This lack of energy security has the effect of raising the costs of operating some types of businesses. This can have particularly adverse effects for small businesses and low income groups that do not have their own financial reserves to absorb short term price rises. And finance is extremely expensive and difficult to obtain in Cambodia. Consequently a relatively small jump in the international oil price may thrust a small business or a family into a situation of debt and hardship that can be difficult to break.

d) Inflation: the reliance on imported fossil fuels for transport and power generation means that reserves of foreign currencies, mainly US dollars, are constantly being depleted. This can have a long term inflationary effect on the economy, especially in the case of Cambodia that has minimal export earnings.

e) Natural Environment: it appears inherently unsustainable that most of Cambodia's households currently rely on dwindling natural forests for their fuelwood. As this source of energy is consumed it is inevitable that households will be faced with rising energy costs and the environment will be further degraded.

2. Introduction to Biofuel

2.1 Biofuel Description

Biofuel is a generic term that is used to refer to liquid or gaseous fuels that are produced from a biological source.[3] The term 'liquid biofuel' is more commonly used to refer to specific types of biofuels used as fossil fuel substitutes. These are further defined by the particular type of biomass from which they are made, and the degree to which they are refined before use. The most common types of liquid biofuel are:

- **Straight Vegetable Oils** (SVO) **-** possibly the simplest form of biofuel is pure vegetable oil, such as the oil from peanuts, olives or sesame seeds. This oil has similar energy content and some similar physical characteristics to diesel fuel. In fact the inventor of the diesel engine, Mr Rudolph Diesel, originally designed his engine to be run on peanut oil.
- **Biodiesel** – this is a product that is made through the 'trans-esterification of suitable biological oils, and strictly speaking should confirm to a commercial standard such as ASTM D 675. This product is very similar to fossil-based diesel fuel and can be used in almost any type of diesel engine without modification, and has a long shelf life.
- **Ethanol** – this can be produced from a wide range of biomass (plant) material using a relatively complex chemical process. Generally the ethanol is mixed with gasoline, in varying concentrations, although cars are now produced for sale in some countries that can run on pure ethanol ("flex-fuel cars").

2.2 Biofuels for Cambodia

Each of the types of liquid biofuel described above has similar characteristics with respect to their applications and benefits for a developing country like Cambodia. However they are not identical and some important differences must be noted.

[3] One possible definition for biofuel is found in the Oregon Senate (USA) House Bill 3481 (see http://www.greencarcongress.com/2005/07/oregon_senate_p.html).

For example SVO biofuel can be produced with a very simple mechanical extraction process, but requires small engine modifications for it to be used in modern diesel engines. The production process for biodiesel is relatively simple but does require additional inputs of hazardous chemicals such as pure methanol and lye, and requires careful quality control. The extra benefits of Biodiesel over SVO are the greater flexibility of uses of the fuel, and also a by-product of its production is glycerine that can be sold for soap production.

The remainder of this paper will focus on one type of liquid biofuel in order to allow a more useful discussion and analysis. This type is SVO biofuel made from seeds of the Jatropha Curcas plant. The reasons for focussing on this one particular type of biofuel for this study are:

a) The simplicity and low cost of producing SVO is appropriate for adoption by rural entrepreneurs in Cambodia;
b) Straight SVO appears to be appropriate for many stationary applications in Cambodia such as power generation by REEs, water pumping, rice milling etc;
c) The Jatropha Curcas species already grows commonly throughout Cambodia and many rural people are familiar with the plant, and it is well suited to growing on degraded land with minimal rain;
d) The Jatropha Curcas has no other commercial value in Cambodia, which is an important factor in its economic viability; and
e) The Jatropha Curcas has been cultivated commercially for biofuel production in other countries, such as India and parts of Africa, and trials have started in Cambodia.

While this paper will now focus on biofuel from Jatropha Curcas, many aspects of the commercialisation and potential benefits will also apply to other types of biofuels.

2.3 The Jatropha Curcas Species

The *Jatropha Curcas*, or Physic Nut plant grows commonly in Cambodia where it is called the "Lhong Kwong". It is a drought-resistant perennial which grows in marginal soils and lives for up to 50 years. It is a close relative of the Castor plant, and its seeds contain about 35% non-edible oil. This oil has similar energy content to diesel oil and can be substituted directly in most types of diesel engine. The oil can also be used for a range of other applications such as lubrication and making high quality soap. The seed cake residue, left after expelling oil from the seeds, can be used as a high grade fertilizer. The plant helps prevent soil erosion from wind and water, and is used as a natural fence or hedge because animals do not eat it (World Bank, 2002).

2.4 Physical Properties of Jatropha Oil

Jatropha Oil is a vegetable oil, and thus is similar to more common household oils such as olive, peanut or sesame oil. It is also has some similar physical and chemical properties to diesel fuel, which is why it is possible to run diesel engines on this fuel (Knotte et al, 2002).

Table 3: Comparison of the Properties of Diesel Fuel and Jatropha Oil (*Source: website www.jatropha.de)*

Parameter	Diesel Fuel	Jatropha Oil
Energy content (MJ/kg)	42.6 - 45.0	39.6 - 41.8
Spec. weight (15/40 °C)	0.84 - 0.85	0.91 - 0.92
Solidifying point (°C)	-14.0	2.0

Flash point (°C)	80	110 - 240
Cetane value	47.8	51.0
Sulphur (%)	1.0 - 1.2	0.13

The most significant differences in the properties of Diesel Fuel and Jatropha Oil are the calorific content and viscosity of the two substances, which have the following implications:

- The **lower calorific content** of Jatropha Oil means that for a given quantity of Jatropha Oil there is about 7% less energy available than for diesel fuel. So an engine will consume slightly more Jatropha Oil than it would if it were running on diesel. However this does not indicate any difference in *efficiency*, because the same total amount of energy will be consumed in both cases.

- The **higher viscosity** of Jatropha Oil, compared to fossil-based diesel, at lower temperatures can cause problems for certain types of diesel engines and particularly during start-up when the engine and fuel are relatively cold. This puts more stress on the fuel pump, filter and injectors. This is a significant problem in cold climates, such as in Western Europe, and is solved by installing heating coils around the fuel lines. Trials in Cambodia and other tropical countries indicate that there is no problem in starting ‘cold’ with pure Jatropha Oil.

Jatropha Oil is also inedible to humans and this is an important factor in its suitability for biofuel. This is because there are no other commercial applications for Jatropha Oil, so therefore the supply and demand for the Biofuel product is not affected by other commodity markets. In contrast the price of high quality edible seed oils, such as almond and walnut oils, can be over US$10 per litre.[4] These oils would also work well in a diesel engine, but obviously they are far too expensive due to their high value in other markets.

[4] Author’s survey of prices for imported almond oil and walnut oil found in supermarkets in Phnom Penh in May 2005.

2.5 Biofuel Applications

Jatropha Oil biofuel can be used for older diesel engines that use "direct injection" system of fuel mixing and delivery. These types of engines are very common in rural Cambodia and can be found in many *stationary* (ie: non-transport) applications such as:

a) **Electricity generation –** Rural Electricity Entrepreneurs (REEs) that operate mini-grids, battery charging businesses, and a high proportion of other types of businesses that have their own on-site generator because grid power is not available, not reliable or not affordable.

b) **Power generation** – rice mills, ice making factories, wood working businesses and other small manufacturing operations.

c) **Water pumping –** for irrigation and drinking.

Most of the smaller businesses that provide these services in rural areas of Cambodia use old pre-used diesel engines and generators. These engines usually use a 'direct-injection' fuel delivery system and are tolerant to a range of fuel quality. Consequently it is assumed that the use of SVO biofuel without engine modifications should not cause any problems. Due to their age these engines require relatively frequent maintenance, so possible longer term effects such as build-up of impurities may not be a significant problem. The current Jatropha biofuel project described later in this paper reports satisfactory operation of a small diesel generator set with SVO biofuel.

Some businesses with greater power demand may use old pre-used car and truck engines. Most of these engines are diesel, and some of the newer ones may use in-direct injection. These engines are less tolerant to varying fuel quality and the higher viscosity of SVO biofuel. Therefore in some cases small engine modifications may be needed, or else a procedure of starting the engine on regular diesel until the engine reaches operating temperature, then switching to the biofuel.

2.6 By-product: Fertilizer

The residue that remains when oil is extracted from Jatropha seeds is high in carbohydrates, nutrients and energy as shown in the table below. It has been used successfully in other countries as a natural fertilizer, and the chemical analysis suggest it would be beneficial for a range of crops and conditions, such as mushroom cultivation. It also may be useful as an ingredient in stock feeds.

Table 4: Analysis Results for Jatropha Seed Cake (*Source: ITC 2005)*

Parameter	Value	Method
Humidity	10%	Drying
Acidity	1.55 mgKOH/g	Titration
Residual oil	8.3%	Extraction
Protein (N * 6.26)	8.27 %	Kjeldahl
Total carbohydrate: - α-chain (starch) - β-chain (cellulose)	 24.4 % (g/g) 31 % (g/g)	 Titration Extraction
Phosphorous content	1.03 % (g/g)	Spectroph.

Potassium (K^+)	0.66 % (g/g)	Atom. Abs.

Cambodian farmers generally use a large quantity of fertilizer on their crops despite the high cost of imported chemicals, and poor knowledge of side effects. Imports of fertilizer increased from 10,000-20,000 tons per year in 1990-1992, to 80,000-90,000 tons per year in 1993-1995 (MAFF, 1996). Jatropha seed cake could offer a safe, natural, and locally-made alternative to imported chemical fertilizers.

2.7 Biofuel Production Process

The process to produce biofuel from Jatropha seeds is relatively simple and can be summarised in the following main steps:

1. **Seed Harvesting** – the whole fruits are collected once they are ripe order to maximise oil content. This is performed by hand as trees are kept pruned to a height that allows easy harvesting, and to maximise the yield.

2. **Seed Drying –** the fruit is opened and the 3 or 4 seeds inside each are removed and sun-dried by spreading on a large flat dry surface such as a concrete slab.

3. **Seed Cleaning** – the seeds are checked for basic quality parameters (not old, mouldy, damaged etc) and then filtered to remove any foreign material that may damage the oil extraction machine such as stones or sticks.

4. **Oil Extraction** - a specially designed oil seed extraction machine is used that typically crushes the seeds in a screw press arrangement and separates oil from the 'seed cake' residue. The machine is driven by either an electric motor or diesel engine. The engine can be run on biofuel which will consume somewhere in the order of 5% of the oil output from the machine.[5]

5. **Oil Filtering** – the extracted oil is passed through a press-filter that removes all remaining seed sediment and impurities from the oil. This step is critical to the quality and performance of the end product. Other chemical and physical qualities of the oil are important and must be monitored and treated within certain parameters if necessary.

6. **Packaging** – the final product is bottled in standard clean, air-tight plastic containers or pumped directly into containers of suppliers at the factory. Special fuel-quality chemical resistant plastic is not required for these containers. The seed cake is packaged into bags or sacks for the fertilizer market.

[5] Estimate based on technical specifications for a 12HP diesel engine driving a TinyTech Oil Mill manufactured by Tinytech Plants, India (see www.tinytechindia.com).