

## Energy Analysis of Biodiesel from Jatropha

Ajay Varadharajan<sup>1</sup>, Venkateswaran W.S.<sup>1</sup>& Prof. Rangan Banerjee<sup>2</sup>

<sup>1</sup> Department of Mechanical Engineering, National Institute of Technology Trichy620015, India.  
Email [ajayvrajan@gmail.com](mailto:ajayvrajan@gmail.com), [ws.venkateswaran@gmail.com](mailto:ws.venkateswaran@gmail.com)

<sup>2</sup> Department of Energy Science and Engineering, IIT Bombay, Powai, Mumbai-400076, India  
Tel:91-22-25767883 Fax:91-22-25726875 Email [rangan@iitb.ac.in](mailto:rangan@iitb.ac.in)

### 1 Introduction

The increasing demand for petroleum based fuels, global warming and environmental pollution has driven the world to search for newer, safer and cleaner sources of fuel. Also, the transportation sector in India is dependant on petroleum and other non-renewable sources of energy. In view of the increased attention to climate change, there is a renewed focus on alternative fuels. The annual consumption of petroleum in India is 175 million metric tonnes as compared to the production of 33 million metric tonnes [1]. Thus India imports more than 80% of its oil. Development of bio-fuels as an alternative and renewable source of energy for transportation has become critical in India's effort towards maximum self-reliance.

Fuels like corn ethanol and soybean oil have been identified as possible alternatives for petroleum fuels. A joint study by the U.S departments of agriculture and energy [2] in 1998 has shown that the fossil energy ratio (ratio of energy output to the fossil energy input) for soybean biodiesel is 3.2. A similar study done by Malca et. al. [3], reveals that the energy output for wheat-based ethanol exceeds the fossil energy input and production is viable from an energy point of view. On the other hand, a study of biodiesel obtained from methanol by Pimentel et. al. [4] shows that net energy value is less than 1. This implies that the fossil energy input for methanol biodiesel is more than the output energy it can provide.

A national mission to produce Bio diesel from Jatropha (13 million tones annually by 2013), has been launched as an initiative of the Indian government to address socio-economic and environmental concerns. Jatropha curcas has been identified as the most suitable crop for this purpose. It is a small tree or shrub with a smooth gray bark. Normally, it grows between three and five meters in height. The seeds become mature when the capsule changes from

green to yellow, after two to four months from fertilization. Jatropha curcas gives a high oil yield, can grow in the harshest of conditions and has properties similar to diesel. In addition to this, it provides rich bio mass and nutrients to the soil and checks degradation of land. In India land degradation is a major problem affecting nearly 65 million hectares of land [5]. The Indian government has identified 13.4 million hectares of land suitable for Jatropha cultivation. A pilot project covering 0.4 million hectares has been launched in many states as shown in Fig 1 [5].

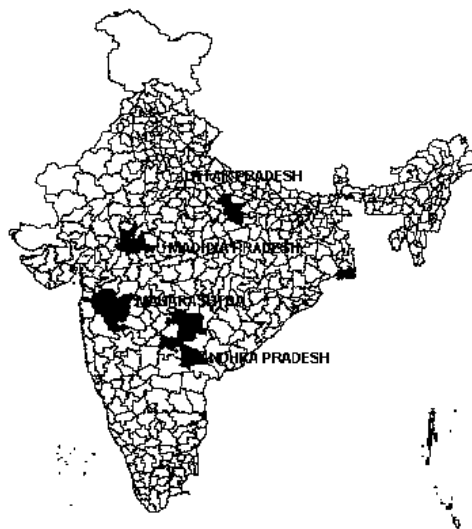


Fig 1. Area allotted for pilot project for Jatropha cultivation.

A comprehensive study of energy efficiency of jatropha biodiesel is required, before starting a large-scale production, especially in view of the conflicting reports of energy efficiency of various other biofuels done in other countries.

The production of Jatropha oil, its processing and production of biodiesel are analyzed for poor, normal and fertile soils. The criterion used is the net energy ratio (NER) defined as the ratio of the energy output to the fossil (non-renewable) energy input supplied. For

viability, the NER must be greater than one. This paper evaluates the viability of biodiesel production from the perspective of energy analysis.

## 2 Methodology

This section presents the modeling of life cycle inventory for jatropha biodiesel in India. In order to do this, a second order life cycle analysis has been followed. This includes agriculture, transport and industrial conversion stages but excludes the capital goods. An inventory of material and energy flows for each sub-process has been calculated and NER has been determined. The functional unit considered is 50 litres of raw jatropha oil.

The byproducts of jatropha are oil cake and glycerol that have commercial value. The by products of biodiesel production cannot be directly used. They need further processing. Based on this, the NER can be calculated following three approaches. a) Without allocation- used when technology is not available for processing b) allocation by mass c) allocation by energy – both mass and energy can be done when the by products of biodiesel production are processed and used. In this paper, determination of NER without allocation is done by taking biodiesel as the only output. The input parameters used were obtained from literature and from a pilot biodiesel plant at the Indian Institute of Technology-Bombay, India. The specifications of the pilot plant are given in Table 1.

Table 1. Specifications of jatropha pilot plant

Type	Batch processing
Capacity	50 lit of raw oil/batch
Rating of crusher	7500 W, 50 kg seeds/hr
Rating of motor	750 W
Rating of chiller	1 ton

## 3 Inventory

Fig. 2 shows the flow of processes involved in jatropha biodiesel production. The primary energy efficiencies for electricity and diesel production are 33% and 83% respectively [11]. NER is critically dependent on various parameters like type of soil, oil content, specific energy consumptions of fertilizers and

manure, production energy of methanol and irrigation facilities. Table 2 shows the parameters involved in the production of jatropha biodiesel. Table 3 shows the year round irrigation requirement for jatropha plantation

Table 2. Parameters affecting Net Energy Ratio

	Parameter	Value
1	Input energy for all agricultural operations [5]	1323MJ/ha
2	Oil content/seed [5]	26.6-35.5 %
3	Amount of urea [6]	20g/plant
4	Amount of single superphosphate(SSP) [6]	120g/plant
5	Amount of muriate of potash(MOP) [6]	60g/plant
6	Amount of farm yard manure(FYM) [6]	50kg/ha
7	Amount of methanol used	10 lit/batch
8	SEC* of urea [7]	42-79.5 MJ/kg
9	SEC of SSP [7]	6.8 MJ/kg
10	SEC of MOP [7]	1.5-6 MJ/kg
11	SEC of FYM [8]	47.9 MJ/kg
12	SEC of methanol [9]	30 MJ/kg

\*SEC- Specific energy consumption

Table 3. Evapotranspiration and rainfall data (All data in mm) [10]

Month	ET <sup>+</sup>	Rainfall	Rainfall after run off	Irrigation required
Jan	32	0	0	32
Feb	19	0	0	19
Mar	55	45	31.5	23.5
Apr	67	129	90.3	0
May	104	50	35	69
Jun	61	59	41.3	19.7
Jul	51	154	107.8	0
Aug	128	196	137.2	0
Sep	103	202	141.4	0
Oct	91	43	30.1	60.9
Nov	47	17	11.9	35.1
Dec	42	0	0	42
TOTAL (assuming 30% run off) is 430.7				

<sup>+</sup>ET- Evapotranspiration

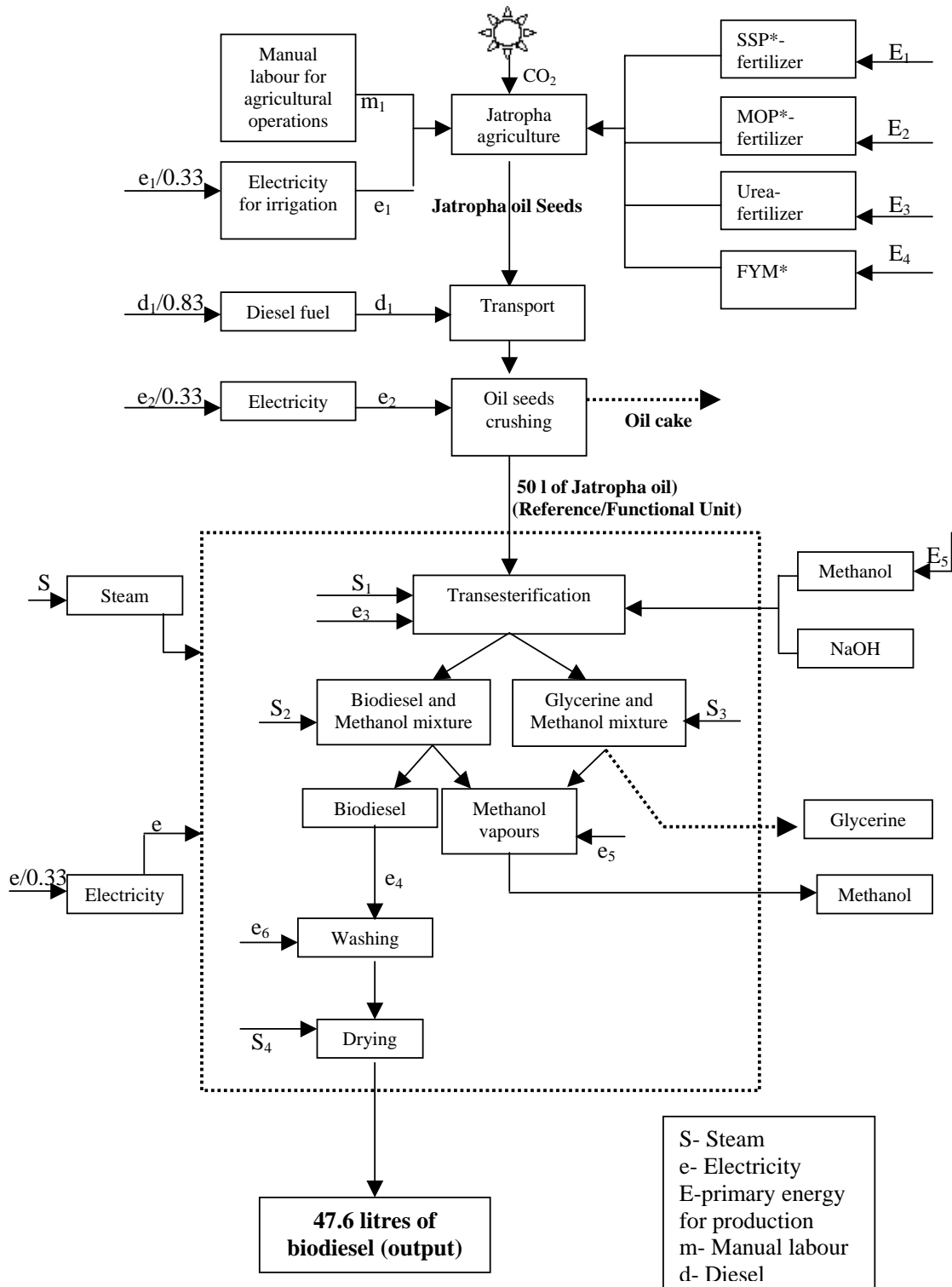


Fig.2. Flow chart showing the stages of Bio-diesel production from Jatropha plants.

- \*SSP- Single super phosphate
- \*MOP- Muriate of potash
- \*FYM- Farm yard manure

The plant density and number of seeds per plant vary with the type of soil. Assuming 30% oil content, the oil yield varies as shown in Tables 4 and 5, depending on whether irrigation has been provided or not [6].

Table 4. Variation of yield – non irrigated soil

	Poor soil	Normal soil	Fertile soil
Population/ha	3330	2500	1670
Seeds/plant	0.2	1	1.5-2.5
Oil yield (kg/ha)	200	750	750-1250

Table 5. Variation of yield- irrigated soil

	Poor soil	Normal soil	Fertile soil
Population/ha	3330	2500	1670
Seeds/plant	0.5	2.5	3.75-5
Oil yield (kg/ha)	500	1875	1875-2500

Industrial transesterification typically consists of the following processes - Oil is pumped to the transesterifier. Methoxide is separately prepared by mixing methanol and caustic soda. Excess methanol is added to ensure high yield and reasonable reaction times. The production energy for caustic soda is negligible as very small quantity is used. This methoxide is transferred to the transesterifier and the mixture is heated and stirred for sufficient amount of time. The mixture is now allowed to settle. Thus, biodiesel and glycerine get separated. The excess methanol present in biodiesel and glycerine are extracted by distillation and the methanol vapours are condensed and reused. The biodiesel is washed with hot water and dried. All pumping and stirring processes are done using a motor. All heating processes use steam.

#### 4 Case Study

Since NER varies significantly with various parameters a case study is performed taking specific values within the ranges shown in inventory. Table 6 shows these specific values. The energy inputs for each process for these specific conditions is shown in Table 7. The contribution of each operation to the total input energy is shown as a pie chart in Fig. 3a. For the same parameters, for non-irrigated conditions, the input energy breakup is shown as a pie chart in Fig. 3b.

Table 6. Parameters considered for case study

	Parameter	Value
1	Type of soil	Normal
2	Irrigation	required
3	Oil content	31 %
4	SEC of Muriate of potash	6 MJ/kg
5	SEC of urea	79.5 MJ/kg

Table 7. Inventory table for the case study

Symbol	Process	Energy	
$m_1$	Manual labour for agricultural operations	31.8 MJ	
$e_1$	Electricity for irrigation	71.7 kWh	
$d_1$	Diesel for transportation	6.6 MJ	
$e_2$	Electricity for crushing	68.2 kWh	
$e = e_3 + e_4 + e_5 + e_6$	Total electricity used during conversion process	3.95 kWh	
$S = S_1 + S_2 + S_3 + S_4$	Total steam used during conversion process	300 MJ	
$E_1$	Primary energy for production of	SSP	48 MJ
$E_2$		MOP	21 MJ
$E_3$		Urea	94 MJ
$E_4$		FYM	57 MJ
$E_5$		Methanol	238 MJ

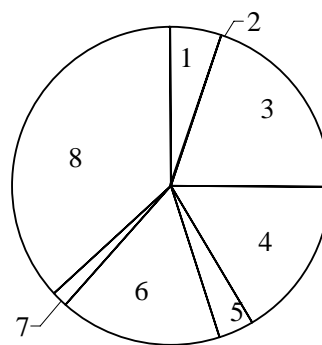


Fig.3a. A pie chart- input energy breakup (in MJ, %) for non-irrigated conditions

The reduced yield due to lack of irrigation leads to an appreciable increase in the area of cultivated land, thus increasing the fertilizer and manure requirement. This is evident from Fig.3a and Table 8, where the contribution of primary energy of fertilizers and manure constitutes almost 40% of the total energy input.

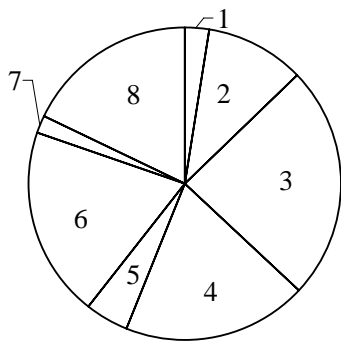


Fig.3b. A Pie chart- input energy breakup (in MJ, %) for irrigated conditions  
Table 8. Input energy breakup as depicted in the pie charts

	Energy contributor	Irrigated		Non-irrigated	
		MJ	%	MJ	%
1	Agriculture	31	2	79	5
2	Irrigation	128	10	0	0
3	Steam for conversion	300	24	300	20
4	Methanol	238	19	238	16
5	Electricity for conversion	56	5	56	4
6	Crushing	243	20	243	16
7	Transportation	24	2	24	2
8	Fertilizers and manure	221	18	553	37
	TOTAL	1241	100	1493	100

It can be clearly seen that irrigation is the most important contributor, along with crushing energy and primary energy required to produce methanol and fertilizers, manure. Although irrigation is an important factor in increasing the yield, it is a significant contributor to the total primary energy input. But the overall NER has been found to increase due to irrigation.

### 5 Allocation

Allocation by mass – The energy inputs are allocated to the different products based on the output mass. Since biodiesel accounts for only 77.9% of the total mass of the output, the energy input is proportionately allocated.

Allocation by energy – The energy inputs are allocated to different products based on the output energy content which depends on calorific value of the products. Since biodiesel accounts for 88.2% of the total energy output, the energy input is proportionately allocated.

### 6 Results

This section provides the net energy ratio values under various conditions thus quantifying the viability of Jatropha bio diesel. There is an uncertainty in the input energy of the fertilizers used in the production of jatropha biosiesel. Hence two conditions are considered. Condition 1 is defined as the case where the lowest values were considered for specific energy consumptions of fertilizers Condition 2 is defined as the case where the highest values were considered for specific energy consumptions of fertilizers.

Case 1: Poor soil –

a) Non irrigated

NER under condition 1 and highest oil content was found to be 0.67 . So, for all other cases also, the net energy ratio will be less than 1.

b) Irrigated

In this case, the NER varies from 0.71 to 1.03. It is clear that  $NER > 1$  only for condition 1 and highest oil content. Often, such conditions are difficult to attain in practical cases, especially in India. A variation of the NER with oil yield has been shown in Fig.4 for condition 1 and run off 0.3.

Case 2: Normal Soil- Variation of NER with oil yield for non-irrigated normal soil under condition 2 is shown in Fig.4. The net energy ratio varies from 1.025 to 1.242. Particular attention has to be paid to the fact that the net energy ratio is only slightly greater than 1 under such conditions. So careful consideration must be given before planting jatropha on a large scale in such conditions. Whereas for irrigated soil, the NER varies from 1.44 in the worst conditions to 2.1 in the best conditions.

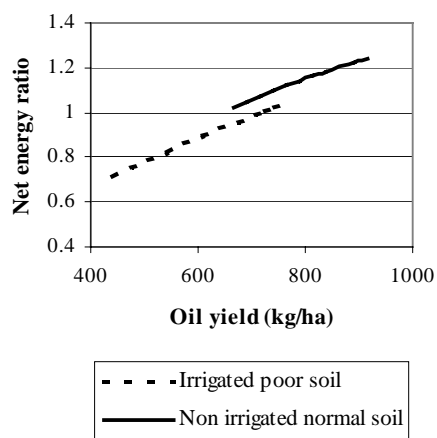


Fig.4. Variation of NER with Oil Yield for non-irrigated normal soil at condition 2 and irrigated poor soil at condition 1.

Case 3: Fertile Soil - Since from the above analysis it has been proved that jatropha is viable in normal soil at all conditions it is reasonable to assume that it is viable under fertile soils where yields are much higher.

The life cycle energy analysis of diesel shows that 1 MJ of fuel output is obtained by spending 1.2 MJ of primary input energy[2]. But, our case study shows that 1 MJ of energy from jatropha biodiesel takes only 0.682MJ of primary input energy.

## 7 Conclusions

Although there is widespread publicity that jatropha can grow under any kind of conditions, from the above discussion it is clear that large scale plantation of jatropha under poor soils is energetically not feasible. The net energy ratio seems to be the highest in the fertile soil areas. But in this case jatropha competes with the more important food crops for prime agricultural land. Therefore displacing food crops from agricultural land for large scale jatropha plantations is not advisable. The best regions for cultivation of jatropha seem to be the lands with normal soil. Under normal agricultural practices and average technology the net energy ratio is more than one. These conditions provide the best opportunity to grow jatropha on a scale that may solve the energy crisis in India. It is recommended that a few studies from the pilot project areas be analysed to estimate the actual net energy ratio to determine the rational strategy before launching a larger jatropha mission.

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