
3	Vanuatu	16,669,000	$ 7,353,000	67%	1.2743%	N/A	235	6,276
4	Romania	169,912,000	$ 25,910,000	64%	0.0160%	0.1650%	2,393	63,970
5	Slovakia	106,302,000	$ 32,553,000	31%	0.0445%	0.2401%	1,497	40,021
6	Hungary	326,957,000	$ 99,934,000	28%	0.0680%	0.6438%	4,605	123,095
7	Togo	16,776,000	$ 3,161,000	12%	0.0352%	N/A	236	5,684
8	Uruguay	39,906,000	$ 6,612,000	11%	0.0236%	0.1383%	562	15,024
9	Poland	135,474,000	$ 30,676,000	9%	0.0070%	0.0270%	1,908	51,004
10	Zambia	4,686,000	$ 938,000	7%	0.0105%	0.0013%	66	1,588

between in Tables 4.15 and 4.17 and a 140% gain for developing countries between Tables 4.16 and 4.18. This gain is primarily due to the more specialized price comparisons which evaluated each country individually, rather than against a single, global price of biodiesel in the last section.

For the developed countries in Table 4.17, however, a 40% rise in overall volume did not translate in significantly larger self-sufficiency potential. The much larger fuel demands of developed economy countries make percentage gains more difficult to achieve without extremely large volumes. For example, the Netherlands and the United Kingdom had the two largest increases in self-sufficiency potential of the countries in Table 4.17, but even they were limited to only 2% gains. Interestingly, these gains also reduced their profitability per liter, as can be seen by profit decreases in columns four between 4.15 and 4.17. Both countries received the majority of their increases from crushed soybeans which are less profitably per liter than their other feedstocks, bringing down the average cost per liter. France also replaced Norway in the last position on the list, having made large gains to due to sunflower and especially rapeseed. Norway, by comparison, had no increases in overall volume from processing whole exported oilseed crops.

Amongst the developing countries in Table 4.18, volume increases were much higher. Because average fuel uses by these countries are comparably lower, developing countries saw larger increases in the degree to which they could profitably offset petroleum diesel imports. Bulgaria, Romania, Slovakia and Hungary all increased self-sufficiency between 17% and 71%. Poland, which was a new addition to Table 4.18, increased its volume four fold, corresponding to a 7% gain in profitable self-sufficiency. Nearly all of the large volume gains made by these Eastern European countries can be attributed to sunflower and rapeseed, which it currently exports whole. Vanuatu also more than doubled both its volume potential and the degree to which it can be self-sufficient between Growth Strategy I and Growth Strategy II. Vanuatu can profitably move from being 30% to 67% self-sufficient by domestically processing coconuts it currently exports whole. Overall, the developing economy countries in Table 4.18 have significant room to expand their vegetable oil processing infrastructure if the market demand for vegetable oil remains higher than that of whole crops.

As explored in previous sections, when calculating volumes from agricultural yields for Growth Strategy III, many of the developed countries fall off the list entirely. This precedence holds true for Table 4.19, which shows only three developed economy countries in the world can profitably offset petroleum diesel imports. This is primarily due to how domestic demand is calculated in the study – only including countries whose domestic oilseed production is greater than their domestic demand. Australia is the only country remaining from the previous

Table 4.19: Growth Strategy III – Top 3 Dev'd Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Volume Potential (lts.)	Savings vs. Diesel ($)	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	French Polynesia	26,708,556	$ 10,996,772	19%	N/A	1.2356%	376	9,945
2	Australia	111,069,938	$ 1,998,346	8%	0.0004%	0.1539%	1,564	41,357
3	Luxembourg	2,776,062	$ 355,757	<1%	0.0013%	0.2354%	39	1,034

growth strategies. Its overall volume and offset percentage have both dropped due to elimination of animal fats in Growth Strategy III, falling from 33% to 9% self-sufficiency. Two new countries are present in Table 4.19, French Polynesia and Luxembourg. However, they only appear due their small populations and, hence, small vegetable oil demand which is able to be met by domestic sources.

The most notable change for developing countries in the third growth strategy is that all top 10 countries can now be more than 100% self-sufficient from imported petroleum diesel fuel [Table 4.20]. Similar to previous scenarios, the majority of the untapped potential, shown by Table 4.20, comes from large increases in coconut and palm oil yields per hectare. Of the top 10, only Romania realizes its gains from different feedstocks, getting the majority of its more than two fold increase in from sunflower and rapeseed. As such, this study shows that Romania is one of few countries that still have potential to increase yields of

Table 4.20: Growth Strategy III – Top 10 Dev'ing Economies w/Profitable Self-Sufficiency Potential

Rank	Country	Volume Potential (lts.)	Savings vs. Diesel ($)	% of Diesel Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Cameroon	3,983,082,000	$ 773,254,000	7458%	2.3664%	1.2121%	56,100	1,349,506
2	Cote d'Ivoire	4,897,385,000	$1,680,707,000	4485%	6.8604%	3.1967%	68,977	1,659,281
3	Sierra Leone	665,264,000	$ 170,013,000	1515%	5.5749%	N/A	9,370	225,398
4	Liberia	581,066,000	$ 128,335,000	1020%	N/A	0.2952%	8,184	196,871
5	Vanuatu	111,387,000	$ 49,137,000	447%	8.5156%	N/A	1,569	41,936
6	Niue	4,744,000	$ 3,123,000	400%	N/A	N/A	67	N/A
7	Togo	417,853,000	$ 77,368,000	293%	0.8609%	N/A	5,885	141,573
8	Central African Republic	84,310,000	$ 42,612,000	237%	1.0800%	0.4097%	1,187	28,565
9	Romania	411,712,000	$ 62,056,000	156%	0.0382%	0.3997%	5,799	155,004
10	Burundi	43,764,000	$ 19,423,000	137%	0.5025%	N/A	616	14,828

temperate oilseed crops through changes in agricultural practices.

The economic and environmental impacts for the countries in Table 4.20 are equally impressive to large volume gains, with increases in GDP per capita, and decreases in unemployment of a few percent being common. In aggregate, over 150,000 jobs could be created and almost 4 million tons of CO_2 could be reduced annually, should these countries fully realize their potential. Whether they could profit by exporting capacity beyond that needed domestically, however, depends on how competitive their production prices are relative to biodiesel imports. In the case of Table 4.20, all countries can produce biodiesel at prices less than the import price in Europe. Nine countries can profit more $0.30 per liter while Romania can profit at least $0.20 compared to EU import prices -- making the gains presented in Growth Strategy III more plausible than a first glance would have them appear.

C. What is the Cost of Self-Sufficiency from Petroleum-Diesel Imports?

The previous sections in this chapter only considered biodiesel which could be made from profitable feedstocks, whether compared internally to petroleum import prices or to world export prices. In this last section, the cost of being self-sufficient in petroleum diesel imports based on all available feedstocks, irregardless of profits, is calculated and assessed. Countries which previously ranked high in profitable self-sufficiency will no doubt score high again due to their proven low cost feedstocks. However, the financials of all countries on the new lists below will have changed to reflect the incorporation of every available feedstock.

The following calculations show the cost (or savings if profitable) per liter of biodiesel which must be incurred to become more self-sufficient. This section makes no assumptions as to how valuable self-sufficiency is or whether the costs necessary for implementation are low *enough*. However, it does assume *some* value as proven by the many existing biofuels implementations around the world which are growing rapidly without being less than the costs of petroleum diesel or gasoline. These conclusions are expected to be of interest primarily for each country to use in its own strategic decision making processes. Due to the increase in the number of countries which can achieve high levels of independence from imports, this section was expanded from 25 countries to 50 countries.

i. Largest Reduction in Imported Petroleum Diesel: Top 50 Countries

Table 4.21 lists the top 50 countries ranked by their potential to be self-sufficient from imported petroleum diesel fuel. Because many of the countries in Table 4.21 must incur costs to become more self-sufficient, this section does not calculate biodiesel volumes from all potential feedstocks if they are not necessary. To limit the costs to only those needed for independence, biodiesel volumes are capped at those necessary to offset 100% of the petroleum imports. In cases where countries can meet more than 100% of their imports, feedstocks are prioritized, using the lowest cost varietals first to keep costs down.

All of the top 8 countries have the potential to meet 100% of their imports. However, only the Ukraine and India are *not* also net exporters of petroleum products. The remaining countries in the top 8, Malaysia, Canada, Argentina, Columbia, the Russian Federation and Azerbaijan, all achieve their potential by

Table 4.21: Top 50 Countries with Self-Sufficiency Potential Regardless of Cost

Rank	Country	Volume Potential (lts.)	Cost vs. Import	% of Import	Rank	Country	Volume Potential (lts.)	Cost vs. Import	% of Import
1	Malaysia	1,702,278,000	$0.01	100%	26	United States	3,212,392,000	($0.13)	21%
2	Ukraine	583,895,000	($0.23)	100%	27	Paraguay	183,558,000	($0.09)	20%
3	Canada	412,999,000	$0.08	100%	28	Costa Rica	119,735,000	($0.05)	18%
4	Argentina	384,516,000	($0.10)	100%	29	Netherlands	2,495,807,000	$0.48	17%
5	India	125,798,000	($0.01)	100%	30	Nepal	49,113,000	($0.03)	16%
6	Colombia	110,370,000	($0.04)	100%	31	Belgium	1,212,740,000	$0.29	16%
7	Russian Federation	5,934,000	($0.22)	100%	32	Benin	28,448,000	$0.00	16%
8	Azerbaijan	3,560,000	$0.01	100%	33	Bulgaria	20,930,000	$0.19	15%
9	Cote d'Ivoire	101,927,000	$0.28	93%	34	Senegal	39,420,000	($0.14)	15%
10	Indonesia	7,595,073,000	($0.02)	89%	35	China	132,636,000	($0.81)	14%
11	Bolivia	228,976,000	($0.16)	80%	36	Slovakia	47,767,000	$0.48	14%
12	Papua New Guinea	383,349,000	$0.17	60%	37	Togo	19,954,000	$0.24	14%
13	Italy	658,323,000	($0.71)	57%	38	U.K.	511,305,000	$0.72	14%
14	Philippines	1,233,893,000	($0.06)	55%	39	Ghana	46,227,000	($0.05)	13%
15	Thailand	344,094,000	($0.09)	49%	40	Honduras	123,994,000	$0.10	12%
16	New Zealand	149,989,000	($0.15)	47%	41	Germany	2,023,526,000	$0.50	12%
17	Oman	43,065,000	($0.44)	45%	42	Uruguay	41,358,000	$0.21	11%
18	Brazil	2,566,633,000	($0.13)	40%	43	Sweden	258,395,000	$0.44	11%
19	Australia	468,512,000	$0.29	34%	44	Swaziland	8,635,000	$0.22	11%
20	Vanuatu	7,533,000	$0.54	30%	45	Kenya	50,535,000	($0.09)	10%
21	Jordan	73,170,000	($0.43)	27%	46	Ecuador	68,656,000	($0.27)	10%
22	Lithuania	15,572,000	$0.24	24%	47	Solomon Islands	4,949,000	($1.11)	10%
23	Cameroon	11,973,000	($0.40)	22%	48	Nigeria	11,025,000	($0.27)	10%
24	Romania	57,941,000	$0.27	22%	49	Spain	1,073,453,000	($0.61)	10%
25	Portugal	147,359,000	$0.06	21%	50	Hungary	113,775,000	$0.42	10%

only importing relatively small, strategic amounts of refined petroleum diesel fuel which they either do not have the capacity to refine domestically, or which is cheaper to import than transport. In fact, fourteen of the top 50 countries, Malaysia, Canada, Argentina, Columbia, the Russian Federation, Azerbaijan, Indonesia, Papua New Guinea, Oman, Brazil, Cameroon, the United Kingdom, Ecuador and Nigeria, are all net petroleum product exporters and another two, Bolivia and Benin, are net exporters of crude oil but import some refined petroleum products (EIA 2005). Indonesia is relatively unique among net petroleum exporters on the list as it has comparatively less petroleum refining capacity and imports over 8 billion liters of diesel fuel annually. However, because Indonesia is such a large grower of palm and coconut, it can still almost offset its considerable imports.

The fourth and ninth columns in Table 4.21 show the calculated difference in domestic petroleum diesel prices and the potential cost of production for biodiesel. The majority of the countries in the list have negative values, shown in red, to indicate the cost per liter to achieve the percentage of independence, shown in columns five and ten respectively. If this list were limited to countries which can potentially achieve their listed level of independence profitably, it would look very similar to the top 25 lists in the previous section which ranked profitable independence.

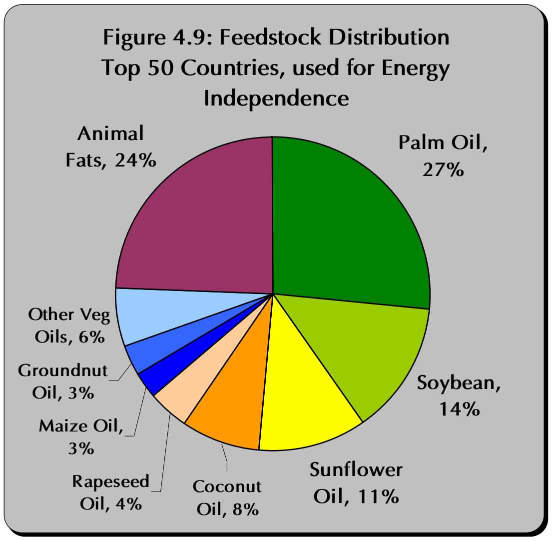


Figure 4.9: Feedstock Distribution Top 50 Countries, used for Energy Independence

Figure 4.9 shows the distribution of feedstocks used by the top 50 countries to achieve their potential independence. This distribution graph includes the most feedstock varieties, 8 with over 3% share, as compared to previous charts. Maize and groundnut oil, known more commonly as corn and peanuts in the United States, appear in significant quantities for the first time in this study as their higher prices do no preclude them from inclusion in this section. The higher distribution of feedstocks is due to the inclusion of twice the number of countries, but also because all of the feedstocks a country produces are included if necessary for self-sufficiency. Given that this condition is met for forty-two of the top 50 countries -- the other 8 of which are capped after meeting 100% of their imports -- the distribution is much more varied, especially within the "Other Vegetable Oils" share which is not detailed.

ii. Most Profitable Reduction of Imports: Top 50 Countries

Table 4.22 ranks countries based on the lowest cost of replacing the petroleum diesel imports. This list is very similar to the previous section assessing profitable import offsets, however, it differs by having average feedstock costs weighted down by the inclusion of more costly varietals. Only seven of the top 50 must incur costs to make the offset and most of those only require a few cents per liter. The $0.01 to $0.03 price premiums of those in these seven countries are actually much lower than those which are common in western countries with strict environmental laws creating guaranteed markets for biodiesel and other biofuels –

Table 4.22: Top 50 Countries with Lowest Cost of Self-Sufficiency Potential

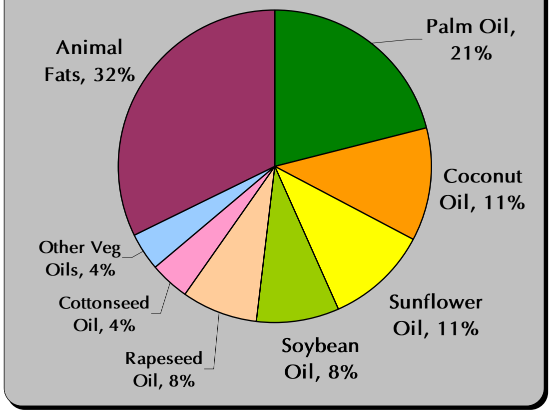
Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import
1	Norway	50,649,000	$0.82	8%	26	Togo	19,954,000	$0.24	14%
2	U.K.	511,305,000	$0.72	14%	27	Lithuania	15,572,000	$0.24	24%
3	Ireland	67,764,000	$0.66	2%	28	Swaziland	8,635,000	$0.22	11%
4	Poland	33,155,000	$0.57	2%	29	Macedonia	1,336,000	$0.22	1%
5	Vanuatu	7,533,000	$0.54	30%	30	Uruguay	41,358,000	$0.21	11%
6	Finland	103,489,000	$0.54	5%	31	Mozambique	2,584,000	$0.21	1%
7	Austria	136,991,000	$0.54	3%	32	Bulgaria	20,930,000	$0.19	15%
8	Germany	2,023,526,000	$0.50	12%	33	Papua New Guinea	383,349,000	$0.17	60%
9	French Polynesia	4,900,000	$0.50	3%	34	Estonia	27,009,000	$0.17	4%
10	France	934,376,000	$0.49	6%	35	Fiji Islands	6,160,000	$0.15	2%
11	Slovakia	47,767,000	$0.48	14%	36	Croatia	13,420,000	$0.14	4%
12	Netherlands	2,495,807,000	$0.48	17%	37	Samoa	2,490,000	$0.11	10%
13	Sweden	258,395,000	$0.44	11%	38	Honduras	123,994,000	$0.10	12%
14	Hong Kong, China	166,831,000	$0.43	2%	39	Canada	412,999,000	$0.08	100%
15	Slovenia	13,493,000	$0.42	1%	40	Portugal	147,359,000	$0.06	21%
16	Hungary	113,775,000	$0.42	10%	41	Azerbaijan	3,560,000	$0.01	100%
17	Burkina Faso	2,265,000	$0.40	2%	42	Malaysia	1,702,278,000	$0.01	100%
18	Czech Republic	59,697,000	$0.38	4%	43	Benin	28,448,000	$0.00	16%
19	Niger	2,834,000	$0.38	2%	44	India	125,798,000	($0.01)	100%
20	Denmark	214,523,000	$0.33	9%	45	Zimbabwe	2,886,000	($0.02)	0%
21	Australia	468,512,000	$0.29	34%	46	Myanmar	2,689,000	($0.02)	1%
22	Belgium	1,212,740,000	$0.29	16%	47	Panama	4,286,000	($0.02)	1%
23	Cote d'Ivoire	101,927,000	$0.28	93%	48	Indonesia	7,595,073,000	($0.02)	89%
24	Romania	57,941,000	$0.27	22%	49	Uganda	1,457,000	($0.02)	1%
25	Serbia and Montenegro	18,153,000	$0.27	3%	50	Nepal	49,113,000	($0.03)	16%

sometimes amounting to $0.25 per liter or more. The remaining countries can achieve their calculated level of self-sufficiency profitably with the top 25 countries having returns in excess of $0.25 per liter. Table 4.22 further highlights the existing untapped potential for profitable biodiesel production which exists in many countries, some even at extremely large volumes by comparison.

The number of countries which are net exporters of refined petroleum products decreased to only seven, most of which fall in the bottom half of the list. Norway and the United Kingdom occupy the top two places, however, more due to their taxes on petroleum diesel being some of the highest in the world, than their petroleum exporting status (GTZ 2005). Again, European and African countries generally populate the majority of the top 25 list as their highly-taxed, petroleum diesel costs make almost any vegetable oil feedstock profitable when converted to biodiesel to offset it.

The distribution of feedstocks used by the top 50 countries is shown in Figure 4.10. The previously established low cost leaders, processed animal fats and palm oils, make up just over one half of the potential. However, because this question is more concerned with overall volume potential, many more expensive feedstocks are lumped in with

Figure 4.10: Feedstock Distribution Top 50 Countries, used for Most Profitable Energy Independence



the most profitable ones. Even so, feedstocks such as rapeseed oil, coconut oil, sunflower oil and soybean oil are clearly useful in making biodiesel to offset imports, with a combined total of 38%.

iv. Largest Reductions of Imports: Top 25 Developed Countries

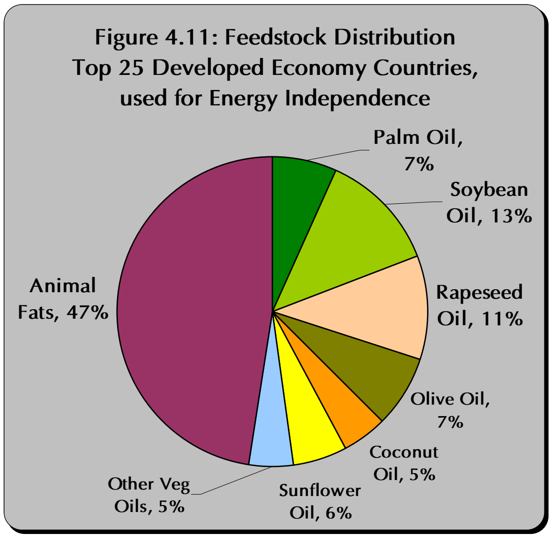


Figure 4.11: Feedstock Distribution
Top 25 Developed Economy Countries, used for Energy Independence

Table 4.23 lists the top 25 countries with developed economies, as classified by the World Bank, ranked by their potential to reduce petroleum diesel imports. Only eight of the countries must incur costs to offset petroleum diesel imports with biodiesel, with the remainder having profitable potential. The eight countries which must incur costs, however, generally require a significant amount per liter. Italy, Greece and Spain require $0.71, $0.81 and $0.61 per liter of additional costs, respectively, to reach their self-sufficiency potential – mainly coming from olive oil which is shown in Figure 4.11. Unfortunately, olive oils are sought after for their cooking properties and make for comparatively expensive biodiesel. Overall, the top 25 countries rely heavily on processed animal fats, soybean oil and rapeseed oil as seen in Figure 4.11.

As expected of countries with highly developed economies, all of the top 25 rank very highly in human development, GDP per capita and travel safety and low in perception of corruption. Cyprus and French Polynesia are the only countries which are not ranked in the top 1/3 of all countries for all indicators, and this only occurs in the amount of foreign direct investment. When implementing biofuels for self-sufficiency reasons in a highly developed country, little in the way of foreign direct investment would be expected in any case, making all the countries on Table 4.23 viable candidates for large-scale production.

Table 4.23: Top 25 Countries Self-Sufficiency Potential – Developed Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	HDI Rank	GDP /cap	Corr Rank	FDI Rank	WB Debt	Trvl Wrn
1	Canada	412,999,000	$0.08	100%	97%	96%	91%	96%	N/A	No
2	Italy	658,323,000	($0.71)	57%	90%	89%	75%	93%	N/A	No
3	New Zealand	149,989,000	($0.15)	47%	89%	87%	99%	83%	N/A	No
4	Australia	468,512,000	$0.29	34%	98%	94%	94%	95%	N/A	No
5	Portugal	147,359,000	$0.06	21%	85%	81%	84%	88%	N/A	No
6	United States	3,212,392,000	($0.13)	21%	94%	98%	89%	99%	N/A	No
7	Netherlands	2,495,807,000	$0.48	17%	93%	93%	93%	97%	N/A	No
8	Belgium	1,212,740,000	$0.29	16%	95%	93%	88%	95%	N/A	No
9	U.K.	511,305,000	$0.72	14%	92%	89%	93%	99%	N/A	No
10	Germany	2,023,526,000	$0.50	12%	89%	92%	90%	97%	N/A	No
11	Sweden	258,395,000	$0.44	11%	97%	88%	96%	91%	N/A	No
12	Spain	1,073,453,000	($0.61)	10%	88%	86%	85%	96%	N/A	No
13	Denmark	214,523,000	$0.33	9%	92%	97%	97%	89%	N/A	No
14	Norway	50,649,000	$0.82	8%	99%	98%	95%	83%	N/A	No
15	Singapore	367,014,000	($0.24)	6%	86%	88%	97%	91%	N/A	No
16	France	934,376,000	$0.49	6%	91%	91%	89%	98%	N/A	No
17	Finland	103,489,000	$0.54	5%	93%	90%	99%	85%	N/A	No
18	Greece	167,807,000	($0.81)	5%	86%	85%	70%	77%	N/A	No
19	French Polynesia	4,900,000	$0.50	3%	N/A	N/A	N/A	11%	N/A	No
20	Austria	136,991,000	$0.54	3%	90%	95%	94%	87%	N/A	No
21	Ireland	67,764,000	$0.66	2%	95%	99%	88%	94%	N/A	No
22	Hong Kong, China	166,831,000	$0.43	2%	88%	90%	91%	98%	N/A	No
23	Cyprus	5,321,000	($0.11)	2%	84%	82%	77%	65%	N/A	No
24	Korea, South	22,993,000	($0.06)	1%	84%	80%	75%	85%	N/A	No
25	Slovenia	13,493,000	$0.42	1%	85%	82%	80%	59%	N/A	No

v. Largest Reductions of Imports: Top 25 Developing Countries

Table 4.24 lists the top 25 developing countries with potential for self-sufficiency in transportation fuels. This list is more evenly matched than the developed country list with just under half of the countries achieving their potential independence profitably, and the remainder requiring additional funding per liter. Of the five countries which can meet 100% of their import demand through

Table 4.24: Top 25 Countries Self-Sufficiency Potential – Developing Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	HDI Rank	GDP /cap	Corr Rank	FDI Rank	WB Debt	Trvl Warn
1	Malaysia	1,702,278,000	$0.01	100%	66%	65%	75%	82%	Mod.	No
2	Argentina	384,516,000	($0.10)	100%	81%	73%	39%	84%	Severe	No
3	India	125,798,000	($0.01)	100%	28%	32%	44%	80%	Less	No
4	Colombia	110,370,000	($0.04)	100%	61%	55%	65%	76%	Mod.	Yes
5	Azerbaijan	3,560,000	$0.01	100%	43%	35%	13%	72%	Less	No
6	Cote d'Ivoire	101,927,000	$0.28	93%	8%	15%	4%	54%	Severe	Yes
7	Indonesia	7,595,073,000	($0.02)	89%	38%	34%	13%	68%	Severe	Yes
8	Bolivia	228,976,000	($0.16)	80%	36%	30%	26%	62%	Mod.	No
9	Papua New Guinea	383,349,000	$0.17	60%	23%	31%	18%	48%	Mod.	No
10	Philippines	1,233,893,000	($0.06)	55%	53%	41%	26%	70%	Mod.	Yes
11	Thailand	344,094,000	($0.09)	49%	59%	61%	63%	82%	Less	No
12	Brazil	2,566,633,000	($0.13)	40%	64%	62%	61%	90%	Severe	No
13	Vanuatu	7,533,000	$0.54	30%	33%	33%	N/A	21%	Less	No
14	Lithuania	15,572,000	$0.24	24%	78%	72%	72%	62%	Mod.	No
15	Romania	57,941,000	$0.27	22%	64%	60%	46%	74%	Less	No
16	Paraguay	183,558,000	($0.09)	20%	50%	42%	9%	34%	Mod.	No
17	Costa Rica	119,735,000	($0.05)	18%	N/A	N/A	68%	59%	Less	No
18	Nepal	49,113,000	($0.03)	16%	23%	14%	26%	12%	Less	Yes
19	Benin	28,448,000	$0.00	16%	8%	10%	44%	17%	Mod.	No
20	Bulgaria	20,930,000	$0.19	15%	69%	61%	65%	64%	Severe	No
21	Senegal	39,420,000	($0.14)	15%	11%	16%	51%	35%	Less	No
22	Slovakia	47,767,000	$0.48	14%	76%	74%	70%	72%	Mod.	No
23	Togo	19,954,000	$0.24	14%	19%	17%	N/A	25%	Severe	No
24	Ghana	46,227,000	($0.05)	13%	22%	27%	59%	44%	Less	No
25	Honduras	123,994,000	$0.10	12%	34%	32%	32%	49%	Mod.	No

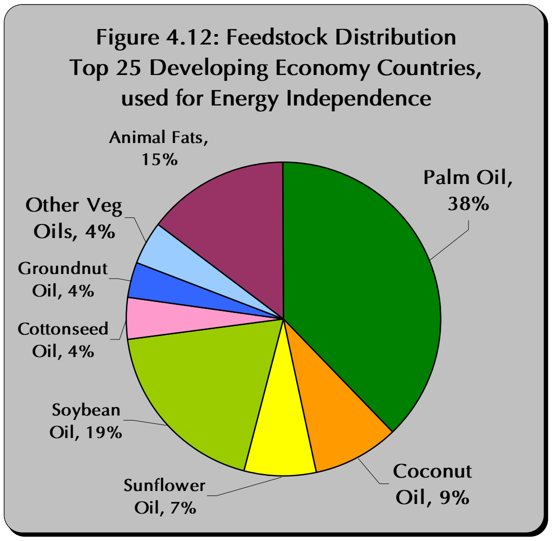


Figure 4.12: Feedstock Distribution
Top 25 Developing Economy Countries,
used for Energy Independence

biodiesel production, four are net exporters of refined petroleum products with India also having a large domestic petroleum production. Because of their relatively large petroleum production, these countries can achieve independence from foreign sources easier than most because of the smaller overall imports required to offset.

Figure 4.12 shows the distribution of feedstocks used by the top 25 countries. Tropical oilseed crops account for 47% of the distribution due to countries already proven to have large production such as Malaysia, Indonesia, Papua New Guinea and the Philippines. Soybean oil is the next most prevalent feedstock amongst countries on Table 4.24. Argentina and Lithuania both get the majority of their potential from soybean oil, however, Argentina's production dwarfs Lithuania's overall production by a factor of twenty-five. Processed animal fats and sunflower oils make up the next largest portion and are mainly used by the Eastern European countries on the list.

If outside investment were the primary means of development, several countries stand out among the group as having more potential for profit and less risk. Lithuania, Romania and Slovakia all offer net positive savings potential as well as having the best group of social and economic indicators. Vanuatu offers the highest savings per liter but at an assumed higher risk due to less favorable economic conditions. While the remaining projects are either higher risk or could only be implemented at a loss, because this list concerns potential for self-sufficiency in imports, the trade-offs may still be worth the investment to some governments.

vi. Economic and Environmental Impacts: Top 25 Countries

In assessing the economic and environmental impacts of the top 25 developed countries in Table 4.25 and developing countries in Table 4.26, the most notable differences are in effects on GDP per capita – many of which are now negative. All of the countries can have positive effects on unemployment and emissions reductions, however, which direction the GDP moves depends on the profitability of the projects.

The developed economies in Table 4.25 can also benefit greatly by achieving their potential for independence. The overall volumes in Table 4.25 are approximately 17% larger than table 4.26 which would correspond to similar reductions in overall greenhouse gases and other emissions. The Netherlands and Belgium are positioned to benefit the most in terms of both increase in GDP per capita and decrease in unemployment among profitable countries. If profitability is not a primary factor, New Zealand and Singapore can also benefit, proportionally, from the jobs created by implementing large-scale biodiesel refining capacity.

Table 4.25: Growth Strategy I - Top 25 Countries Self-Sufficiency Potential – Dev'd Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO$_2$ Reduced
1	Canada	412,999,000	$0.08	100%	0.0034%	0.2681%	5,817	153,781
2	Italy	658,323,000	($0.71)	57%	-0.0297%	0.2026%	9,272	245,129
3	New Zealand	149,989,000	($0.15)	47%	-0.0260%	1.3514%	2,113	55,849
4	Australia	468,512,000	$0.29	34%	0.0232%	0.6492%	6,599	174,452
5	Portugal	147,359,000	$0.06	21%	0.0046%	0.2819%	2,075	54,870
6	United States	3,212,392,000	($0.13)	21%	-0.0037%	0.3084%	45,245	1,196,145
7	Netherlands	2,495,807,000	$0.48	17%	0.2525%	3.2653%	35,152	929,322
8	Belgium	1,212,740,000	$0.29	16%	0.1192%	2.1873%	17,081	451,567
9	U.K.	511,305,000	$0.72	14%	0.0226%	0.2556%	7,201	190,386
10	Germany	2,023,526,000	$0.50	12%	0.0447%	0.2984%	28,500	753,467
11	Sweden	258,395,000	$0.44	11%	0.0480%	0.6833%	3,639	96,214
12	Spain	1,073,453,000	($0.61)	10%	-0.0731%	0.3728%	15,119	399,704
13	Denmark	214,523,000	$0.33	9%	0.0418%	0.9873%	3,021	79,878
14	Norway	50,649,000	$0.82	8%	0.0245%	0.3754%	713	18,859
15	Singapore	367,014,000	($0.24)	6%	-0.0800%	3.4142%	5,169	136,659
16	France	934,376,000	$0.49	6%	0.0274%	0.2196%	13,160	347,918
17	Finland	103,489,000	$0.54	5%	0.0391%	0.3559%	1,458	38,534
18	Greece	167,807,000	($0.81)	5%	-0.0642%	0.2056%	2,363	62,484
19	French Polynesia	4,900,000	$0.50	3%	N/A	0.2267%	69	1,825
20	Austria	136,991,000	$0.54	3%	0.0298%	0.4631%	1,929	51,009
21	Ireland	67,764,000	$0.66	2%	0.0304%	0.5852%	954	25,232
22	Hong Kong, China	166,831,000	$0.43	2%	0.0359%	0.5547%	2,350	62,120
23	Cyprus	5,321,000	($0.11)	2%	-0.0041%	0.2792%	75	1,981
24	Korea, South	22,993,000	($0.06)	1%	-0.0002%	0.0183%	324	8,561
25	Slovenia	13,493,000	$0.42	1%	0.0152%	0.1003%	190	5,024

Of the developing countries which can profitably reduce their petroleum imports in Table 4.26, Vanuatu's and Papua New Guinea's potentials will bring about the most improvement in GDP per capita. Due to incomplete data sets for these countries, effects on unemployment cannot be estimated. However, considering their current low GDP per capita rankings and having populations of only 196,000 and 5.2 million respectively, Vanuatu and Papua New Guinea can both benefit greatly from biodiesel development. In terms of proportional job growth, Malaysia, Costa Rica, Thailand and Indonesia are expected to benefit the most if profitability is not paramount. If profitability is required, Uruguay, Lithuania and Slovakia are expected to create the most employment opportunities proportionally.

Table 4.26: Growth Strategy I - Top 25 Countries Self-Sufficiency Potential – Dev’ing Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO$_2$ Reduced
1	Malaysia	1,702,278,000	$0.01	100%	0.0084%	2.9388%	23,976	640,885
2	Argentina	384,516,000	($0.10)	100%	-0.0084%	0.1273%	5,416	144,765
3	India	125,798,000	($0.01)	100%	-0.0000%	0.0019%	1,772	42,622
4	Colombia	110,370,000	($0.04)	100%	-0.0018%	0.0321%	1,555	41,553
5	Azerbaijan	3,560,000	$0.01	100%	0.0002%	0.0536%	50	1,340
6	Cote d’Ivoire	101,927,000	$0.28	93%	0.1167%	0.0665%	1,436	34,534
7	Indonesia	7,595,073,000	($0.02)	89%	-0.0192%	0.4624%	106,973	2,859,444
8	Bolivia	228,976,000	($0.16)	80%	-0.1723%	0.4774%	3,225	86,206
9	Papua New Guinea	383,349,000	$0.17	60%	0.4907%	N/A	5,399	129,882
10	Philippines	1,233,893,000	($0.06)	55%	-0.0204%	0.1716%	17,379	464,544
11	Thailand	344,094,000	($0.09)	49%	-0.0067%	0.5439%	4,846	129,547
12	Brazil	2,566,633,000	($0.13)	40%	-0.0236%	0.2030%	36,150	966,303
13	Vanuatu	7,533,000	$0.54	30%	0.7065%	N/A	106	2,836
14	Lithuania	15,572,000	$0.24	24%	0.0087%	0.1149%	219	5,863
15	Romania	57,941,000	$0.27	22%	0.0097%	0.0563%	816	21,814
16	Paraguay	183,558,000	($0.09)	20%	-0.0608%	0.2746%	2,585	69,107
17	Costa Rica	119,735,000	($0.05)	18%	N/A	0.6663%	1,686	45,079
18	Nepal	49,113,000	($0.03)	16%	-0.0034%	0.0057%	692	16,640
19	Benin	28,448,000	$0.00	16%	0.0015%	N/A	401	9,638
20	Bulgaria	20,930,000	$0.19	15%	0.0068%	0.0336%	295	7,880
21	Senegal	39,420,000	($0.14)	15%	-0.0330%	0.0112%	555	13,356
22	Slovakia	47,767,000	$0.48	14%	0.0313%	0.1079%	673	17,983
23	Togo	19,954,000	$0.24	14%	0.0527%	N/A	281	6,761
24	Ghana	46,227,000	($0.05)	13%	-0.0047%	0.0162%	651	15,662
25	Honduras	123,994,000	$0.10	12%	0.0730%	0.0956%	1,746	46,682

vi. Alternative Growth Strategy Impacts on Self-Sufficiency Potential

This final section assesses the two alternative growth strategies for self-sufficiency not limited by profits. The results of Growth Strategy II, which adds vegetable oil volumes from processed whole oilseed crops to those from the base scenario, are shown in Tables 4.27 and 4.28 for developed and developing economy countries respectively. The results of Growth Strategy III, which are

Table 4.27: Growth Strategy II - Top 25 Countries Self-Sufficiency Pot. – Dev'd Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Canada	412,998,666	$0.04	100%	0.0016%	0.2681%	5,817	153,781
2	Australia	934,749,101	$0.18	67%	0.0294%	1.2953%	13,165	348,057
3	Italy	664,792,341	($0.70)	57%	-0.0296%	0.2046%	9,363	247,538
4	New Zealand	150,667,097	($0.16)	47%	-0.0275%	1.3575%	2,122	56,101
5	United States	7,021,183,321	($0.12)	45%	-0.0081%	0.6740%	98,890	2,614,360
6	Portugal	149,153,709	$0.06	22%	0.0048%	0.2854%	2,101	55,538
7	Netherlands	2,800,045,524	$0.47	19%	0.2790%	3.6633%	39,437	1,042,606
8	Belgium	1,296,101,426	$0.28	17%	0.1234%	2.3377%	18,255	482,608
9	U.K.	564,879,355	$0.71	15%	0.0248%	0.2825%	7,956	210,335
10	Germany	2,246,388,266	$0.51	13%	0.0497%	0.3312%	31,639	836,450
11	Sweden	261,710,886	$0.43	11%	0.0479%	0.6921%	3,686	97,449
12	France	1,677,232,030	$0.49	11%	0.0499%	0.3942%	23,623	624,523
13	Denmark	226,130,411	$0.34	10%	0.0450%	1.0407%	3,185	84,200
14	Spain	1,079,695,614	($0.61)	10%	-0.0733%	0.3750%	15,207	402,028
15	Norway	50,707,517	$0.82	8%	0.0245%	0.3758%	714	18,881
16	Singapore	369,101,494	($0.25)	6%	-0.0836%	3.4337%	5,199	137,436
17	Greece	193,337,467	($0.65)	5%	-0.0590%	0.2369%	2,723	71,990
18	Finland	103,502,704	$0.54	5%	0.0391%	0.3560%	1,458	38,540
19	Austria	172,455,997	$0.45	4%	0.0318%	0.5830%	2,429	64,215
20	French Polynesia	4,900,161	$0.50	3%	N/A	0.2267%	69	1,825
21	Ireland	69,559,783	$0.65	3%	0.0311%	0.6007%	980	25,901
22	Hong Kong, China	170,514,123	$0.41	3%	0.0350%	0.5670%	2,402	63,491
23	Cyprus	5,320,620	($0.11)	2%	-0.0041%	0.2792%	75	1,981
24	South Korea	23,175,106	($0.06)	1%	-0.0002%	0.0184%	326	8,629
25	Israel	6,702,743	($0.62)	1%	-0.0034%	0.0176%	94	2,496

based on average oil yields from existing land under cultivation, are shown in Tables 4.29 and 4.30.

For the countries in Table 4.27, there was an almost 40% increase in total biodiesel volumes; however, no new countries became 100% self-sufficient. The countries witnessing the largest gains from processed whole crops were Australia and the United States, each nearly doubling the degree to which they can be self-

Table 4.28: Growth Strategy II - Top 25 Countries Self-Sufficiency Pot. – Dev'ing Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Imports	% of Imports	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Malaysia	1,702,278,437	$0.01	100%	0.0081%	2.9388%	23,976	640,885
2	Ukraine	583,894,665	($0.23)	100%	-0.0503%	0.4472%	8,224	219,829
3	Argentina	384,515,999	($0.12)	100%	-0.0103%	0.1273%	5,416	144,765
4	India	125,798,444	($0.50)	100%	-0.0021%	0.0019%	1,772	42,622
5	Colombia	110,370,333	($0.07)	100%	-0.0030%	0.0321%	1,555	41,553
6	Cote d'Ivoire	109,183,555	$0.28	100%	0.1257%	0.0713%	1,538	36,992
7	Russian Federation	5,933,889	($0.35)	100%	-0.0002%	0.0008%	84	2,234
8	Azerbaijan	3,560,333	($0.47)	100%	-0.0059%	0.0536%	50	1,340
9	Indonesia	7,639,119,719	($0.02)	89%	-0.0216%	0.4651%	107,593	2,876,027
10	Bulgaria	119,101,818	($0.36)	88%	-0.0727%	0.1914%	1,677	44,840
11	Bolivia	247,309,967	($0.20)	86%	-0.2279%	0.5156%	3,483	93,109
12	Lithuania	54,878,406	$0.17	84%	0.0228%	0.4050%	773	20,661
13	Brazil	5,224,511,843	($0.12)	82%	-0.0455%	0.4131%	73,585	1,966,959
14	Kiribati	3,387,091	$0.13	71%	N/A	2.4847%	48	1,275
15	Sudan	98,731,714	($0.95)	67%	-0.1323%	0.0201%	1,391	33,451
16	Vanuatu	16,668,624	$0.54	67%	1.5632%	N/A	235	6,276
17	Romania	171,798,573	$0.25	65%	0.0262%	0.1668%	2,420	64,680
18	Papua New Guinea	399,183,047	$0.17	63%	0.5089%	N/A	5,622	135,247
19	Paraguay	555,273,838	($0.13)	62%	-0.2531%	0.8307%	7,821	209,053
20	Philippines	1,234,287,593	($0.06)	55%	-0.0205%	0.1717%	17,384	464,693
21	Thailand	377,005,128	($0.29)	53%	-0.0228%	0.5959%	5,310	141,937
22	Oman	43,065,417	($0.44)	45%	-0.0517%	0.1491%	607	16,214
23	China	393,304,785	($0.83)	42%	-0.0051%	0.0103%	5,540	148,074
24	Uruguay	130,875,363	$0.04	36%	0.01821%	0.45353%	1,843	49,273
25	Nigeria	36,041,078	($1.10)	32%	-0.02903%	0.01341%	508	12,211

sufficient. The United States, which increased its potential for self-sufficiency from 21% to 45% between Tables 4.25 and 4.27, reaches its potential from the huge amount of soybeans it currently exports. Australia, which moved up from 34% to 67% self-sufficiency, utilized unprocessed rapeseed exports. Most other countries realized comparatively small gains which only affected the degree of petroleum offset by a few percent. However, while the percentages are lower overall than the results from Table 4.28, the higher fuel prices in most developing countries make the majority of biodiesel volumes profitable when offsetting petroleum diesel. Only nine of the top 25 countries in Table 4.27 require additional costs per liter to offset their imports.

For developing countries in Growth Strategy II, the opposite is true with only seven of the top 25 countries in Table 4.28 being able to profitably offset petroleum diesel imports. Additionally, developing countries realized lower volume gains than their developed counterparts which grew 40%. Between Tables 4.26 and 4.28 there was an approximate 28% increase in overall volume which can be attributed to newly processed whole oilseed crops. As might be expected from the lower fuel demands by these countries, however, even though the overall volume increases were comparatively less, the percentage increases by which countries could potentially become independent from petroleum diesel imports were much higher. On average, the top 25 countries became approximately 25% more self-sufficient through the addition of whole oilseed crop exports. In fact, three additional countries, the Ukraine, Cote d'Ivoire and the Russian Federation, now have the potential to become 100% self-sufficient from imported petroleum diesel. Cote d'Ivoire, the only additional country which can achieve 100% self-sufficiency from imports profitably, realizes its new volume potential in Growth Strategy II from coconuts and cottonseeds which it currently exports whole.

Once again, Growth Strategy III eliminated the majority of developed countries from the Table 4.29. By having to estimate the domestic demand of for individual crops from aggregate vegetable oil data, only countries which could supply more than their domestic needs could be included in the final growth strategy. While not an intentional outcome this study, the presence of only seven countries on Table 4.29 shows that the majority of developed countries are not only reliant on foreign petroleum oil, as is more widely known, but also on foreign vegetable oil. The presence of French Polynesia, Guam, Luxembourg and Puerto Rico is less surprising due to the smaller sizes. However, Canada, Australia, and the United States, also manage to retain spots on Table 4.29. Their proportionally large farm lands compared to their populations, allows them to meet their domestic

Table 4.29: Growth Strategy III - Top 7 Countries Self-Sufficiency Pot. – Dev'd Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Canada	412,998,666	($0.05)	100%	-0.0021%	0.2681%	5,817	153,781
2	Australia	669,206,383	$0.08	48%	0.0091%	0.9273%	9,425	249,181
3	French Polynesia	26,708,556	$0.51	19%	N/A	1.2356%	376	9,945
4	United States	1,303,347,743	($0.11)	8%	-0.0013%	0.1251%	18,357	485,306
5	Guam	14,422,512	($0.08)	6%	N/A	0.8411%	203	5,370
6	Luxembourg	2,776,062	$0.23	<1%	0.0023%	0.2354%	39	1,034
7	Puerto Rico	1,366,343	($0.03)	<1%	N/A	0.0042%	19	509

vegetable oil needs as well as contributing some volumes towards self-sufficiency from petroleum diesel imports.

Table 4.30 shows the opposite characteristic of the limiting nature of Table 4.29. By basing volumes on average oil yields in Growth Strategy III, Table 4.30 has grown by more than double, to include all 52 countries which could be 100% self-sufficient from imported petroleum diesel. In fact, there were many additional

Table 4.30a: Growth Strategy III - Top 52 Countries Self-Sufficiency Pot. – Dev'ing Countries Only

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
1	Indonesia	8,574,469,423	($0.04)	100%	-0.0400%	0.5221%	120,767	3,228,174
2	Philippines	2,234,702,550	($0.06)	100%	-0.0355%	0.3109%	31,475	841,336
3	Malaysia	1,702,278,437	($0.06)	100%	-0.0508%	2.9388%	23,976	640,885
4	Guatemala	1,052,671,886	$0.06	100%	0.1104%	1.4598%	14,826	396,317
5	Honduras	1,039,617,331	$0.13	100%	0.7537%	0.8028%	14,642	391,402
6	China	933,994,109	($0.36)	100%	-0.0052%	0.0245%	13,155	351,636
7	Paraguay	898,390,775	($0.14)	100%	-0.4550%	1.3441%	12,653	338,232
8	Thailand	706,879,877	$0.00	100%	0.0005%	1.1174%	9,956	266,131
9	Costa Rica	672,902,998	$0.03	100%	N/A	3.7444%	9,478	253,339
10	Ecuador	669,342,665	($0.07)	100%	-0.0907%	0.6260%	9,427	251,999
11	Tanzania	643,233,554	$0.18	100%	0.5185%	N/A	9,060	217,934
12	Papua New Guinea	634,835,161	$0.21	100%	0.9793%	N/A	8,941	215,088
13	Ukraine	583,894,665	($0.23)	100%	-0.0506%	0.4472%	8,224	219,829
14	Myanmar	522,182,221	$0.04	100%	N/A	0.3479%	7,355	176,920
15	Argentina	384,515,999	($0.14)	100%	-0.0114%	0.1273%	5,416	144,765
16	Ghana	353,659,777	($0.10)	100%	-0.0806%	0.1235%	4,981	119,823
17	Bolivia	286,013,444	($0.20)	100%	-0.2591%	0.5963%	4,028	107,680
18	Senegal	270,585,333	$0.18	100%	0.2809%	0.0770%	3,811	91,677
19	Romania	263,464,666	$0.25	100%	0.0407%	0.2558%	3,711	99,191
20	Uganda	219,553,888	($0.77)	100%	-0.4634%	N/A	3,092	74,387
21	Uzbekistan	189,884,444	($0.26)	100%	-0.1103%	1.4946%	2,674	64,335
22	Benin	176,829,888	$0.18	100%	0.4194%	N/A	2,491	59,912
23	Sudan	147,160,444	($0.53)	100%	-0.1110%	0.0299%	2,073	49,859
24	Togo	142,413,333	$0.29	100%	0.4519%	N/A	2,006	48,251
25	Congo, Republic of	141,226,555	$0.00	100%	0.0002%	N/A	1,989	47,849

countries which were just under 100% which are not included. Table 4.30 is ranked by the quantity of biodiesel needed for independence from imports. More then half of the countries on the list can become self-sufficient profitably, with many having enough profits per liter to extend fuel taxation to biodiesel. Papua

Table 4.30b: Growth Strategy III - Developing Countries Only – Continued…

Rank	Country	Biodiesel Potential (lts.)	Cost vs. Import	% of Import	Rise in GDP/ capita	Drop in Unemp.	Jobs Created	Tons CO_2 Reduced
26	Bulgaria	135,292,666	$0.23	100%	0.0519%	0.2174%	1,906	50,936
27	India	125,798,444	($0.26)	100%	-0.0011%	0.0019%	1,772	42,622
28	Angola	123,424,889	($0.12)	100%	-0.0621%	N/A	1,738	46,468
29	Nigeria	111,557,111	($0.08)	100%	-0.0068%	0.0415%	1,571	37,797
30	Colombia	110,370,333	($0.07)	100%	-0.0026%	0.0321%	1,555	41,553
31	Cote d'Ivoire	109,183,555	$0.44	100%	0.1975%	0.0713%	1,538	36,992
32	Burkina Faso	99,689,333	$0.12	100%	0.0807%	N/A	1,404	33,776
33	Mali	97,315,778	($0.04)	100%	-0.0307%	0.0831%	1,371	32,972
34	Guinea	89,008,333	$0.16	100%	0.0749%	N/A	1,254	30,157
35	Liberia	56,965,333	$0.32	100%	N/A	0.0290%	802	19,300
36	Gambia	55,778,555	$0.20	100%	0.4032%	N/A	786	18,898
37	Cameroon	53,405,000	$0.29	100%	0.0481%	0.0163%	752	18,094
38	Solomon Islands	49,844,667	($0.07)	100%	-0.3790%	N/A	702	16,888
39	Equatorial Guinea	43,910,778	($0.06)	100%	-0.0289%	0.4140%	618	16,532
40	Sierra Leone	43,910,778	$0.36	100%	0.5120%	N/A	618	14,877
41	Guinea-Bissau	37,976,889	($0.09)	100%	-0.3591%	N/A	535	12,867
42	Central African Republic	35,603,333	$0.61	100%	0.5463%	0.1730%	501	12,063
43	Burundi	32,043,000	$0.54	100%	0.4508%	N/A	451	10,856
44	Chad	30,856,222	$0.24	100%	0.0687%	N/A	435	10,454
45	Gabon	30,856,222	$0.16	100%	0.0583%	0.1607%	435	11,617
46	Samoa	26,109,111	$0.11	100%	0.2733%	N/A	368	9,830
47	Sao Tome and Principe	24,922,333	$0.21	100%	2.4850%	N/A	351	8,444
48	Vanuatu	24,922,333	$0.54	100%	2.3373%	N/A	351	9,383
49	Comoros	16,614,889	($0.09)	100%	-0.1468%	0.1906%	234	5,629
50	Russian Federation	5,933,889	($0.22)	100%	-0.0001%	0.0008%	84	2,234
51	Kiribati	4,747,111	$0.13	100%	N/A	3.4823%	67	1,787
52	Niue	1,186,778	$0.76	100%	N/A	N/A	17	N/A

New Guinea, Romania, Togo, Bulgaria, Cote d'Ivoire, Liberia, Gambia, Cameroon, Sierra Leone, the Central African Republic, Burundi, Chad, Sao Tome and Principe, Vanuatu and Niue can all save between \$0.20 and \$0.76 per liter while becoming 100% self-sufficient from imports. Being able to tax biodiesel and still have it competitively priced vs. petroleum diesel is important for many developing countries which rely heavily on fuel taxes for government operating budgets. Even for countries which must pay to become more self-sufficient, twelve can do it for less than \$0.10 per liter.

Growth Strategy III shows that by increasing oilseed crop yields to only average levels, the total biodiesel volumes and related impacts attributable to these 52 developing countries could be huge. In aggregate, these 52 countries could free up 25 billion liters of petroleum diesel from the world markets, create over 350,000 jobs and reduce over 9 million tons of CO_2, which, at the current value of \$32.64 per ton, would be worth over \$300 million. These gains, while seemingly massive, serve to highlight the consumption gap between developing and developed economy countries. To achieve the results from this highly theoretical growth strategy, all of the countries in Table 4.30 would have to increase agricultural yields and build huge amounts of new vegetable oil processing and biodiesel refining infrastructure. If all 52 of these countries, accounting for more than a quarter of the total members of the United Nations, were to then to become independent from petroleum diesel imports, the 25 billion liters of diesel fuel freed up from world markets could only meet 11% of US diesel demand. If biodiesel is to globally replace petroleum diesel in significant quantities, huge increases in palm and coconut oil yields will be needed, such as those presented in the first section of this chapter which analyzed profitable export quantities. Additionally, new feedstock crops – either from higher-yielding varieties such as algae or from sources currently classified as waste streams --would be necessary to meet global diesel fuel demand.

Chapter V: Conclusion

Everyday around the world, policy decisions on countless issues of long-term, strategic importance are left unmade. Unless short-term benefits (read: election-term or fiscal-term) can be easily quantified, many of the most important concerns are neglected until crises lose their "long-term" status. Biodiesel, and more generally biofuels, have suffered from these politics of procrastination due to their image of being too costly, too land intensive, or too temporary of a solution to our worsening liquid fuel supply problems. The recent resurgence in support of biofuels is not likely to be an exception given that refining technology, feedstock pricing and biofuels ability to smooth the transition away from petroleum fuels have remained largely unchanged for the last five years or more. If the current interest in biofuels were truly part of a strategic, long-term effort to reduce dependence on imported petroleum, these decisions would have been made well before today's crisis rather than during the ensuing political fallout. What lawmakers *do* understand is instant gratification in the form of capital; either actual (e.g. economic growth, job creation, emissions reductions, rural development) or "political capital" (e.g. the goodwill politicians hope to gain from championing those issues). While existing biodiesel programs have been sold to the public more for the political benefits, this study attempts to show that biodiesel no longer need be viewed as a niche environment-friendly fuel or a temporary response to rising petroleum prices. Biodiesel can also offer the immediate monetary benefits necessary for action *today* in many countries across the globe.

The most activity in the biodiesel industry is currently taking place in the European Union and in the United States, which jointly make up over 95% of the global market (WI 2005). However, because supply and demand in those locations are driven primarily through environmental legislation (WI 2005), the willingness to pay has led an unspoken assumption that developed countries are the only ones which can afford to consume biodiesel. This limiting presumption about where biodiesel will be successful is witnessed most readily in the literature review in the introduction to this paper -- of the 13 identified biodiesel assessments which calculated volume potential, 85% bound their scope to either the US or EU. This paper, in contrast, takes a fresh approach to assessing biodiesel potential -- one which includes *all* countries, all farmland and all lipid feedstocks. By using a consistent framework, countries can be compared to one another on equal footing to determine *a priori*, which hold the most potential for biodiesel production. It is important to note that this study is not a *global* assessment of biodiesel potential, but a *national* assessment replicated 226 times -- the number of countries evaluated. The results presented are intended to be useful individually to governments and in aggregate for comparison between countries by groups such as the World Bank, the United Nations and others.

The results of this thesis study confirm that existing markets in developed countries show much potential for biodiesel growth due to high petroleum prices, high liquid fuel demand and strict environmental laws. More interestingly, the results also show that large untapped markets exist in developing and less-developed countries that have either extensive vegetable oil production, high petroleum prices or some combination of the two. Before continuing on to the country-level results, it is useful first to address some of the more common image problems biodiesel has acquired over the years -- namely the fact that biodiesel is viewed to be too costly, too land intensive and too temporary of a solution to garner support on a large-scale.

Concern #1: Biodiesel is Too Costly

Biodiesel's reputation for being too costly is a result of two primary factors – biodiesel's current price premium in compulsory markets and historically low petroleum diesel pricing that gives its recent increase the impression of being temporary. Though intended to help new technologies become viable, legislating mandatory markets may also the impression that the new technologies cannot stand on their own as a serious monetary competitor. Moreover, high petroleum prices in the past were temporary giving the impression that today's prices will come back down. The EIA recently revised their long-term oil price forecasts up significantly to \$56.97 per barrel in 2030 -- but they still expect prices to fall quickly from our current peak to below \$50 per barrel (EIA 2006). The problem is that previous price spikes were caused by short-term supply problems or political in-fighting, whereas today's high prices have been triggered by surging global demand, the elimination of spare production capacity and new reserve discovery which cannot keep pace -- none of which are temporary in nature (Hirsch 2005; IEA 2005). To address the concern that biodiesel is too costly, this study compares potential biodiesel volumes for export and for domestic consumption using various modes of profitability, as well as in situations where countries can implement biodiesel programs at a cost. As demonstrated by Brazil's ethanol program – started in the 1970's under the auspices of national security (Pessoa et al. 2005) – and the EU's and US's biofuels programs – primarily targeted at rural development and reducing environmental impacts – countries are willing to pay out-of-pocket for biofuel's benefits. The results of this study show, however, that a large number of countries can receive these same benefits profitably.

Concern #2: Biofuels are Too Land Intensive

Biodiesel production is just beginning to grow in significant quantities and already it has the impression of consuming too much land. Most recently, palm-based biodiesel in South East Asia has been accused of destroying intact rainforests (Monbiot 2006; Pontoniere 2006). What is important to realize is that vegetable oil used in biodiesel production is currently dwarfed by that used in human and animal food. Global vegetable oil production is currently 125 billion liters annually, of which only 1.8% (2.2 billion liters) is used in biodiesel production (WI

2005; USDA 2006). Even when limiting the statistics to the last 5 years – the time during which biodiesel has grown the most -- vegetable oil production grew by 25 billion liters, 10 billion of which were attributable to palm (USDA 2006). Of the 2.2 billion liters of biodiesel produced during that same period, well under 5% was made with palm oil -- making it responsible for less than 1% of palm oil's recent growth (WI 2005). There is no doubt that if palm-biodiesel continues growing unchecked, further deforestation will result. However, currently the blame lies with food demands and not biodiesel. This study helps to address this concern by calculating potential using only land already under cultivation. The results show that if new vegetable oil growth were reached through yield increases instead of clearing new land, current food requirements could be met while simultaneously enlarging the biodiesel market. Malaysia alone has the potential to profitably increase its palm oil exports 17 fold through yield increases from best-practice farming techniques. This new growth could feasibly meet the expected doubling of palm oil demand by 2020 while single-handedly expanding the biodiesel market by more than 100 fold (Hai 2002).

Concern #3: Biofuels are Too Temporary of a Solution

> *"With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and pollution-free."*
>
> — President Bush, State of the Union Address, January 28, 2003

If hydrogen transportation is indeed so close to becoming common place, why bother with biofuels at all? Biofuels are often referred to as a bridge fuel to the hydrogen economy; however, if the "bridge" to hydrogen is perceived to be that short, biofuels risk being considered instead as a band-aid fuel solution without serious plans for large-scale development. Unfortunately for hydrogen, the spin does not always match up with the reality. There are a variety of factors which are expected to delay the introduction of hydrogen into the transportation market, as well as accelerate the need for petroleum substitutes. Hydrogen technology itself has many obstacles to resolve, including: production, distribution, storage and the cost of the fuel cells themselves (Forsberg 2005; Murphy 2006; Zegers 2006). Meanwhile, manufacturers of internal combustion engine technologies are not expected to give up on their sunk capital costs without a fight -- increases in engine efficiency through greater use of diesel and hybrid technology will present a moving target for hydrogen to compete against. Dwindling petroleum supplies pose a problem as well, effectively widening the gap between the time when substitutes are needed and when hydrogen transportation technologies are expected to become viable. When viewing all of these problems in combination, it becomes apparent that a more diversified suite of options would be desirable in case the gamble on multiple breakthroughs in hydrogen technology falls short. Biofuels technology can fill this need for diversification today, utilizing the existing infrastructure, easing petroleum demand and reducing vehicle emissions. The results of this study show that biodiesel can immediately and profitably make a large impact using only existing land, as well as provide steady growth into the near future through yield increases. With the proper political and commercial support to encourage research and innovation, there is no reason biodiesel cannot also become a moving target to compete against. Biodiesel could one day replace petroleum outright through crop selection optimization, growing dedicated energy crops such as jatropha on marginal lands, and eventually through the use of algae-based oils which do not compete for fresh water or farm land (Sheehan et al. 1998; Kumar et al. 2005). What this paper ultimately reveals is that biodiesel has a large and immediate potential, as well as a bright future should action be taken today. Even if full support is slow to develop, the minimum that should be done is to begin properly representing biodiesel's chief concerns so as not to exaggerate their effect on large-scale production.

Today

This study was structured to eliminate as many factors as possible which might delay countries from realizing their potential biodiesel volumes. All of the resulting volumes were calculated using existing lipid exports from existing crop lands and increase profits as compared to normal vegetable oil exports. Assuming the desire to implement large-scale biodiesel programs will follow -- how much potential can be realized in the immediate-term? The aggregate results from Growth Strategy 1 (existing lipid exports only) show that a total of 47.2 billion liters of biodiesel per year can be produced and exported profitably [Table 5.1]. The volumes are spread across 109 countries, each having production capacities of at least 1 million liters per year and the top 8 exceeding 1 billion liters per year.

To better compare these volumes to current and future petroleum demand, it is useful to convert the biodiesel liters into equivalent barrels of oil. According to the U.S. Energy Information Administration (EIA), 70% of a barrel of petroleum can be used to produce liquid fuels suitable for road use (47% gasoline, 23% diesel). Assuming the biodiesel was replacing both gasoline and diesel fuel, every 111 liters of fuel would be equivalent to a barrel of petroleum (EIA 2006). Table 5.1 shows the aggregate potential, potential by feedstock

Table 5.1: Aggregate Potential Biodiesel Volumes

Description	Billions Ltrs./Yr.	Millions Barrel/Yr. Equivalent
Aggregate Potential	47.2	425
from Fat	7.7	69
from Palm	21.8	196
from Coconut	2.0	18
from Soy	9.7	87
from Rape	2.2	20
from Sunflower	3.0	27
Existing Biodiesel Production	2.2	20

Table 5.2: 2003 Petroleum Demand

Region	Millions Barrels/Day	Millions Barrel/Yr.
World	80.1	29,237
US	20.1	7,337
Europe	15.5	5,658
China	5.6	2,044
India	2.3	840

and the current biodiesel production in both billions of liters per year and the barrels of petroleum equivalents. The aggregate total of 47.2 billion liters of biodiesel translates into 425 million barrels of petroleum equivalent. When compared to existing petroleum demands from Table 5.2, it is possible to see the scale of the potential volumes (EIA 2005). In the case of GS1, the 425 million barrels equivalent of biodiesel could meet over one half of India's total demand or over one fifth of China's -- two countries whose petroleum demands are growing rapidly.

Of the feedstocks which make up the aggregate 47.2 billion liters, Table 5.1 shows that palm oil is responsible for just under one half all potential biodiesel. The temperate vegetable oils, soybean, rape and sunflower, also combine to make up about one third of the potential. Animal fat by-products from slaughterhouses are the third largest individual feedstock and present an inexpensive and quick entry into biodiesel production. Coconut oil is one of the smallest feedstocks in terms of volume, however, it is one of the more intriguing opportunities. Many individual countries have experienced a decline in overall coconut production in the recent past due to competition from palm (FAOSTAT 2005). And while aggregate coconut production has remained flat for last 5 years, it is projected to fall at the end of this year (USDA 2006). Coconut producers have a unique possibility with biodiesel to increase profits per liter while rejuvenating their overall production and increasing rural development (Ribier et al. 1998; Cloin 2005).

Also using Growth Strategy 1, this study calculates which countries can produce biodiesel profitably to offset petroleum diesel imports. Of the 109 countries that can profitably export biodiesel, 75 of them have the choice of using their potential to become more self-sufficient in petroleum fuels. These 75 countries have an aggregate potential of 14.3 billion liters of biodiesel per year -- again, each with operations of at least 1 million liters of annual production. The decision of whether to use the fuel internally or to export would need to be made by each country individually as both the profits per liter and the less quantifiable *value* placed on self-sufficiency can vary greatly.

Overall, the volumes which could be produced profitably are over 21 times greater than the existing 2.2 billion liters of annual biodiesel production. Not all this potential can be realized immediately, since even with animal fats removed, it makes up almost one third of all vegetable oil demand. Converting all of these volumes to biodiesel would surely affect food supplies and drive up feedstock prices. However, if biodiesel producers worked with oilseed growers to update their operations and resulting yields during the time the biodiesel refining infrastructure was being built, much of this new potential could be utilized quickly (within 1-2 years).

Today + 10

Growth Strategy 3 calculated potential biodiesel volumes based existing farm lands achieving best-practice yields through technology and management improvements. The amount of time to implement these changes can be as short as a single growing season; however, for a large-scale transition, several years would be needed for the knowledge, equipment and capital to be distributed to the growers (Pandey et al. 2001). This study defines "Today + 10" to be 10 years from the day the decision is made to significantly grow the biodiesel industry. All of the results from GS3 are considered to be sustainable and will not contribute to further deforestation if done through best-practice yield increases. However, a detailed analysis of each oilseed crop would be required to fully evaluate the sustainability of achieving best-practice yields through the necessary land, labor and raw material inputs.

Table 5.3 shows the results of biodiesel volumes from GS3 which can be profitably exported, as well as their barrels of oil equivalents. Through simple yield improvements, the total potential biodiesel volumes increase to 605 billion liters per year. Assuming vegetable oil demand for food purposes will also grow at historic rates during this time – at the current rate food

Table 5.3: Future Aggregate Potential Biodiesel Volumes

Description	Billions Ltrs./Yr.	Millions Barrel/Yr. Equivalent
Biodiesel Potential	604.9	5,450
from Palm	559.8	5,043
from Coconut	13.2	119
from Soy	10.6	95
from Rape	6.2	56
from Sunflower	7.2	65
Biodiesel Now + 10 Less Food Demand	417.0	3,757

demands would total 188 billion liters annually in 2015 -- 417 billion liters of biodiesel can still be produced with the remainder. When comparing current petroleum demands with the 2015 EIA forecasts in Table 5.4, this new biodiesel would free up the equivalent of all of China's demand growth for the previous 12 years. That in itself is a significant feat since China is frequently cited as the largest contributor to tightening petroleum supplies.

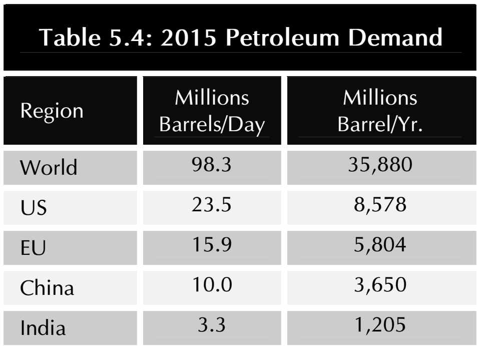


Table 5.4: 2015 Petroleum Demand

Region	Millions Barrels/Day	Millions Barrel/Yr.
World	98.3	35,880
US	23.5	8,578
EU	15.9	5,804
China	10.0	3,650
India	3.3	1,205

This newly profitable biodiesel production, which would not compete with food supplies, comes from a total of 106 countries. The sub-set which has the option for self-sufficiency (from petroleum imports) is smaller in GS3 at only 54 countries; however, the degree to which they can become independent is much greater. In the GS1 "Today" results above, the average amount the 75 countries could move towards independence is only 10%. In the GS3, the average degree of self-sufficiency leaps to 60% with 22 of the 54 countries having the option of becoming 100% independent from petroleum diesel imports.

Another important consideration for the "Today + 10" results is the fact that the vast majority of the gains come from tropical oils typically grown by less-developed or developing countries. Biodiesel can offer these countries opportunities for economic development, to leap-frog developed countries which are more reliant petroleum fuels and the chance to become more independent (Holm 2005). Brazil is an excellent example of a developing country that became self-sufficient in part by implementing the largest biofuels program in the world. Though it took many years to grow to its current capacity, today Brazil meets approximately 50% of their liquid fuel needs with ethanol (Pessoa et al. 2005). The potential volumes of biodiesel identified by this study offer countries an even more attractive option as all of the fuel would be profitable from day one, whereas Brazil started its program at a loss.

While over 100 countries can profit from large-scale biodiesel development, several stand out above the rest. Malaysia and Indonesia, which are currently the two largest palm producers; both stand to gain immensely from increased agricultural yields. Together they make up three-quarters of the potential volumes from GS3. As expected, their profits, the number of jobs created and the economic and environmental impacts outperform all the other countries combined. It is important to note that these two countries are also most at risk of furthering deforestation by growing palm production through clear-cutting as is currently practiced. Instead of calling for palm oil boycotts to stop deforestation, it would instead be wise for governments to work with Malaysia and Indonesia to improve their yields.

Two other countries with significant potential are Brazil and Argentina, both of which would rely on soybeans. The growth opportunities are not as great as Malaysia or Indonesia, but their large volumes and low production costs position them well. Many of the countries identified in this study can benefit from biodiesel, only at somewhat lesser volumes. Most rely on tropical oils which give them great opportunities for growth through yield increases. These countries include: Nigeria, Thailand, Colombia, India, Ecuador, The Philippines, Cote d'Ivoire, Papua New Guinea, The Democratic Republic of the Congo, and Cameroon.

Finally, it is crucial to point out that in addition to identifying some of the less well known opportunities in developing or less developed countries, this study also reaffirms the direction in which the industry is already headed in certain developed countries. Because of high fuel prices, high demand, and markets' willingness to pay for the benefits biodiesel offers, developed countries also show a great deal of potential. Some of those with the greatest profit potential are: The United States, The Netherlands, Germany, Belgium, France, Canada, Spain, Australia, The United Kingdom and Italy.

Given the political shortsightedness described in the beginning of this chapter, calculations of volume potentials beyond 10-15 years are outside the scope of this study. This limit should not be viewed as discounting the importance of long-term planning and research and development, however. Biodiesel fuels would not be in their competitive position today without the commitment and lasting vision of previous supporters. Continued research into more cost effective biofuels which do not compete with farmland is essential so that future fuels can be fully embraced without reservation.

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