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## SUSTAINABILITY ANALYSIS OF JATROPHA AS A VEHICLE FUEL

Prabhat Lakhera and Rangan Banerjee

Department of Energy Science and Engineering, IIT Bombay (Powai), Mumbai

### Abstract

The energy import of India in terms of petroleum liquid fuels has increased from 11.7 million tonnes in 1971 to 100 million tonnes in 2005. This paper analyses the feasibility of replacing fossil diesel with an alternative fuel known as bio-diesel derived from *Jatropha curcas*. Net Energy Ratio and Production cost (Rs/kg JME output) has been taken as the criterion for depicting viability of replacement. Analysis has been performed in context of micro-mission (covering a total of 0.4 mha land) proposed by government of India through National mission on bio-diesel. Results indicate that Net Energy ratio (without co-product utilization) varies from 0.79 to 3.04 with an average value of 2.32 for three different yield scenarios while it varies from 1.7 to 6.54 with an average of 4.99 when co-products are utilized properly. Cost calculations suggest that production cost have potential to reduce from 21 Rs/kg JME to 17 Rs/kg JME if yield increases from 0.5 tonnes/ha to 5 tonnes/ha. Sensitivity analyses show that 50% increase in fertilizer input energy decreases NER by 21.5% (0.62) which make replacement of fossil diesel with bio-diesel unviable option. Decrease in the fertilizer input energy by 50% increases NER by 34.17% (1.06) thus replacement becomes a viable option even for poor soil scenario without co-product utilization. The key findings of the paper is production of bio-diesel derived from *Jatropha* is a viable option only for normal and best yield scenarios while it is not a viable option for poor soil scenario when co-products are not utilized.

### 1. Introduction

India imports more than 70% of oil it uses (Ministry of Petroleum and Natural Gas statistics). It is estimated that bio-diesel blending requirement will be 16 million tonnes (with 20% blending) in transport sector by the year 2016-17 (Singh et. al.). Bio-diesel derived from *Jatropha* has similar properties to the diesel and can be an alternative fuel for diesel. *Jatropha* is a draught resistant, large shrub belonging to Euphorbiaceae family (Chitra et. al. 2005), and normally three to five meters in height (Vardharajan et. al. 2004). *Jatropha* is a non edible plant which can grow in draught resistant and marginal soils thereby do not divert the food from human chain (Vardharajan et. al. 2004). This analysis has been performed for three different yield scenarios (0.5tonnes/ha, 2.5tonnes/ha and 5tonnes/ha) considering variation in the yields reported for different agro-climatic zones.

#### 1.1 Criteria

Net energy ratio (NER) is defined as bio-diesel (output) energy to the summation of input fossil energy consumed in each stage for production of bio-diesel. NER and Production cost (Rs/kg JME output) are criterion used for the analysis as given on equation 1.

$$NER = \frac{E_{out}}{E_{in}} \dots\dots\dots (1)$$

NER < 1, Replacement is not viable and NER >1, Replacement is viable

A study done by Vardharajan et. al. 2004 shows that NER varies from 0.66 to 2.01 for poor, normal and good soil scenarios. A similar study done by (USDA and USDOE) on bio-diesel calculated NER to be 3.2 for soybean bio-diesel which makes the production of bio-diesel a viable option. The minimum support price for bio-diesel set by government of India (Tewari et. al.) has a variation of Rs. 13.24 to Rs. 14.10 per liter. Government will have to provide compensation (in terms of subsidies) if the production cost of bio-diesel will be higher than minimum support price.

## 2. Materials and Methodology

Life cycle inventory includes agricultural cultivation stage, transportation stage, conversion stage and vehicle operation with fuel combustion stage. Calculation has been done on per tones of JME output and per km of a standard Mercedes Benz C class bio-diesel car driven basis (Daimler Crystler report 2008). Sensitivity analysis has been done to observe the changes in output for +50% and -50% Changes in input energy and cost data in whole life cycle of JME production.

Inputs to the analysis are seed yield (tonnes/ha) which are three different scenarios based on best case (good soil), worst case (degraded soil), and average case (normal soil). The output of the model is NER, energy MJ/km driven of a standard bio-diesel car and cost involved in production of bio-diesel. Data has been collected from various research sites, government organizations, and personal talk which are reported in table 1.

*Table 1 Assumptions and data collection*

(Sources: Guidelines for weeding and interculture operation, Vardharajan et. al. 2004, Achten et. al. 2008, Daimler Crystler report 2008, Arjun Plantation scheme, Kureel et. al. 2006, Personal talk to Zen Chemicals (Thane), Yule et. al. 1999, Kritana et. al., Ajav et. al. 1999, National Physical Laboratory table, Tewari D.N. et. al. 2003)

Material used in life cycle	Value
Field capacity(ha/hr)	0.72
Urea applied (g/plant)	20
FYM applied (kg/ha)	50
Plant density (plants/ha)	2500
Bio-diesel car fuel economy (km/l)	8.5
Cost of Urea, FYM (Rs/kg)	5, 4
Seed application for nursery (kg/ha)	6
Seed cost (Rs/kg)	5
Labour potential (men-hr/ha)	5
Working hour per day	10
Labour cost, (Rs/person/day)	100
Cost of MeOH, NaOH (Rs/l), and (Rs/kg)	65, 70

Material used in life cycle	Energy factor (MJ/kg)
Diesel specific consumption in farm tractor (kg/kW-hr)	0.253
Urea	28.4
Farm yard manure	47.9
MeOH	38.08
NaOH	19.87
Glycerol	25.6
Seed cake (fuel stock)	18.81
Maximum Blending taken	B20
Diesel	46
JME bio-diesel	37.5

### 2.2 Life cycle stages

Agricultural cultivation stage includes seed bed preparation, sowing of plantings, irrigation, fertilizer application, harvesting and seed collection. For accounting different agro-climatic zones (regions) three different yield scenarios as best case (5 tonnes/ha), worst case (0.5 tonnes/ha) and average case (2.5 tonnes/ha) has been considered (Achten et. al. 2008). Oil content of seed considered to be 35 % with an extraction efficiency of 94% and transesterification efficiency 95%. Electrical energy and diesel manufacturing efficiency is taken as 33% and 83% respectively (Vardharajan et. al. 2004). Transportation and conversion stage includes transporting the harvested seeds at the conversion plant and converting the seeds into raw Jatropha oil. Raw Jatropha oil is then fed to the transesterification plant which is base catalyzed reaction chamber in which raw Jatropha oil reacts with methyl alcohol in presence of a catalyst (normally NaOH) to produce ester of corresponding free fatty acid. A 2 hp machine for cracking is considered with 120 kg/hr capacity. A 5 hp rated power pressing machine with 20 l/hr oil production rate has been considered for the analysis. A 2 hp rated power filtrating machine with 170 l/hr capacity has been considered for the analysis, (Kritana et. al.) The ratio of oil to methanol is 5:1 and 1% (w/v) NaOH taken for the analysis. The co-products of the conversion stage are glycerol and seed cake. NER has been calculated with and without considering co-products energy values. Blending and distribution stage includes blending of bio-diesel with fossil diesel which can reduce the import of diesel from foreign sources. But several researchers have reported that an optimum blending ratio (B5, B10, and B20) is required to get the optimum performance of the engine. Blending up to 20% (B20) can be easily done without the modification of engine design (Ajav et. al. 1999) which is considered for the analysis. Vehicle operation with fuel combustion stage includes the use of blended fuel in a standard car taken for analysis.

Fossil energy used for the manufacturing of vehicles and other facilities is not considered. A schematic for life cycle inventory has been drawn as on figure 1.

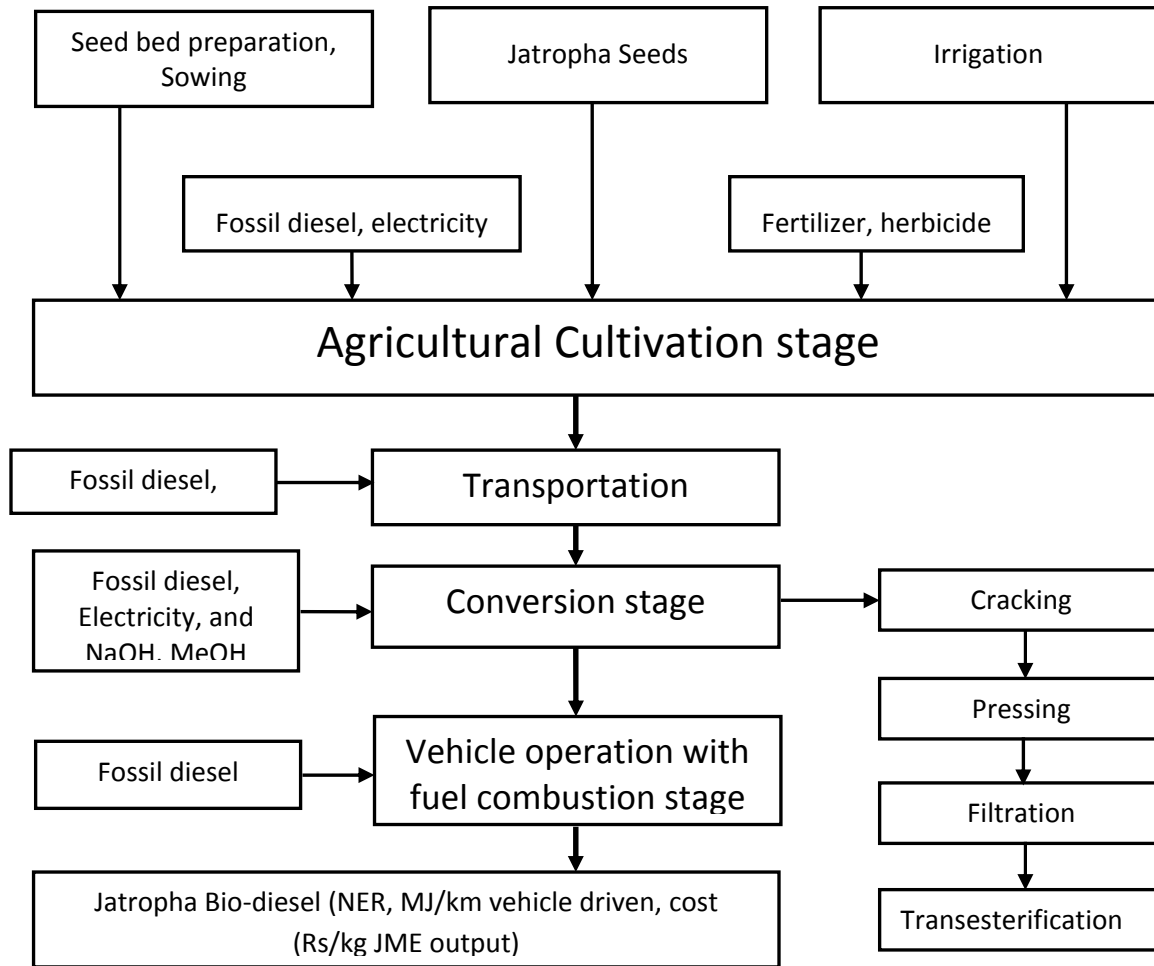


Fig 1 Schematic of life cycle analysis inventory

### 3. Results and discussion

#### 3.1 Energy analysis

It has been found that the NER varies from 0.79 to 3.04 with an average value of 2.32 when co products have not been accounted, which suggest the production of Jatropha bio-diesel is energetically viable for normal and best yield scenarios while it is not viable for poor soil scenario. If the energy values of co-products are realized the NER varies from 1.7 to 6.5 with an average values of 4.99, which indicate that for all yield scenario the production of bio-diesel from Jatropha curcas is a viable option. Therefore the utilization of co-products is an important factor which determines the viability of replacing fossil diesel by Jatropha bio-diesel.

Analysis is validated by comparing the results produced by other researchers. A similar study done by (Vardharajan et. al. 2004) have calculated NER which varies from 0.66 to 2.1 and identified that the bio-diesel production from Jatropha can be viable option in terms of energy criteria under an optimum input conditions of agricultural practices. A similar study done by (Kritana et. al.) calculated NER to be 6.03 and 1.42 with and without co-product utilization. Fertilizer followed by conversion, herbicides and irrigation are the three major fossil energy input in the JME bio-diesel production chain. It can be inferred that proper advancement in conversion process (transesterification on super critical fluids) may increase the value of NER thus making bio-diesel option viable even without utilizing co-products in poor yield scenario. Fertilizer input energy can be minimized by utilizing seed cake again as a fertilizer which have a potential to reduce the amount of conventional fertilizer use. Further uses of organic fertilizers are

recommended which are available locally (cow dung and manure etc). Use of B20 on vehicles is planned by the government of India by 2012 (Kumar et. al., Singh et. al.) NER variation and energy consumed is shown in Fig. 2 and table 2 quantifies the NER values with and without co-product utilization.

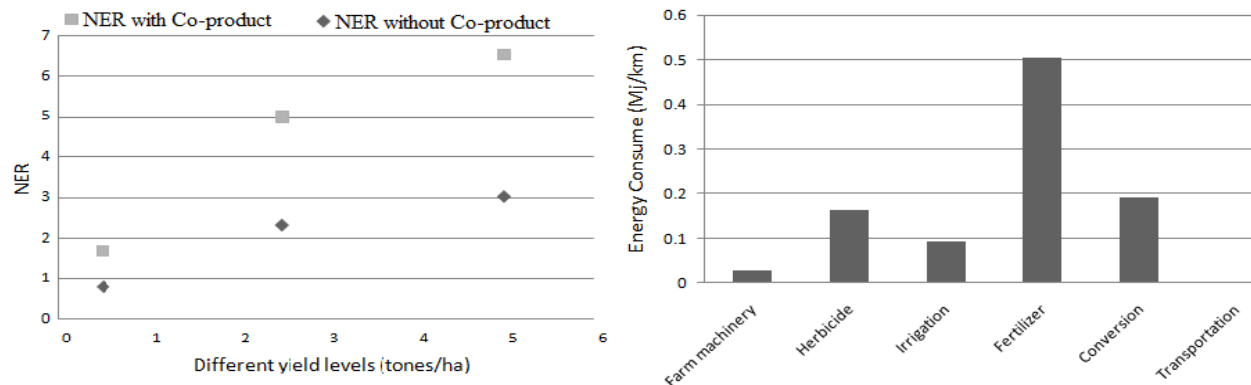


Fig. 2 Variation of NER with respect to different yield scenarios and Energy consumed (MJ/km vehicle driven) in each life cycle stage of Jatropha

Table 2 NER values with and without considering co-product utilization

Description	Yield scenario, tones/ha	NER without co-products	NER with co-products
Present Study	5 (Best)	3.04	6.5
	0.5 (Worst)	0.79	1.7
	2.5 (Average)	2.32	4.99
Study by Vardharajan et. al. 2004		(min, max) = (0.666, 2.1)	
Study by Kritana et. al. 2008		Variation 1.42 – 6.03	

### 3.2 Cost analysis

The production cost of JME decreased from 21 Rs/kg JME to 17 Rs/kg JME when yield is increased from 0.5 ton to 5 tons per hectare. The analysis show that the major production cost is due to the high cost of NaOH and MeOH which are used in the transesterification process. It suggest that the alternative technology i.e. transesterification on super critical fluids may decrease the production cost of bio-diesel from Jatropha. A similar study done by (Dhillon et. al. 2006) and (Euler et. al.) have calculated the cost of bio-diesel production as 20 Rs/l. production cost with different yield levels and with different stages of production has been shown in fig. 3 as below.

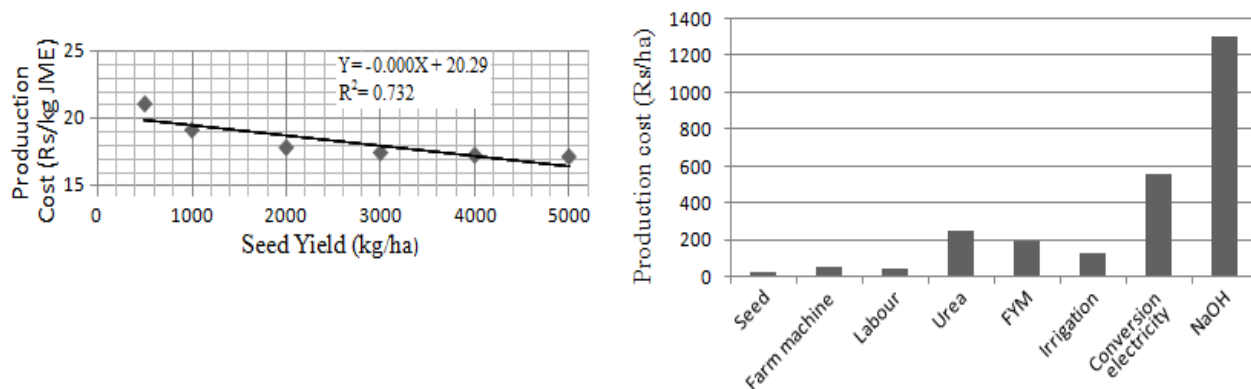


Fig. 3 Production cost (Rs/ha) in each activity of Jatropha life cycle and variation with seed yield

#### 4. Sensitivity analyses (impact on NER and cost)

Sensitivity analysis has been performed to calculate the changes in the output value of energy and cost section (NER and production cost) under a variation of +50% and -50% of input values, thereby testing the range of viability. The analysis has been divided into two sections. One is impact on NER and other being impact on production cost, which is defined in following sections.

It has been found that farm machines and transportation energy consumption do not have a significant effect on NER. However highest impact of fertilizer input energy has been found. The increase in fertilizer input energy by 50% have decreased NER by 21.5% and 20.58% respectively without and with co-product utilization and finally reducing the value of NER below one, thereby production and replacement of fossil diesel with bio-diesel will not be a viable option. However the decrease in the value of fertilizer input energy by 50% has increased the NER by 34.17% and 34.75% with NER above one which makes production and replacement of fossil diesel with bio-diesel a viable option. Decrease in fertilizer input fossil energy can be achieved by again utilizing seed cake as fertilizer in the fields. Conversion, irrigation and herbicides are among other energy consuming fossil inputs which can be minimized by using improved techniques of conversion.

Cost sensitivity analysis has been done in order to find the potential by which the production cost will change with respect to varying (+50%, and -50%) input conditions in seed cost, fertilizer cost, irrigation cost, labour cost, conversion cost and transportation cost. Changes in seed and labour cost do not have a significant effect on the production cost of JME. Conversion process has the highest impact on production cost of bio-diesel. Sensitivity analysis for costing shows that overall production cost of bio-diesel is economically viable when a small subsidy will be provided. Changing the conversion cost by (+50%, -50%) changes the bio-diesel cost by 28%, 35% (increase) and 42%, 52% (decrease) respectively. A schematic has been drawn to show impact of input on NER as shown in table 3.

*Table 3 Sensitivity analysis for NER (with and without co-products)*

Impact analysis		NER without co-product	Percentage change in NER	NER with co-product	Percentage change in NER (%)
Farm Input	50%	0.78-3.04	1.2-0.65	1.6-6.5	1.7-0
	-50%	0.8-3.04	1.2-0	1.7-6.5	1.17-0
Irrigation	50%	0.75-2.9	5-1.9	1.6-6.4	4.7-1.8
	-50%	0.83-3.04	5-1.6	1.7-6.6	4.7-1.8
Fertilizer	50%	0.62-2.7	21.5-9.2	1.3-5.9	20.5-9
	-50%	1.06-3.3	34.1-10.8	2.2-7.2	34.7-10.8
Herbicide	50%	0.73-3.04	7.6-0	1.5-6.5	7.6-0
	-50%	0.86-3.04	8.8-0	1.8-6.5	8.8-0
Conversion	50%	0.72-2.2	8.8-27.6	1.5-4.7	8.8-27.3
	-50%	0.87-4.8	10.1-60.5	1.8-10.5	10.5-60.5
Transportation	50%	0.79-3.04	0-0	1.7-6.5	0-0
	-50%	0.79-3.04	0-0	1.7-6.5	0-0
Co-product	50%	0.79-3.04	0-0	2.1-8.2	26.4-26.
	-50%	0.79-3.04	0-0	1.2-4.7	27-26.7

#### 5. Conclusion

The NER (Net Energy Ratio) of the life cycle production processes of bio-diesel from Jatropha varies from 0.79 to 3.04 with an average value of 2.32 for three different yield scenarios when co-products are not utilized. The NER value less than one suggest that production of bio-diesel from Jatropha is not a viable option under these conditions. However the value of NER varies from 1.7 to 6.54 with an average value of 4.99 which is for poor soil, best soil and normal soil scenarios respectively when energy values of co-products are utilized properly. It suggests that the production of bio-diesel from Jatropha is a viable option even for all the soil scenarios considered with co-product

utilization. Further it is analyzed that the fossil energy input is highest for fertilizer followed by conversion, herbicide and irrigation.

Cost analysis suggest that the *Jatropha* bio-diesel production cost can be decreased from 21 to 17 Rs/kg when yield improves from 0.5 to 5 tonnes/ha. The variation in fertilizer input energy impact the viability of bio-diesel production and its use on transport vehicles. Decreasing fertilizer energy by fifty percent has potential to make NER greater than one even for poor soil scenario. The conversion cost has a high impact for reducing production cost of bio-diesel which can be decreased by proper advancement in conversion technology. At present prices *Jatropha* is not cost competitive and require subsidies. The analysis shows the possible improvements that may result in the viability of JME as a fuel for vehicles.

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