Evaluating the Economic Potential and Feasibility of Producing Bioenergy from Underutilized Crops in Sri Lanka

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Evaluating the economic potential and feasibility of producing bio-energy from underutilized crops in Sri Lanka

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EXECUTIVE SUMMARY

Sri Lanka's agricultural sector has an immense supply of natural resources that can be further developed and utilized to produce bioenergy. Production of bioenergy from underutilized resources could reduce the country's dependence on fossil fuel importation and could also stimulate economic growth, improve environmental quality, and enhance the country's energy security. However, there is limited understanding currently of the potential biofuel resources, their utilization, and economic potential. The future of Sri Lanka's biofuel sector will depend on the continued implementation of research and incentive programs. This study sought to evaluate the economic feasibility of selected bioenergy crops in Sri Lanka and to compare their economic competitiveness. The ethanol feedstocks investigated in this study were sugar feedstock (sugarcane), starch feedstock (corn, sorghum, millet and cassava), and cellulosic feedstock (napier, guinea grass, *Eucalyptus*, and *Leucaena*).

The net economic returns model was used to select economically feasible feedstock for biofuel production. For each feedstock, net return, feedstock cost per Btu, feedstock cost per gallon of ethanol, breakeven price of feedstock, and breakeven price of ethanol were calculated. Most of the cellulosic feedstock showed the lowest feedstock cost per 1000 Btu and gallon of ethanol. Sugarcane, cassava, corn, and cellulosic feedstocks such as grass species appeared to be the leading biofuel crops among the investigated crops. For cellulosic feedstocks, however, the process of converting the feedstock into ethanol is still in the demonstration phase, hence results should be interpreted with caution.

1.0 Introduction

The economic development of modern societies is crucially dependent on energy. The way energy is produced, supplied, and consumed strongly affects the local and global environment and is therefore a key issue in sustainable development. Previous reports have predicted that over the next few decades, energy demand in developing countries will rise at a rate well above that in the Organization for Economic Co-operation and Development (OECD) countries (IEA 1995, 1996, 2002; World Bank 1994). In many developing countries, particularly those in Africa and South and East Asia, annual growth rates in energy consumption are predicted to remain in the range of 5-10 percent in the next two or three decades. As far back as 1996, the International Energy Agency's (IEA) World Energy Outlook starkly warned that, notwithstanding the considerable effort being made to reduce greenhouse gases, global emissions will continue to increase unless governments and communities collectively choose to change their pattern of energy use. This change will involve a dramatic move away from the current situation in which most world energy is supplied by fossil fuels. It will involve a much more rapid growth in the deployment of renewable sources of energy. In the longer term, renewable energy should play a dominant role in the world energy mix so that economic growth would be no longer dependent on fossil fuels. A World Energy Council (WEC) study back in 1993 indicates that world energy would need to come from renewable sources by the year 2020 in order to stabilize global greenhouse gas emissions.

Depending on their energy resources and needs, many countries support the move toward having renewable energy through research, development and demonstration programs, incentives to the manufacturing industry, and measures to eliminate increased market deployment (OECD 1997). However, the financial and human resources being devoted to the development and deployment of renewable energy technologies are limited vis-a-vis the big emphasis being placed on renewable energy as seen in national and international statements on longer term energy and environmental goals.

If the national goals for renewable energy are to be met, urgent actions must be taken to accelerate the pace of development and deployment of renewable energy technologies. Such action are needed to dramatically move away from the current dependence by most sectors on fossil fuels, as well as to reduce energy consumption and the intensity of pollution from economic activities. Doing so would necessarily require a much more rapid growth in the deployment of renewable energy than has yet been achieved or planned for in most countries. In the longer term, renewable energy must account for a large part of a country's energy mix if economic growth is no longer to be dependent on fossil fuels. This would require considerable efforts as well as motivation and political support.

Crops grown for energy, fast growing trees, short rotation forestry species, and certain grass species will most likely become increasingly important energy resources in the coming decades. Considerable research and development has been, and continuous to be, devoted to the production of alternative transport fuels from biomass feedstock. Several countries are demonstrating the production of biofuels (mainly ethanol) in a commercial environment.

Biofuels are currently the only renewable sources of liquid transportation fuels. At present, the primary sources for transportation biofuels are grain and sugar crops, from which over 18 billion liters of ethanol are produced annually for the transportation sector. In the USA, approximately 4 billion liters of ethanol are produced each year for transportation applications. Cellulosic biomass can also be converted into ethanol or other liquid biofuels. The use of these feedstocks, however, requires more advanced technologies. Research to reduce ethanol production costs by the use of low-cost woody biomass and energy crops is under way. Ethanol is generally blended with gasoline at concentrations of 5-10 percent. In some locations, net ethanol is used as a fuel. Ethanol production facilities are large scale, typically producing 100-400 million liters per year. Biodiesel is extracted from seed crops such as *Jatropha*, kukui, oil palm, and soy bean. At present, biodiesel has a relatively low market penetration (Francis et al. 2005).

Biofuel processing facilities or refineries and feedstock vary with the biofuel to be produced and the processing method used. The various pathways that connect energy crops to feedstock, processing method, and the desired biofuel are shown in Figure 1. However, this figure is unable to show whether any economically and environmentally feasible pathway exists, and if there are such pathways, which crop, feedstock, or processing method growers and processors should choose.

Biofuels offer alternative benefits on several fronts. These include energy benefits, environmental benefits (McLaughlin and Walsh 1998), and industrial growth and employment opportunities. In the short to medium term, renewable energy can help diversify energy sources, thus improving the security of energy supply necessary for sustainable economic development.

Biofuel development is hindered by technical, economic, and institutional factors. These will have to be overcome in order to increase the market deployment of renewable energy. Many of the bioenergy technologies are still at an early stage of development and are not yet technically mature; there are still technical barriers to overcome.

High production cost, capital intensity, and high projection costs are some of the problems. Although the capital costs of producing most new renewable energy are falling quite rapidly, the initial installation costs are often higher per unit of capacity than those for fossil-fueled plant, and this can deter investors. Lack of awareness among key market players, policymakers, financial institutions utilities equipment suppliers, and energy users are some of the institutional barriers in the development and promotion of biofuels.

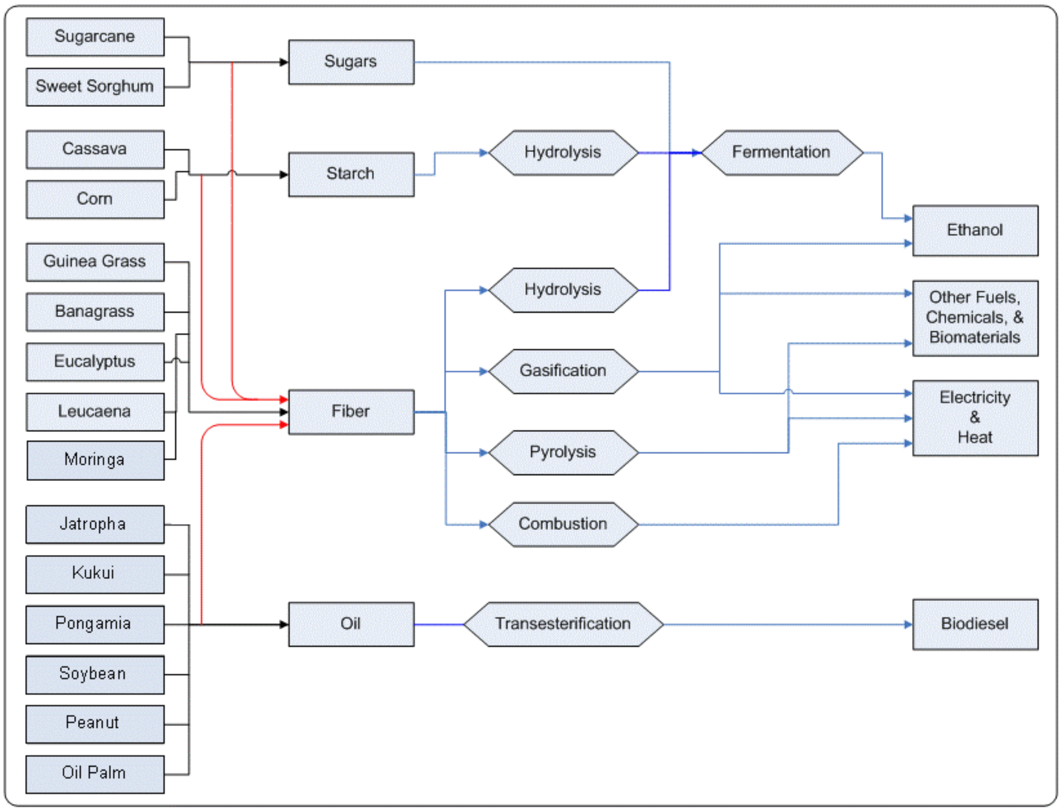

Figure 1. Flow chart linking crops to feedstock, conversion process, and bioenergy products. (Source: Kinoshita et al. 2006)

1.1 Rationale and Significance

The growing concern with rising oil prices, global warming and its consequences are the immediate justification for lessening Sri Lanka's dependence on imported fossil fuels. The feedstock the country chooses will have to be determined by: (1) its energy balance (defined as the renewable energy output per unit of fossil energy input) and (2) its cost of production. Pimentel and Patzek (2005) argue that more fossil fuel energy is consumed in producing ethanol from corn grain than is contained in the biofuel. A more recent report by Farrell et al. (2006), on the other hand, shows that corn grain alcohol produces net carbon emission gains, and improvements in energy balance and production cost are occurring at an even faster pace now. According to Goldemberg (2007), the current energy balance for corn grain ethanol is 1.4. This means that a unit input of fossil fuel energy is needed to produce 1.4 units of bioenergy; but if corn stalk instead of grain is used as feedstock, one unit of fossil fuel energy can produce 10 units of bioenergy. However, ethanol producing nations like the USA continue to produce ethanol from corn grain rather from cellulosic stalk because it costs them only about US$1.03 to produce a gallon of ethanol but between US$3 and US$4 to produce the same volume of ethanol from stalks. The US Department of Energy aims to lower the production cost of cellulosic ethanol to US$1.07/gal by 2012 (Goldemberg 2007).

A report prepared by the World Watch Institute (2006) for the German government indicates that the next generation of biofuel feedstocks will be composed of cellulose-rich organic materials, which are harvested for their total biomass. Cellulosic biomass such as wood, tall grasses, and crop residues is much more abundant than food crops, can be harvested with less interference to the food economy, and places less strain on land, air, and water resources. According to the report, the potential for biofuels is particularly large in tropical countries, where high biomass yields and lower costs for land and labor - which dominate the cost of these fuels - provide an economic advantage that is difficult for countries in temperate regions to match.

According to the Central Bank of Sri Lanka (2007), Sri Lanka continues to face high energy costs (Fig. 2) and energy insecurity as the country is mostly dependent on imported petroleum products for energy (Table A.1, Fig. 3). Therefore, the high cost of imported fossil fuels, the additional benefits of increased energy security, and the creation of new income and employment opportunities favor local biofuel production in Sri Lanka.

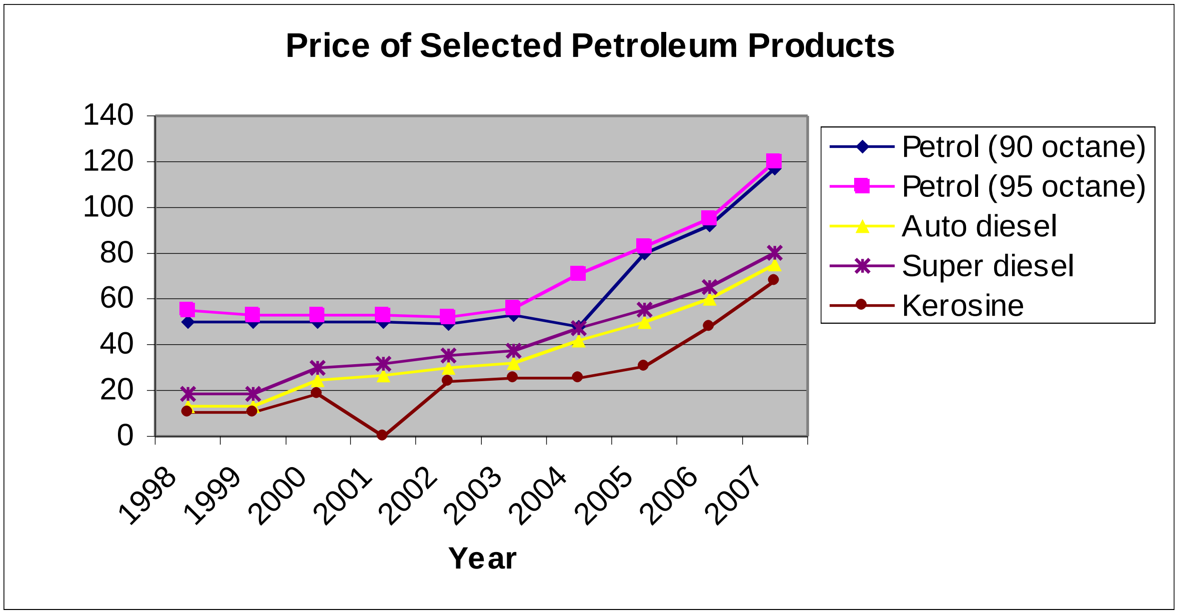

Figure 2. Price of selected petroleum products in Sri Lanka.
Source: Central Bank of Sri Lanka (2007)

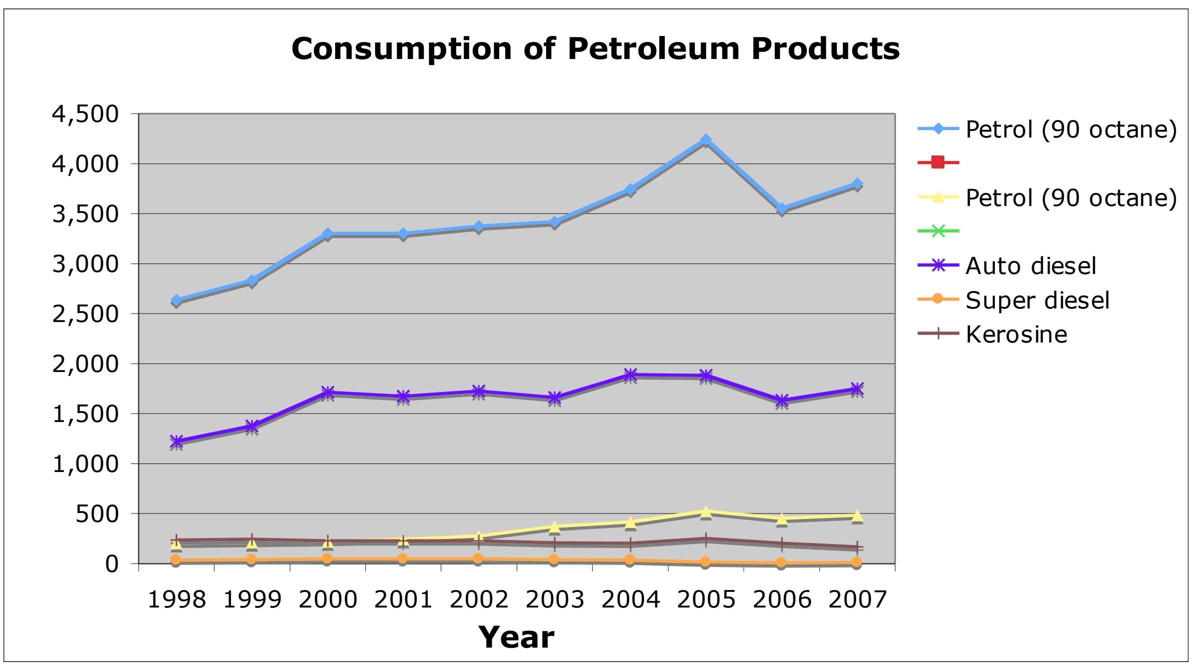

Figure 3. Consumption of selected petroleum products in Sri Lanka.
Source: Central Bank of Sri Lanka (2007)

Sri Lanka has various agro-climatic regions with a year-round growing season, relatively large arable lands, and largely unexplored feedstock resources. In addition, unlike food crops that require high production standards for uniformity, appearance, and safety, energy crops mainly need only to produce biomass, thus may be grown on marginal lands with little input and protection from pests. To date, the available biomass or the utility of candidate energy crops is not well-documented in Sri Lanka. Therefore, there is an urgent need for careful characterization and study to determine the feasibility for generating bioenergy in Sri Lanka. This research provides baseline knowledge critical for assessing resources and ensuring science-based analysis of key economic issues across the value chain. The information resulting from this study will be valuable to investors interested in bioenergy development and government agencies responsible for achieving renewable energy and economic development milestones.

This research mainly focused on adding value to the bioenergy knowledge base to enable growers and processors to efficiently produce and convert biomass into affordable biofuels to enhance energy security and generate income and new employment opportunities in Sri Lanka. This study aimed to provide scientific information needed to develop a biomass feedstock industry in Sri Lanka. Specifically, the study aimed to determine the economic feasibility of producing ethanol from first and second generation biofuel feedstocks.

2.0 Data Sources and Methodology

2.1 Project Description

A baseline research was conducted on candidate energy crops at two regions (Badulla and Monaragala districts) in Sri Lanka. These districts have different agro-environments ranging from warm to cool and wet to dry zones. Both have large amounts of underutilized agricultural land areas that may be used to grow energy crops. Table A.2 shows the land use pattern in the study sites. This research focuses on first generation candidate crops, which include corn, sugarcane, grain sorghum, and cassava, as well as on second generation cellulosic feedstock producing candidate crops such as napier, guinea grass (*Panicum maximum*), Eucalyptus, and Leucaena (*Leucaena leucocephala*). Private agricultural land owners experienced in growing the above crops were selected for the field research. Secondary data sources included local and international publications, sectoral studies, and previous research studies. Production data were also gathered from the annual cultivation report (for the purpose of comparing the survey data obtained) published by the Department of Agriculture in Sri Lanka.

2.2 Data

Some of the proposed crops are not widely grown in Sri Lanka, hence, finding appropriate field data for economic analysis had been challenging. Field data were used for crops such as sugarcane, corn, sorghum, millet, and cassava. For napier and Eucalyptus, secondary data sources were used. Production of several crops was assumed to be similar to other crops (e.g., napier for guinea grass, Eucalyptus for Leucaena). The study found that biofuel processing facilities or refineries and feedstock vary with the biofuel to be produced and the processing method used. As the ethanol conversion technology is not available in Sri Lanka, per gallon conversion cost data under different conversion technologies in the USA was used as proxy in estimating the conversion cost of feedstock to ethanol. Moreover, as the market price of ethanol is also not available, revenue was estimated based on the assumption that the ethanol costs half the price of gasoline in 2007 price.

2.3 Framework for Economic Analysis

The cost of producing each feedstock includes commonly used cost categories from land preparation to harvesting. The analysis assumes that feedstock production is rainfed and the producer has the necessary capital except for farm machinery. Although the analysis concentrates on the production of feedstock, energy conversion assumptions are also utilized such that preliminary analysis involving the processing of feedstock to biofuels can be conducted. (A note of caution, however: some of the conversion technologies are still in the development phase.)

It should be noted that certain field operations are not performed regularly and uniformly year after year, therefore, annual costs may differ over the crop's life. From an economic point of view, the overall approach is to estimate the average annual costs and returns over the entire economic life of the crop, which allows for direct comparison among different crops. To calculate costs and revenues in annual equivalent terms, the present values of all costs and revenues over the useful life of the crop were transformed into an equivalent annuity. The following procedure was adopted in estimating annual equivalent costs and revenues (Monti et al. 2007).

1. Present value of the total investment over a 25-year period was estimated as:

$$PVC_{ij} = \sum_{t=1}^{n} \frac{TCP_{ij}}{(1+r)^n} \qquad PVB_{ij} = \sum_{t=1}^{n} \frac{GR_{ij}}{(1+r)^n}$$

2. Annual Equivalent Cost (AEC) and Annual Equivalent Revenue (AER) were estimated as:

$$AEC_{ij} = \frac{PVC_{ij} \times r}{1-(1+r)^{-n}} \qquad AEB_{ij} = \frac{PVB_{ij} \times r}{1-(1+r)^{-n}}$$

PVC_{ij} = Present value of production cost in ith crop in jth farm (Rs/acre).
TCP_{ij} = Total cost of production in in ith crop in jth farm (Rs/acre).
PVB_{ij} = Present value of benefits in ith crop in jth farm (Rs/acre).
GR_{ij} = Gross revenue in ith crop in jth farm (Rs/acre).
r = discount rate

n = project duration (years)

In this analysis, n was assumed equal to 25 years (except in the case of sugarcane and Leucaena) and r was 10 percent (see Bhattacharya et al. 2003 for a similar discount rate used for Sri Lanka in analyzing biomass production). PVC_{ij} and PVB_{ij} are the present value of cost and revenue, respectively, over the 25-year period. The analysis for each crop was based on assumptions, modifications, and adjustments, which are explained in the technical notes for each crop (see Appendix B).

The feedstock cost of ethanol per 1000 Btu was estimated by dividing the cost per acre of producing each feedstock by the corresponding crop's total per acre energy production. Total energy per gallon of ethanol is 91600 Btu (adopted from Jaeger et al. 2007). Feedstock cost of gallon of ethanol was estimated by dividing the per acre cost of producing the feedstock by the total gallons (per acre) of ethanol produced for each crop. The breakeven price of feedstock is that price of feedstock where net revenue equals zero. The breakeven price is calculated as cost divided by yield, where yield is either in terms of feedstock or the appropriate conversion to energy.

3.0 Results and Discussion

Table A.3 summarizes the ethanol requirement that could be met and the land area requirements of the three different ethanol production goals. If the total unused but cultivable land area in the two districts is utilized for growing energy crops, a considerable portion of the 10 percent ethanol goal of the county could be fulfilled. For example, from the sugarcane production, 56 percent of the ethanol requirement under the 10 percent ethanol goal can be achieved. From the production of cassava and other cellulosic feedstocks, 28-38 percent of the ethanol requirement under 10 percent ethanol goal can be fulfilled.

Table 1 provides a comparison of crop yields, ethanol yields, feedstock costs per gallon, and feedstock costs per 1000 Btu for selected crops. Napier has the highest ethanol production (597 gallons/acre/year) among the cellulosic feedstocks (Figure 5) and the lowest feedstock cost per gallon of ethanol (37 Rs./gallon). Compared with the feedstock cost per gallon of ethanol (Figure 6) from sugar and starch feedstock, cellulosic feedstocks yield a lower cost per gallon of ethanol (ranging from Rs 37 - Rs. 88). Millet has the highest feedstock cost per gallon of ethanol (Rs. 470) followed by sorghum (Rs. 290). The analytical results show that millet and sorghum are not competitive crops in terms of bioenergy production under the present yield conditions. However, conversion costs to ethanol from cellulosic feedstocks are preliminary and should be interpreted with caution.

Table 1. Comparison of biofuel yields and feedstock cost/gallon of biofuel crops (2008).

Crop	Unit	Yield (acre/year)	Conversion factor	Ethanol (gal/acre/year)	Feedstock cost (Rs./gallon)[1]	Feedstock cost (Rs./1000 Btu)
1. Sugarcane	ton	54.00	19.5 gal/ton	877	68.07	0.74
2. Corn	kg	3,086.51	0.09 gallon/kg	278	135.22	1.48
3. Sorghum	kg	1,118.08	0.09 gallon/kg	101	290.17	3.17
4. Millet	kg	481.42	0.09 gallon/kg	43	469.51	5.13
5. Cassava	kg	12,053.13	0.04 gallon/kg	442	97.41	1.06
6. Napier	ton	10.7	67 gal/ton	597	36.67	0.40
7. Guinea grass	ton	7.76	67 gal/ton	433	88.28	0.96
8. Eucalyptus	ton	8.00	65 gal/ton	433	50.23	0.55
9. Leucaena	ton	9.00	65 gal/ton	487	50.41	0.55

[1] In 2007, 105 rupees = US$1

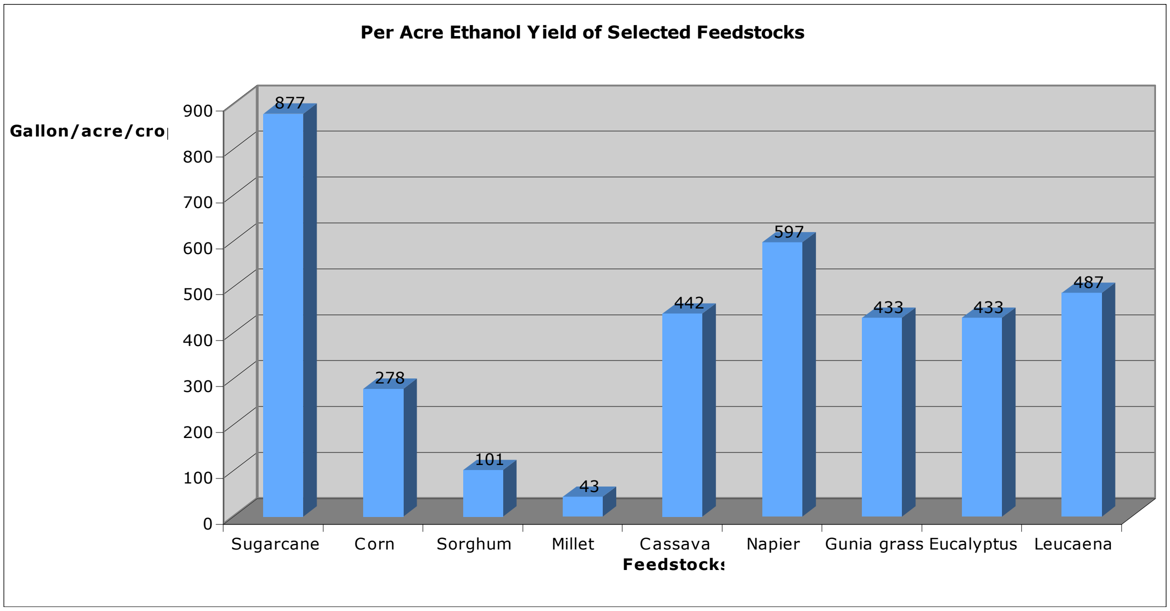

Figure 4. Ethanol yield (gallon/acre) of selected ethanol feedstocks (2007)

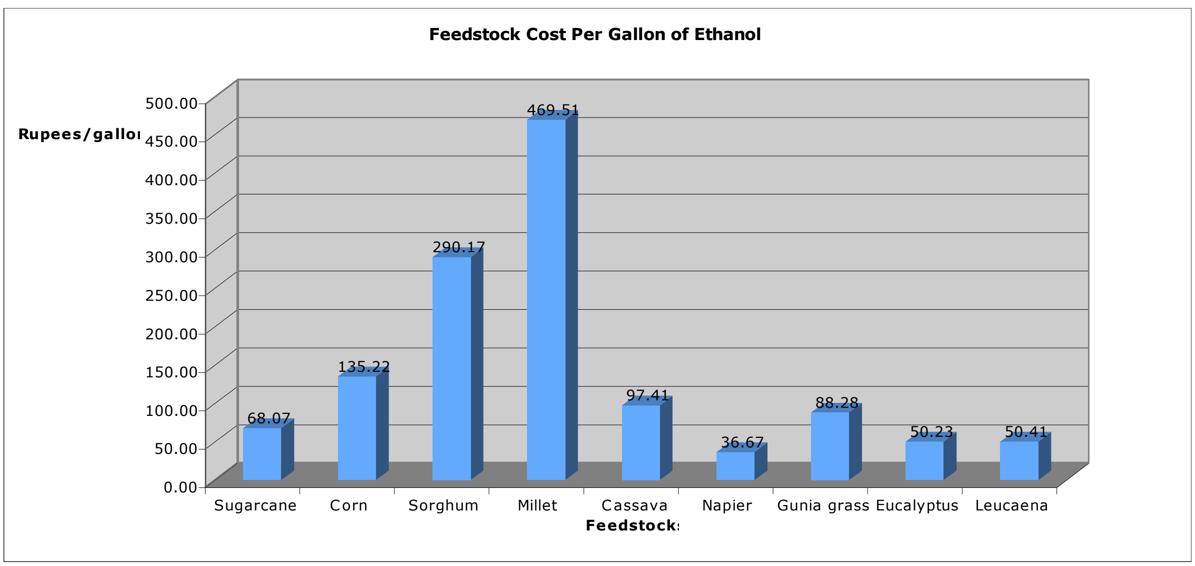

Figure 5. Feedstock cost per gallon of ethanol (2007)

Tables 2a and 2b summarize the major components of the economic analysis, including the analysis involving the feedstocks and their conversion to ethanol. The major findings are as follows:

- Net returns (based on feedstock price) are not available for Eucalyptus and Leucaena because of the absence of feedstock price data. Of the remaining bioenergy crops investigated, millet, napier and guinea grass show a negative Net Present Value (NPV) in terms of feedstock production.

- Calculation of the NPV after conversion to ethanol shows that sorghum, millet, Eucalyptus, and Leucaena have a negative NPV from ethanol production. This is due to either the crop's low energy yield (as in the case of millet) or low dry matter yield (as in the case of Leucaena and Eucalyptus). The cellulosic feedstocks such as napier shows the highest NPVs, lowest feedstock cost of ethanol in terms of Rs/1000 Btu and Rs/gallon. However, it should be noted that conversion costs of cellulosic feedstock to ethanol are still under investigation and hence the results should be interpreted with caution. Crop residues of some of the sugar and starch feedstocks (sugarcane, corn, sorghum, and millet) can be used for cellulose ethanol production, hence with technological advancement, there is a potential to increase total ethanol yield from these crops.

- The break-even price of ethanol (Figure 6) is highest for millet and sorghum (Rs. 424 and Rs. 327 per gallon, respectively). Those for sugarcane, cassava, and corn are Rs. 215, Rs. 218, and Rs. 256 per gallon, respectively. Among the investigated cellulosic feedstocks, the grass species show a lower breakeven price of ethanol. The low production cost and high ethanol yield are the reason for the lower breakeven prices of the grass species. Compared with Eucalyptus, Leucaena has a lower breakeven price (Rs. 243/gallon vs. Eucalyptus Rs. 277/gallon).

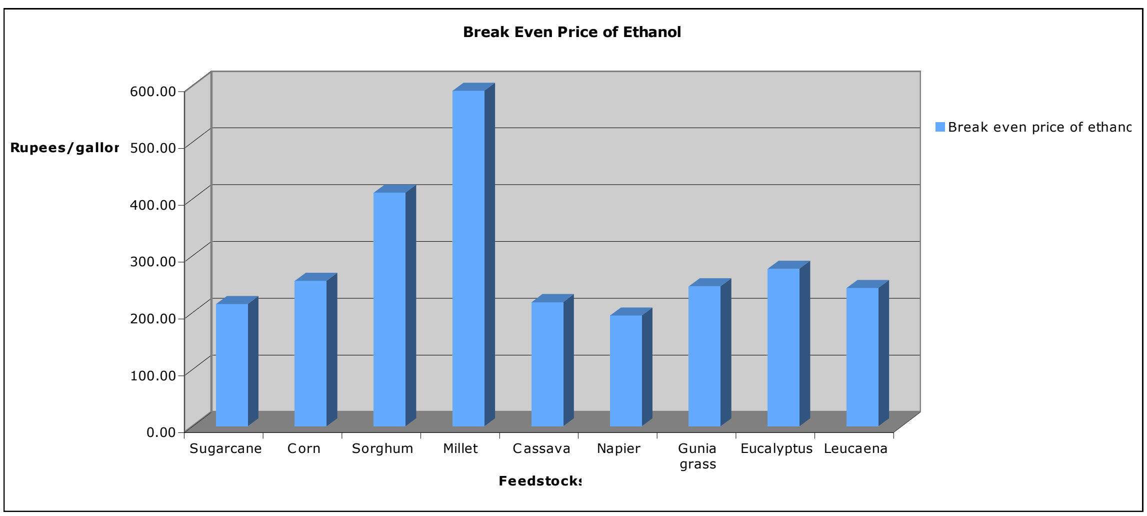

Figure 6. Breakeven price of ethanol in selected feedstock (2007).

The analysis shows that sugarcane, corn, cassava, and cellulosic feedstocks such as grass species are promising bioenergy sources. If the goal toward energy self-sufficiency is for Sri Lanka to produce 10 percent of its transportation fuel from renewable resources, the required annual ethanol production would be 185,470,000 gallons/year. Consequently, 118,437 acres of non-prime land (i.e., cultivable but abandoned) in Badulla and Monaragala districts are sufficient to produce the feedstocks needed for this purpose. Sugarcane can meet up to 56 percent of the ethanol requirement and the cellulosic feedstocks can take care of 28-38 percent.

Table 2a. Summary of feedstock and ethanol data (production, costs, gross revenues and net revenue): sugar and starch feedstock (2007).

Item	Unit	Sugarcane	Corn	Sorghum	Millet	Cassava
1**. Land preparation**						
Machinery	hour	1,648.35	3,673.33	3,206.25	2,507.14	4,930.66
Hired labor	hour	86.19	1,769.23	3,253.85	1,441.32	1,904.00
Family labor	hour	172.38	1,964.13	3,720.00	3,054.14	2,840.31
2. Planting						
Cuttings	kg	2,334.81	2,183.11	417.33	265.06	10,529.30
Machinery	hour					
Hired labor	hour	564.32	526.40	1,533.33		942.15
Family labor	hour	366.30	1,137.96	1,458.22	840.31	1,529.30
Chemicals	kg					
Other costs						
3. Other field operations						
Machinery	hour					
Hired labor	hour	1,800.00	4,434.30	2,400.00	1,303.70	1,869.60
Family labor	hour	4,370.00	6,099.11	3,832.89	2,113.75	3,578.59
Fertilizer						
a. Urea	kg	4,802.00	6,157.20	2,462.50		2,450.68
b. N:P:K (30:0:20 mixture)	kg	6,160.00	2,070.00			
Herbicides	liter					
Pesticides						
a. Type 1	liter					
b. Type 2	liter					
Other costs						
4. Harvesting						
Machinery	hour					
Hired labor	hour	11,200.00	800.00	105.00	893.88	2,912.00
Family labor	hour	2,470.00	1,007.41		1,523.44	3,682.62
5. Transportation						
Machinery	hour	17,500.00	317.31	3,093.33	330.00	476.07
Hired labor	hour	400.00	350.00	105.00	200.00	595.83
Family labor	hour	400.00				
Other costs	hour					
5. Other operations			787.50	953.85	1,260.00	
6. Equipment			866.67		950.89	857.73
7. Operation overhead	10%	5,427.43	3,414.37	2,654.16	1,700.86	3,909.89
Total costs		59,701.78	37,558.02	29,195.71	18,709.50	43,008.74
A. Production						
Primary production (per acre)	ton or kg	54.00	3086.51	1118.08	481.42	12,053.13
Gross revenue	Rs/acre	94,500.00	70,934.57	45,841.15	18,044.61	79,098.63
B. Net revenue						
Net revenue	Rs/acre	34,798.22	33,376.55	16,645.44	-664.89	36,089.89

C. Production of ethanol						
1. Processing cost	Rs/gallon					
2. Total processing cost	Rs/acre	108,353.70	33,584.06	12,165.71	4,818.21	53,383.58
3. Total production cost	Rs/acre	188,771.24	71,142.08	41,361.42	23,527.71	96,392.32
Gross revenue	Rs/acre	233,465.90	73,931.55	26,781.45	10,606.75	117,517.97
D. Net revenue from ethanol						
Net revenue	Rs/acre	44,694.66	2789.47	-14579.97	-12,920.96	21,125.65
Feedstock cost of ethanol	Rs/1000 Btu	0.74	1.48	3.17	5.13	1.06
Feedstock cost of ethanol	Rs/gallon	68.07	135.22	290.17	469.51	97.41
Break even price		1,105.59	12.17	26.11	42.25	3.57
Break even price of ethanol	Rs/gallon	215.22	256.13	411.08	590.42	218.33

Table 2b. Summary of feedstock and ethanol data (production, costs, gross revenues and net revenue): cellulosic feedstock (2007).

Item	Unit	Napier	Guinea grass	Eucalyptus	Leucaena
1. Land preparation					
Machinery	hour	1,549.32	1,549.32		
Hired labor	hour	1,297.03	1,297.03	81.34	90.40
Family labor	hour	417.39	417.39	8.13	9.04
2. Planting					
Cuttings	kg	382.26	382.26	3.56	3.95
Machinery	hour				
Hired labor	hour	940.94	940.94	36.61	40.68
Family labor	hour	470.47	470.47	12.20	13.56
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	3,300.00	6,600.00	10,800.00	10,800.00
Family labor	hour	3,900.00	7,800.00	4,000.00	4,000.00
Fertilizer					
a. Urea	kg				
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	3,600.00	7,200.00	2,275.42	2,301.26
Family labor	hour	2,700.00	5,400.00	1,706.56	1,725.94
5. Transportation					
Machinery	hour				
Hired labor	hour	750.00	1,500.00	474.05	479.43
Family labor	hour	600.00	1,200.00	379.24	383.54
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%	1,990.74	3,475.74	1,977.71	1,984.78
Total costs		21,898.14	38,233.14	21,754.82	21,832.59
A. Production					
Primary production (per acre)	ton	10.70	7.76	8.00	9.00
Gross revenue from feedstock	Rs/acre	21,400.00	15,520.00		

B. Net revenue					
Net revenue		-498.14	-22,713.14		
C. Production of ethanol					
1. Processing cost	Rs/gallon				
2. Total processing cost	Rs/acre	94,469.50	6,8512.46	78,580.43	84,766.50
3. Total production cost	Rs/acre	116,367.64	106,745.60	120,117.80	118,616.50
Gross revenue	Rs/acre	158,947.48	115,274.06	115,291.80	11,7912.07
D. Net revenue from ethanol					
Net revenue	Rs/acre	42,579.84	8,528.46	-4,826.00	-704.43
Feedstock cost of ethanol	Rs/1000 Btu	0.40	0.96	0.55	0.55
Feedstock cost of ethanol	Rs/gallon	36.67	88.28	50.23	50.41
Break even price of feedstock	Rs/ton	2,046.56	4,926.95	2,719.35	2,425.84
Break even price of ethanol	Rs/gallon	194.87	246.48	277.32	243.42

4.0 Conclusion and Policy Options

4.1 Summary

The analysis shows that sugarcane, corn, cassava, and cellulosic feedstocks are promising bioenergy sources. If Sri Lanka's goal toward energy self-sufficiency is to produce 10 percent of its transportation fuel from renewable resources, the required annual ethanol production would be 185,470,000 gallons/year. Consequently, 118,437 acres of the non-prime land (cultivable but abandoned) in Badulla and Monaragala districts would be sufficient to produce 64 percent of the target from napier; sugarcane would meet 56 percent; and the cellulosic feedstocks would cover 28-38 percent. Given the issues related to the availability of biofuel conversion technology, sugarcane, corn, and cassava can be considered in the short term as biofuel candidate crops while cellulosic feedstocks can be considered as long term prospective sources for ethanol production in Sri Lanka. In order to establish a sustainable biofuel production program, the technical, financial, and institutional challenges should be properly addressed.

4.2 Limitations of the Study

Before drawing inferences for policy options, it may be useful to note first the study's limitations. Foremost is that this research was confined to Badulla and Monaragala districts, due to limitation of resources to conduct field research in a wider geographical area. As such, the diverse and heterogeneous possibilities in biofuel production in a broader agro-climatic and socioeconomic situation were not fully captured. This diversity and heterogeneity should be considered in interpreting the results in a broader context. Also, adequate specifications and measurements of input and output variables are critical to the accuracy of estimation results. Information error is expected in studies of this nature. Although maximum effort was made to minimize errors, the possibility of making under- or over-valuation exists. Slight errors in original estimates may cause differences in the annual figures. Such errors were minimized by checking the internal consistency and re-checking the data. However, some errors and discrepancies are still unavoidable in a study of this nature. The lack of yield data of cellulosic feedstocks and specific biofuel conversion rates and associated costs under various technologies were one of the major obstacles in this study. This was overcome by investigating best available secondary data sources and applying appropriate adjustment factors to local conditions. Most of the data limitations can be overcome once locally developed biofuel production and extraction technology become available in the future.

4.3 Policy Options

In Sri Lanka, biofuel technology is relatively new, thus there is little information on potential biofuel crops, processing paths, and refineries, which contribute to the technical, financial, and institutional barriers biofuel production.

Though small-scale ethanol production from sugarcane molasses exists, the extraction pathways of most biofuel feedstocks are relatively new. The high investment cost for energy crops, establishment of extraction plants, transportation and postharvest logistic issues, uncertainty of biomass production, lack of experience or local research on conversion technologies are the major barriers in promoting biofuel production.

The financial barriers include high production cost, initial investment cost for large-scale mechanized biofuel crop production systems and plantations, difficulty in finding financial sources, and lack of subsidies.

The institutional barriers are the lack of a central agency that promotes biofuel research and production, potential conflicts that might arise among different agencies that are expected to coordinate with each other, and unavailability of extension service to biofuel crop growers.

The policy barriers are the lack of government policy that promotes biofuel production as the government continues to be in favor of conventional energy sources.

Sri Lanka's agricultural policy needs to address the emerging potential for large-scale bioenergy production in order to reduce the country's dependence on non-renewable sources of energy. One path to energy independence lies in the development of renewable energy technologies and policy, such as those that promote the expansion of biofuel production. However, the biofuel sector research and development in Sri Lanka is still in infancy. Sri Lanka needs to have a national strategic plan to overcome the barriers to biofuel production. Further, there is a need to identify short- and long-term strategies to promote sustainable biofuel production. Government and private sector participation is key to promoting biofuel plantations. Investment on research and development in biofuel production is also a necessary factor.

Biofuel production measures can be categorized as technical, financial, and institutional. The technical measures include identification of the most appropriate feedstock that result in the highest biofuel yield and net benefits. This would reduce the land area requirement for biofuel production. As the biofuel production technology is new, a complete package of information is needed for the growers. A decentralized, rural ethanol industry may favor a greater number of farmers over a wider area. Production credits for smaller ethanol facilities would also promote the formation of farmer-owned ethanol processing cooperatives that will give maximum benefits to the farmers. Farmer-managed ethanol processing cooperatives would be a better option than considering foreign/privately owned ethanol plants. There is need to put in place incentive programs that will promote regional, cooperative-owned biofuel production.

Financial incentives such as credit and subsidies are needed to encourage growers to produce energy crops at least at the initial stage of biofuel production. Over time, incentive programs may increase homegrown production of ethanol. An efficient market mechanism should be guaranteed to ensure the continuous supply of biofuel feedstocks.

The institutional measures for biofuel production may include having strong market ties between producers and growers to ensure that supply meets the demand, decentralization of extension service for easy access of growers to receive information, and securing land tenure for a continuous supply of biofuel feedstocks.

Information is a key factor in determining adoption and adaptation decisions. The problem of adoption is reduced to communicating information on the technology to the potential end users. A rational farmer will adopt a superior technology when information is available about how it is used and obtained, and the information suggests that actual results correspond to expected results. Hussian et al. (1994), Feder and Slade (1984), and Caviglia and Khan (2001) highlighted that information on new technology can increase the rate of adoption. As knowledge of the new technology increases, the rate of adoption is expected to increase. However, the spread of information in rural areas of developing countries can be difficult. This may be the case for rural farming communities in Sri Lanka. In such situation, agricultural extension plays an important role in the diffusion of a new technology.

Agricultural extension can play a major role in promoting biofuel crop production. Availability, effectiveness, and access to information and services are vital for rural agricultural development (Feder et al. 2004; Hussain and Perera 2004; Kularatne 1997). However, agricultural extension is not available on a regular basis for farming communities in the two study sites. Hence, a restructuring of agricultural extension is an urgent need in support of the future bioenergy initiative program.

Outreach and extension efforts may need to be refocused to reach rural farmers in order to improve their understanding of agricultural productivity and management of input use. Establishment of a cooperative extension system with closer integration of extension services offered by different institutions will increase the availability of assistance to rural communities. This type of policy change requires extra investment to strengthen agricultural extension. However, estimation of the actual cost to implement such a program is beyond the scope of this study.

In order to secure the benefits from biofuel feedstock production and to encourage rural households to invest in biofuel crop production, improved access to productive resources such as land is necessary. Insecurity in land titles may discourage rural households in forest margins from making long-term investments in land. As Scherr (2000) highlighted, property rights affect long-term agricultural productivity and incentives for conservation and investment in resource improvement. Therefore, policymakers should view land security issues as a necessary goal for the sustainability of biofuel production program.

4.4 Future Research

The complexity of biomass production systems requires a multidisciplinary approach that integrates information from different disciplines into a cohesive management system that can accurately predict seasonal feedstock production, economic profit, and risk under widely varying climatic, soil, land, and economic conditions. Therefore, continuous research on development of new methodologies and technologies to enhance the profitability, operational efficiency, and sustainability of the bioenergy industry is needed. This research should focus on the economics of feedstock for the production of ethanol. The assessment of net energy balance and the carbon balance of biofuel feedstock could not be completed in this research due to demand of resources and time constraints. There are a large number of underutilized crops including biodiesel crops that can be developed as biofuel feedstock, hence the research questions in the area of biofuel development are enormous. The environmental concerns associated with biofuel production are another potential area of research in the future.

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Appendix A

Table A.1. Energy consumption in Sri Lanka.

Category	Unit	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Local Sales											
Petrol (90 octane)	MT'000	2,638	2,835	3,303	3,305	3,375	3,419	3,747	4,243	3,553	3,802
Petrol (90 octane)	MT'000	204	213	220	244	277	375	417	526	454	487
Auto diesel	MT '000	1,224	1,377	1,715	1,675	1,728	1,663	1,890	1,882	1,633	1,752
Super diesel	MT '000	38	40	47	49	47	42	36	17	9	14
Kerosene	MT '000	236	243	229	228	229	207	204	252	206	168
Local Price											
Petrol (90 octane)	Rs/litre	50	50	50	50	49	53	48	80	92	117
Petrol (95 octane)	Rs/litre	55	53	53	53	52	56	71	83	95	120
Auto diesel	Rs/litre	13.20	13.20	24.50	26.50	30	32.00	42.00	50.00	60.00	75.00
Super diesel	Rs/litre	18.50	18.50	29.80	31.80	35.30	37.30	47.30	55.30	65.30	80.30
Kerosene	Rs/litre	10.40	10.40	18.40	17.,40	24.00	25.50	25.50	30.50	48.00	68.00

Source: Central Bank of Sri Lanka (2007)

Table A.2. Land use pattern by divisional secretariat division in Uva province (ha).

Division	Total	Paddy	Upland crops	Chena (slash and burn)	Cultivable	Cultivable but abandoned	River and tanks	Forests	Buildings, roads, grounds
Uva province	543,127	43,805	139,461	37,755	53,143	47,905	12,044	183,296	25,718
Badulla district	176,405	26,823	47,634	9,932	25,408	16,689	3,403	34,331	12,185
Badulla district	5,384	356	1,949	3	148	229	50	172	2,477
Soranatota	4,126	485	1,877	310	438	239	40	381	356
Meegahakiula	7,842	693	1,672	2,604	676	666	90	1,034	407
Kandaketiya	8,416	1,473	2,505	930	583	1,684	270	710	261
Rideemaliyadda	33,088	3,983	8,365	3,225	5,681	6,459	810	3,225	1,340
Mahiyangana	33,371	12,304	5,339	1,167	2,791	752	1,690	7,824	1,504
Passara	15,233	1,078	7,202	409	2,722	1,538	-	1,372	912
Hali-Ela	6,618	1,177	2,795	283	454	421	100	289	1,099
Ella	5,692	517	2,527	66	383	443	-	1,017	739
Bandarawela	3,257	557	1,418	33	367	76	10	225	571
Haputale	4,262	275	1,134	6	554	301	10	1,294	688
Haldummulla	31,416	801	4,847	196	9,640	3,453	80	11,844	555
Welimada	10,626	1,504	3,094	256	585	65	113	4,197	812
Uva Paranagama	7,074	1,620	2,910	444	386	363	140	747	464
Monaragala district	366,722	16,982	91,827	27,823	27,735	31,216	8,641	148,965	13,533
Monaragala	31,158	745	9,418	1,834	3,834	4,185	60	11,000	1,082
Wellawaya	42,661	1,623	16,193	5,689	1,280	3,441	400	12,467	1,568
Buttala	28,602	2,531	11,730	980	1,068	496	297	10,540	960
Thanamalwila	85,783	3,814	11,662	4,283	2,176	3,479	3,740	50,781	50,848
Bibila	30,412	1,441	6,529	1,391	3,634	2,844	285	13,623	665
Medagama	23,002	1,430	6,313	1,451	1,443	1,927	298	9,685	455
Badalkumbura	18,746	861	8,629	408	4,082	3,405	54	772	535
Siyambalanduwa	43,095	3,243	11,658	4,571	6,117	5,169	1,311	10,103	923
Madulla	36,800	965	7,017	4,648	3,281	5,070	1,660	13,279	880
Katharagama	25,463	329	2,678	2,568	820	1,200	536	16,715	617

Source: Establishment of Management Information System Survey (1997)

Table A.3. Ethanol requirement and land area needed to meet the different ethanol goals

Crop	Unit	Yield /acre	Ethanol yield gallons/acre	Non prime agriculture land area (acres)[a]	Total ethanol production potential (10^6 gl)	Ethanol goals (‘1000 gallons)			% as ethanol requirement meet under current production			Land area requirement to meet ethanol goals (‘’000 acres)		
						10%	15%	20%	10%	15%	20%	10%	15%	20%
Sugarcane	Tons	54.00	877.11	118,436.5	103.8	118,436.5	278,205	370,940	0.56	0.37	0.28	211	317	422
Corn	Kg	3,086.51	277.76	118,436.5	32.8	118,436.5	278,205	370,940	0.18	0.12	0.09	667	1001	1335
Sorghum	Kg	1,118.08	100.62	118,436.5	11.9	118,436.5	278,205	370,940	0.06	0.04	0.03	1843	2765	3686
Millet	Kg	481.42	43.32	118,436.5	5.1	118,436.5	278,205	370,940	0.03	0.02	0.01	4281	6421	8562
Cassava	Kg	12,053.13	441.51	118,436.5	52.2	118,436.5	278,205	370,940	0.28	0.19	0.14	420	630	840
Napier	Tons	10.70	597.15	118,436.5	70.7	118,436.5	278,205	370,940	0.38	0.25	0.19	310	465	621
Guinea grass	Tons	10.70	597.15	118,436.5	70.7	118,436.5	278,205	370,940	0.38	0.25	0.19	310	465	621
Eucalyptus	Tons	8.00	433.14	118,436.5	51.2	118,436.5	278,205	370,940	0.28	0.18	0.14	428	642	856
Leucaena	Tons	9.00	487.29	118,436.5	57.7	118,436.5	278,205	370,940	0.31	0.21	0.16	380	570	761

[a]Total unused land area (cultivable but abandoned) in Badulla and Monaragala districts

Appendix B

Table B.1. Sugarcane production costs and returns per planted acre (2007)

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	8.50	900.00	7,650.00	1,648.35
Hired labor	hour	8.00	50.00	400.00	86.19
Family labor	hour	16.00	50.00	800.00	172.38
2. Planting					
Cuttings	kg	4,089.00	2.65	10,835.85	2,334.81
Machinery	hour				
Hired labor	hour	54.00	48.50	2,619.00	564.32
Family labor	hour	34.00	50.00	1,700.00	366.30
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	36.00	50.00	1,800.00	1,800.00
Family labor	hour	92.00	47.50	4,370.00	4,370.00
Fertilizer					
a. Urea	kg	98.00	49.00	4,802.00	4,802.00
b. N:P:K (30:0:20 mixture)	kg	110.00	56.00	6,160.00	6,160.00
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	224.00	50.00	11200.00	11,200.00
Family labor	hour	52.00	47.50	2470.00	2,470.00
5. Transportation					
Machinery	hour	10.00	1750.00	17,500.00	17,500.00
Hired labor	hour	8.00	50.00	400.00	400.00
Family labor	hour	8.00	50.00	400.00	400.00
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%			7,310.69	5,427.43
Total costs				80,417.54	59,701.78
A. Production of Sugarcane					
Primary production (per acre)	ton	54.00			

Gross revenue from sugarcane	Rs/acre	54.00	1,750.00	94,500.00	94,500.00
B. Net revenue from Sugarcane					
Net revenue				14,082.47	34,798.22
C. Production of ethanol					
1. Processing cost	Rs/gallon		123.53		
2. Total processing cost	Rs/acre	877.11	123.53	108,353.7	108,353.70
3. Total production cost	Rs/acre			188,771.24	188,771.24
Gross revenue	Rs/acre	877.11	266.18	23,3465.9	233,465.90
D. Net revenue from ethanol					
Net revenue	Rs/acre			44,694.66	44,694.66
Feedstock cost of ethanol	Rs/1000Btu				0.74
Feedstock cost of ethanol	Rs/gallon				68.07
Break even price of sugarcane	Rs/ton				1,105.59
Break even price of ethanol	Rs/gallon				215.22

Notes: Sugarcane

1. Cost estimation is based on field level data.
2. Sugarcane planting cycle is every four years.
3. Ethanol per ton of sugarcane = 19.5 US gallons (Shapouri et al. 2006) = 16.24 UK gallons (conversion factor =0.83)
4. Conversion cost of ethanol from sugarcane = US$0.063/pound of raw sugar equivalent in 2005 prices. 1 gallon = 14.77 lb, therefore processing cost/gallon = 14.77 x 0.063 = US$0.93 (Shapouri et al. 2006). Inflating to 2007 prices = US$0.93 x 1.06 = US$0.98/US gallon (inflation factor = average US CPI 2005-2007) = US$1.18/UK gallon. Accordingly, conversion cost of ethanol from sugarcane = 123.53 rupees (US$1 = Rs. 105 in 2007).
5. Economic analysis was conducted for a 24-year period to represent complete crop cycles.
6. Operating overhead is assumed to be 10% of total operational cost.
7. Cost and revenue figures may differ slightly due to rounding off.
8. Energy per gallon (US) of ethanol = 76,300 Btu (Jaeger et al. 2007) =91,600 Btu (UK gallon)

Table B.2. Corn production costs and returns per planted acre (2007).

Category	Unit		Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation						
Machinery	hour		3.87	950.00	3,673.33	$3,673.33
Hired labor	hour		35.38	50.00	1,769.23	$1,769.23
Family labor	hour		40.14	48.93	1,964.13	$1,964.13
2. Planting						
Seeds	kg		5.12	426.67	2,183.11	$2,183.11
Machinery	hour					
Hired labor	hour		11.20	47.00	526.40	$526.40
Family labor	hour		23.43	48.57	1,137.96	$1,137.96
Chemicals	kg					
Other costs						
3. Other field operations						
Machinery	hour					
Hired labor	hour		92.91	47.73	4434.30	$4,434.30
Family labor	hour		126.50	48.21	6,099.11	$6,099.11
Fertilizer						
a. Urea	kg		126.00	48.87	6157.20	$6,157.20
b. N:P:K (30:0:20 mixture)	kg		38.33	54.00	2,070.00	$2,070.00
Herbicides	liter					
Pesticides						
a. Type 1	liter					
b. Type 2	liter					
Other costs						
4. Harvesting						
Machinery	hour					
Hired labor	hour		16.00	50.00	800.00	$800.00
Family labor	hour		22.67	44.44	1,007.41	$1,007.41
5. Transportation						
Machinery	hour		2.12	150.00	317.31	$317.31
Hired labor	hour		7.00	50.00	350.00	$350.00
Family labor	hour					
Other costs	hour					
5. Other operations			22.50	35.00	787.50	$787.50
6. Equipment			1.44	600.00	866.67	$866.67
7. Operation overhead		10%			3,414.37	3,414.37
Total costs					37,558.02	37,558.02
A. Production of corn						
Primary production (per acre)	kg		3,086.51			
Gross revenue from corn	Rs/acre		3,086.51	22.98	70934.57	$70,934.57
B. Net revenue from corn						
Net revenue					33,376.55	$33,376.55

C. Production of ethanol					
1. Processing cost	Rs/gallon		120.91		
2. Total processing cost	Rs/acre	277.76	120.91	33,584.06	$33,584.06
3. Total production cost	Rs/acre			71,142.08	71,142.08
Gross revenue	Rs/acre	277.76	266.17	73931.55	$73,931.55
D. Net revenue from ethanol					
Net revenue	Rs/acre			2,789.47	$2,879.47
Feedstock cost of ethanol	Rs/1000Btu				1.48
Feedstock cost of ethanol	Rs/gallon				135.22
Break even price of corn	Rs/ton				12.17
Break even price of ethanol	Rs/gallon				256.13

Notes: Corn

1. Cost estimation is based on field level data
2. Average labor cost for 2007 is Rs. 50 and Rs. 45 for male and female laborer respectively.
3. Cost of pesticide is zero since pesticides are not used in corn production.
4. Cost of other operations includes cost for protecting crop from wild boar.
5. Conversion cost of ethanol from corn = US$0.88/gallon in 1999 prices (McAloon et al. 2000). The processing cost was inflated to 2007 prices by a factor of 1.09 = US$0.985/gallon = US$1.15/UK gallon. Accordingly, conversion cost of ethanol from corn = 120.91 rupees (US$1 = 105 Rs in 2007).
6. Total per acre corn production is reported as pods/acre. The yield was converted to kg/acre using a factor of 4.5 (4.5 corn pods = 1kg).
7. The mean per acre yield from field survey data is higher than the estimates of the Department of Agriculture. However, the estimated yield is within the range of corn yield in tropical/subtropical areas (see Kinoshita et al. 2006).
8. Operating overhead is assumed to be 10% of total variable cost.
9. Although 2.5 crops per year can be grown, for the analysis, a single crop per year is assumed as irrigation is not available for year round cultivation.

8. Price of corn is estimated as US$6.00/bushel (import price)
9. Gallons of ethanol per bushel of corn = 2.75 (Kinoshita et al. 2006) = 0.09/kg
10. Cost and revenue figures may differ slightly due to rounding off.

Table B.3. Sorghum production costs and returns per planted acre (2007).

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	3.56	900.00	3,206.25	3,206.25
Hired labor	hour	65.08	50.00	3,253.85	3,253.85
Family labor	hour	74.40	50.00	3,720.00	3,720.00
2. Planting					
Seeds	kg	5.22	80.00	417.33	417.33
Machinery	hour				
Hired labor	hour	30.67	50.00	1,533.33	1,533.33
Family labor	hour	31.08	46.92	1,458.22	1,458.22
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	48.00	50.00	2,400.00	2,400.00
Family labor	hour	82.13	46.67	3,832.89	3,832.89
Fertilizer					
a. Urea	kg	50.00	49.25	2462.50	2462.50
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	0.50	210.00	105.00	105.00
Family labor	hour				
5. Transportation					
Machinery	hour	64.00	48.33	3,093.33	3,093.33
Hired labor	hour	0.50	210.00	105.00	105.00
Family labor	hour				
Other costs	hour				
5. Other operations		19.08	50.00	953.85	953.85
6. Equipment					
7. Operation overhead	10%			2,654.16	2,654.16
Total costs				29,195.71	29,195.71
A. Production of Sorghum					
Primary production (per acre)	kg	1,118.08			
Gross revenue from Sorghum	Rs/acre	1,118.08	41.00	4,5841.15	4,5841.15

B. Net revenue from sorghum					
Net revenue				16,645.44	16,645.44
C. Production of ethanol					
1. Processing cost	Rs/gallon		120.91		
2. Total processing cost	Rs/acre	100.62	120.91	12,165.71	1,2165.71
3. Total production cost	Rs/acre			41,361.42	41,361.42
Gross revenue	Rs/acre	100.62	266.18	26781.45127	2,6781.45
D. Net revenue from ethanol					
Net revenue	Rs/acre			-14,579.97	-14,579.97
Feedstock cost of ethanol	Rs/1000Btu				3.17
Feedstock cost of ethanol	Rs/gallon				290.17
Break even price of sorghum	Rs/ton				26.11
Break even price of ethanol	Rs/gallon				411.08

Notes: Grain sorghum

1. Cost estimation is based on field level data.
2. Cost of pesticide is zero since pesticides are not used in sorghum production.
3. Cost of other operations includes cost for protecting crop from wild boar.
4. Conversion cost of ethanol from grain sorghum is assumed to be the same as ethanol produced from corn (starch feedstock). Processing cost of ethanol from corn = US$0.88/gallon in 1999 prices (McAloon et al. 2000). The processing cost was inflated to 2007 prices by a factor of 1.09 = US$0.985/gallon = US$1.15/UK gallon. Accordingly, conversion cost of ethanol from sorghum = 120.91 rupees (US$1 = 105 Rs in 2007).
5. Operating overhead is assumed to be 10% of total variable cost.
6. Although 3 crops can be grown per year, for the analysis, a single crop per year is assumed as irrigation is not available for year round cultivation.
7. Gallons of ethanol per bushel of field sorghum = 2.75 (Kinoshita et al. 2006) = 0.09 /kg
8. Cost and revenue figures may differ slightly due to rounding off.

Table B.4. Millet production costs and returns per planted acre (2007).

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	2.79	900.00	2,507.14	2,507.14
Hired labor	hour	29.09	49.55	1,441.32	1,441.32
Family labor	hour	62.25	49.06	3,054.14	3,054.14
2. Planting					
Seeds	kg	5.17	51.25	265.06	265.06
Machinery	hour				
Hired labor	hour	6.50	50.00	325.00	325.00
Family labor	hour	17.43	48.21	840.31	840.31
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	26.67	48.89	1,303.70	1,303.70
Family labor	hour	44.50	47.50	2,113.75	2,113.75
Fertilizer					
a. Urea	kg				
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	18.91	47.27	893.88	893.88
Family labor	hour	32.50	46.88	1,523.44	1,523.44
5. Transportation					
Machinery	hour	2.20	150.00	330.00	330.00
Hired labor	hour	4.00	50.00	200.00	200.00
Family labor	hour				
Other costs	hour				
5. Other operations		13.50	93.33	1,260.00	1,260.00
6. Equipment		1.54	618.08	950.89	950.89
7. Operation overhead	10%			1,700.86	1,700.86
Total costs				18,709.50	18,709.50
A. Production of millet					
Primary production (per acre)	kg	442.81			
Gross revenue from millet	Rs/acre	442.81	40.75	18,044.61	18,044.61
B. Net revenue from millet					
Net revenue					-664.89

C. Production of ethanol					
1. Processing cost	Rs/gallon		120.91		
2. Total processing cost	Rs/acre	39.85	120.91	4,818.21	4,818.21
3. Total production cost	Rs/acre			23,527.71	23,527.71
Gross revenue	Rs/acre	39.85	266.175	10,606.74	10,606.75
Net revenue	Rs/acre			-12,920.96	-12,920.96
Feedstock cost of ethanol	Rs/1000Btu				5.13
Feedstock cost of ethanol	Rs/gallon				469.51
Break even price of millet	Rs/ton				42.25
Break even price of ethanol	Rs/gallon				590.42

Notes: Millet

1. Cost estimation is based on field level data.
2. Cost of pesticide is zero since pesticides are not used in millet production.
3. Cost of other operations includes cost for protecting crop from wild boar.
4. Conversion cost of ethanol from millet is assumed to be the same as ethanol produced from corn (starch feedstock). Processing cost of ethanol from corn = US$0.88/gallon in 1999 prices (McAloon et al. 2000). The processing cost was inflated to 2007 prices by a factor of 1.09 = US$0.985/gallon = US$1.15/UK gallon. Accordingly, conversion cost of ethanol from millet = 120.91 rupees (US$1 = 105 Rs in 2007).
5. Operating overhead is assumed to be 10% of total variable cost.
6. Gallons of ethanol per kg of millet = 0.09.
7. Cost and revenue figures may differ slightly due to rounding off.

Table B.5. Cassava production costs and returns per planted acre (2007).

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	5.84	843.75	4,930.66	4,930.66
Hired labor	hour	40.80	46.67	1,904.00	1,904.00
Family labor	hour	61.00	46.56	2,840.31	2,840.31
2. Planting					
Seeds	kg	7487.50	1.41	10,529.30	10,529.30
Machinery	hour				
Hired labor	hour	20.73	45.45	942.15	942.15
Family labor	hour	32.63	46.88	1,529.30	1,529.30
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	49.20	38.00	1,869.60	1,869.60
Family labor	hour	77.38	46.25	3,578.59	3,578.59
Fertilizer					
a. Urea	kg	54.69	44.81	2,450.68	2,450.68
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	62.40	46.67	2,912.00	2,912.00
Family labor	hour	78.56	46.88	3,682.62	3,682.62
5. Transportation					
Machinery	hour	2.03	234.38	476.07	476.07
Hired labor	hour	13.00	45.83	595.83	595.83
Family labor	hour				
Other costs	hour				
5. Other operations					
6. Equipment		1.40	612.67	857.73	857.73
7. Operation overhead	0.10			3,909.89	3,909.89
Total costs				43,008.74	43,008.74
A. Production of cassava					
Primary production (per acre)	kg	12,053.13			
Gross revenue from cassava	Rs/acre	12,053.13	6.56	79,098.63	79,098.63
B. Net revenue from cassava					
Net revenue				36,089.89	36,089.89

C. Production of ethanol					
1. Processing cost	Rs/gallon		120.91		
2. Total processing cost	Rs/acre	441.51	120.91	53,383.58	53,383.58
3. Total production cost	Rs/acre			96,392.32	96,392.32
Gross revenue	Rs/acre	441.51	266.18	117,517.97	117,517.97
D. Net revenue from ethanol					
Net revenue	Rs/acre			21,125.65	21,125.65
Feedstock cost of ethanol	Rs/1000Btu				1.06
Feedstock cost of ethanol	Rs/gallon				97.41
Break even price of cassava	Rs/ton				3.57
Break even price of ethanol	Rs/gallon				218.33

Notes: Cassava

1. Cost estimation is based on field level data
2. Cost of pesticide is zero since pesticides are not used in corn production.
3. Conversion cost of ethanol from cassava is assumed to be the same as ethanol produced from corn (starch feedstock). Processing cost of ethanol from corn = US$0.88/gallon in 1999 prices (McAloon et al. 2000). The processing cost was inflated to 2007 prices by a factor of 1.09 = US$0.985/gallon = US$1.15/UK gallon. Accordingly, conversion cost of ethanol from cassava = 120.91 rupees (US$1 = 105 Rs in 2007).
4. The mean per acre yield from field survey data is higher than the estimates of the Department of Agriculture. Cassava tuber yield in tropical/subtropical areas is typically 33 tons/acre (Kinoshita et al. 2006), hence the estimated yield is within the range of cassava yield in tropical/subtropical areas.
5. Operating overhead is assumed to be 10% of total variable cost.
6. Although 3 crops per year can be grown, for the analysis, a single crop per year is assumed.
7. Gallons of ethanol per kg/cassava = 0.04 (6kg of cassava produces 1 liter of ethanol)
8. Cost and revenue figures may differ slightly due to rounding off.

Table B.6. Napier production costs and returns per planted acre (2007).

Category	Unit	Quantity (per crop)	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	5.50	958.00	5,269.00	1,549.32
Hired labor	hour	88.22	50.00	4,411.00	1,297.03
Family labor	hour	28.39	50.00	1,419.50	417.39
2. Planting					
Cuttings	kg	650.00	2.00	1300.00	382.26
Machinery	hour				
Hired labor	hour	64.00	50.00	3,200.00	940.94
Family labor	hour	32.00	50.00	1,600.00	470.47
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	44.00	50.00	3,300.00	3,300.00
Family labor	hour	52.00	50.00	3,900.00	3,900.00
Fertilizer					
a. Urea	kg				
b. TDM	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	48.00	50.00	3,600.00	3,600.00
Family labor	hour	36.00	50.00	2,700.00	2,700.00
5. Transportation					
Machinery	hour				
Hired labor	hour	10.00	50.00	750.00	750.00
Family labor	hour	8.00	50.00	600.00	600.00
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%			3204.95	1990.74
Total costs				35,254.45	21,898.14
A. Production of napier					
Primary production (per acre)	tons	10.70			
Gross revenue from napier	Rs/acre	10.70	2,000.00	21,400.00	21,400.00

B. Net revenue from napier					
Net revenue				-13854.45	-498.14
C. Production of ethanol					
1. Processing cost	Rs/gallon		158.20		,
2. Total processing cost	Rs/acre	597	158.20	94,469.498	94,469.50
3. Total production cost	Rs/acre			129,723.95	116,367.64
Gross revenue	Rs/acre	597.15	266.17	158,947.48	158,947.48
C. Net revenue from ethanol					
Net revenue	Rs/acre			29223.54	42579.84
Feedstock cost of ethanol	Rs/1000Btu				0.40
Feedstock cost of ethanol	Rs/gallon				36.67
Break even price of napier	Rs/ton				2,046.56
Break even price of ethanol	Rs/gallon				194.87

Notes: Napier

1. Cost of production data is based on secondary data sources and personal communication with animal science experts.
2. Average price of a ton of dry matter (1000 x Rs. 2/kg) was based on the assumption that price of dry matter (straw) = Rs. 2 (personal communication with livestock farmers)
3. Ethanol yield for a ton of napier dry matter (67 US gallons) was based on Gieskes and Hackett (2003). This was converted to UK gallon using a factor of 0.83.
4. The harvesting cycle of napier is assumed to take 8 months (1.5 crops/acre/year).
5. Conversion cost of ethanol from napier is assumed to be the same as ethanol produced from corn stover. Total processing ethanol from lignocellulose source like corn stover = US$1.50/gallon less US$0.49 stove cost/gallon (McAloon et al. 2000) = US$1.01/gallon (in 1999 prices).The processing cost was inflated to 2007 prices by a factor of 1.24 = US$1.255 (US CPI average 1999-2007) = US$1.04/UK gallon. Accordingly, conversion cost of ethanol from napier = 158.20 rupees (US$1 = 105 Rs in 2007).
6. Operating overhead is assumed to be 10% of total operational cost.
7. Cost and revenue figures may differ slightly due to rounding off.
8. Energy per gallon of ethanol = 76,300 Btu (Jaeger et al. 2007) = 91,600 Btu (UK gallon)

Table B.7. Guinea grass production costs and returns per planted acre (2007).

Category	Unit	Quantity (per crop)	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour	5.50	958.00	5,269.00	1,549.32
Hired labor	hour	88.22	50.00	4,411.00	1,297.03
Family labor	hour	28.39	50.00	1,419.50	417.39
2. Planting					
Cuttings	kg	650.00	2.00	1,300.00	382.26
Machinery	hour				
Hired labor	hour	64.00	50.00	3,200.00	940.94
Family labor	hour	32.00	50.00	1,600.00	470.47
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	44.00	50.00	6,600.00	6,600.00
Family labor	hour	52.00	50.00	7,800.00	7,800.00
Fertilizer					
a. Urea	kg				
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	48.00	50.00	7,200.00	7,200.00
Family labor	hour	36.00	50.00	5,400.00	5,400.00
5. Transportation					
Machinery	hour				
Hired labor	hour	10.00	50.00	1,500.00	1,500.00
Family labor	hour	8.00	50.00	1,200.00	1,200.00
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%			4,689.95	3,475.74
Total costs				51,589.45	38,233.14
A. Production of guinea grass					
Primary production (per acre)	tons	7.76			
Gross revenue from guinea grass	Rs/acre	7.76	2,000.00	15,520.00	15,520.00
B. Net revenue from guinea grass					
Net revenue				-36,069.45	-22,713.14

C. Production of ethanol					
1. Processing cost	Rs/gallon		158.20		
2. Total processing cost	Rs/acre	433.08	158.20	68,512.458	68,512.46
3. Total production cost	Rs/acre			120,101.91	106,745.60
Gross revenue	Rs/acre	433.08	266.18	115,274.0628	115,274.06
D. Net revenue from ethanol					
Net revenue	Rs/acre			-4,827.85	8,528.46
Feedstock cost of ethanol	Rs/1000Btu				0.96
Feedstock cost of ethanol	Rs/gallon				88.28
Break even price of guinea grass	Rs/ton				4,926.95
Break even price of ethanol	Rs/gallon				246.48

Notes: Guinea grass

1. In estimating production costs, napier was used as an analog crop for guinea grass (see Kinoshita et al. 1999 for a similar assumption).
2. Average price of a ton of dry matter (1000 x Rs. 2/kg) was based on the assumption that price of dry matter (straw) = Rs. 2 (personal communication with livestock farmers).
3. Ethanol yield for a ton of guinea grass dry matter (67 gallons) was based on Gieskes and Hackett (2003). This was converted to US$/gallon (UK) using a factor of 0.83.
4. The harvesting cycle of guinea grass is assumed to take 3 months.
5. According to Kinoshita et al. (2006), green matter yields of 38.8 and 55.8 tons/acre/year have been obtained from unfertilized stand and well manured/fertilized stands, respectively. Based on the yield data of unfertilized stand, estimated dry matter yield of guinea grass is 7.76 tons/acre/year (38.8 tons/acre/year x 20%). It is assumed that dry matter content = 20% of green matter.
6. Conversion cost of ethanol from guinea grass is assumed to be the same as ethanol produced from corn stover. Total processing ethanol from lignocellulose source like corn stover = US$1.50/gallon less US$0.49 stover cost/gallon (McAloon et al. 2000) = US$1.01/gallon (in 1999 prices).The processing cost for ethanol processing inflated to 2007 prices by a factor of 1.24 = US$ 1.255 (US CPI average 1999-2007) = US$1.04/UK gallon. Accordingly, conversion cost of ethanol from guinea grass = 123.53 rupees (US$1 = 105 Rs in 2007).
7. Operating overhead is assumed to be 10% of total operational cost.
8. Cost and revenue figures may differ slightly due to rounding off.
9. Energy per gallon of ethanol = 76,300 Btu (Jaeger et al. 2007) = 91,600 Btu (UK gallon)

Table B.8 Eucalyptus production costs and returns per planted acre (2007).

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour				
Hired labor	hour	160.00	50.00	8,000.00	81.34
Family labor	hour	16.00	50.00	800.00	8.13
2. Planting					
Cuttings	seed	7.00	50.00	350.00	3.56
Machinery	hour				
Hired labor	hour	72.00	50.00	3,600.00	36.61
Family labor	hour	24.00	50.00	1,200.00	12.20
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	216.00	50.00	10,800.00	10,800.00
Family labor	hour	80.00	50.00	4,000.00	4,000.00
Fertilizer					
a. Urea	kg				
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	48.00	50.00	2400.00	2,275.42
Family labor	hour	36.00	50.00	1800.00	1,706.56
5. Transportation					
Machinery	hour				
Hired labor	hour	10.00	50.00	500.00	474.05
Family labor	hour	8.00	50.00	400.00	379.24
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%			3,385.00	1,977.71
Total costs				37,235.00	21,754.82
A. Production of Eucalyptus					
Primary production (per acre)	tons	8.00			
Gross revenue from Eucalyptus	Rs/acre	8.00			
B. Net revenue from eucalyptus					
Net revenue					

C. Production of ethanol					
1. Processing cost	Rs/gallon		191.35		
2. Total processing cost	Rs/acre	433.14	191.35	82,882.80	78,580.43
3. Total production cost	Rs/acre			120,117.80	120,117.80
Gross revenue	Rs/acre	433.14	266.18	115,291.8	115,291.80
D. Net revenue from ethanol					
Net revenue	Rs/acre			-4,826.00	-4826.00
Feedstock cost of ethanol	Rs/1000Btu				0.55
Feedstock cost of ethanol	Rs/gallon				50.23
Break even price of Eucalyptus	Rs/ton				2,719.35
Break even price of ethanol	Rs/gallon				277.32

Notes: Eucalyptus

1. Cost of production data is based on production data from the Department of Forest Conservation of Sri Lanka and personal communication with forest officials.
2. Operating overhead is assumed to be 10% of total operational cost.
3. Eucalyptus yield is assumed at 8 tons/acre/year. According to Kinoshita et al. (2006), Eucalyptus on good sites produces 9-12 tons/acre/year; the worldwide production is about 11 tons/acre/year.
4. A 25-year rotation period is assumed for Eucalyptus.
5. Harvesting of Eucalyptus for ethanol production is done every 5 years.
6. In calculating ethanol yield, it is assumed that on average 1 ton of dry matter yields 65 gallons of ethanol = 54.14 UK gallons.
7. Revenue from eucalyptus (feedstock) was not estimated as there is no market price for chips.
8. Conversion cost of ethanol from Eucalyptus (wood based ethanol) = US$98.7/ dry ton (in 2006 prices) (Jaeger et al. 2007). This cost is converted to per gallon of ethanol and 2007 prices as follows: cost/gallon = US$98.7/65 = US$1.518/gallon x 1.032 (average CPI West urban for Oregon 2006-2007) = US$1.39/UK gallon. Accordingly, conversion cost of ethanol from Eucalyptus = 191.35 rupees (US$1 = 105 Rs in 2007).
9. Operating overhead is assumed to be 10% of total operational cost.
10. Cost and revenue figures may differ slightly due to rounding off.
11. Energy per gallon of ethanol = 76,300 Btu (Jaeger et al. 2007) =. 91,600 Btu (UK gallon)

Table B.9. Leucaena production costs and returns per planted acre (2007).

Category	Unit	Quantity	Rs/unit	Cost and Revenue 2007 (Rs./acre)	Annual equivalent cost and revenue (Rs./acre)
1. Land preparation					
Machinery	hour				
Hired labor	hour	160.00	50.00	8,000.00	90.40
Family labor	hour	16.00	50.00	800.00	9.04
Other					
2. Planting					
Cuttings	kg	7.00	50.00	350.00	3.95
Machinery	hour				
Hired labor	hour	72.00	50.00	3,600.00	40.68
Family labor	hour	24.00	50.00	1,200.00	13.56
Chemicals	kg				
Other costs					
3. Other field operations					
Machinery	hour				
Hired labor	hour	216.00	50.00	10,800.00	10,800.00
Family labor	hour	80.00	50.00	4,000.00	4,000.00
Fertilizer					
a. Urea	kg				
b. N:P:K (30:0:20 mixture)	kg				
Herbicides	liter				
Pesticides					
a. Type 1	liter				
b. Type 2	liter				
Other costs					
4. Harvesting					
Machinery	hour				
Hired labor	hour	48.00	50.00	2,400.00	2,301.26
Family labor	hour	36.00	50.00	1,800.00	1,725.94
5. Transportation					
Machinery	hour				
Hired labor	hour	10.00	50.00	500.00	479.43
Family labor	hour	8.00	50.00	400.00	383.54
Other costs	hour				
5. Other operations					
6. Equipment					
7. Operation overhead	10%			3,385.00	1,984.78
Total costs				37,235.00	21,832.59
A. Production of Leucaena					
Primary production (per acre)	tons	9.00			
Gross revenue from Leucaenas	Rs/acre	9.00			
B. Net revenue from Leucaena					

Net revenue					
C. Production of ethanol					
1. Processing cost	Rs/gallon		191.35		
2. Total processing cost	Rs/acre	487	191.35	93,243.15	84,766.50
3. Total production cost	Rs/acre			130,478.15	118,616.50
Gross revenue	Rs/acre	487.29	266.18	129,703.27	117,912.07
D. Net revenue from ethanol					
Net revenue	Rs/acre			-774.87	-704.43
Feedstock cost of ethanol	Rs/1000Btu				0.55
Feedstock cost of ethanol	Rs/gallon				50.41
Break even price of Leucaena	Rs/ton				2,425.84
Break even price of ethanol	Rs/gallon				243.42

Notes: Leucaena

1. In estimating production costs, Eucalyptus was used as an analog crop for Leucaena (see Kinoshita et al. 1999 for a similar assumption).
2. Leucaena dry matter yield is assumed to be 9 tons/acre/year. Kinoshita et al. (2006) estimated Leucaena yield at 13 tons/acre/year; yield up to 25 tons/acre/year is possible on agricultural soils.
3. A 24-year rotation period is assumed for Leucaena.
4. Harvesting of Leucaena for ethanol production is done every 4 years.
5. In calculating ethanol yield, it is assumed that on average 1 ton of dry matter yields 65 gallons of ethanol = 54.14 UK gallons
6. Conversion cost of ethanol from Leucaena (wood based ethanol) = US$98.7/ dry ton (in 2006 prices) (Jaegee et al. 2007). This cost is converted to per gallon of ethanol and 2007 prices as follows: cost/gallon = US$98.7/65 = US$1.518/gallon x 1.032 (average CPI West urban for Oregon 2006-2007) = US$1.39/UK gallon. Accordingly, conversion cost of ethanol from Leucaena = 191.35 rupees (US$1 = 105 Rs in 2007).
7. Operating overhead is assumed to be 10% of total operational cost.
8. Cost and revenue figures may differ slightly due to rounding off.
9. Energy per gallon of ethanol = 76,300 Btu (Jaeger et al. 2007) = 91,600 Btu (UK gallon)