CHAPTER 5

LIFE CYCLE ASSESSMENT OF JATROPHA GREEN DIESEL SYSTEM

5.1.Introduction

This chapter discusses in detail the various challenges of Jatropha cultivation and Jatropha green diesel production system. It talks about various reasons for failure of Jatropha projects for biofuel production in India, and suggests measures to overcome them from the learning over the years.

Keeping the above in mind, life cycle energy balance for Jatropha green diesel production and green house gas emissions from post-energy use, and end combustion of biodiesel has been examined. It also talks about the cost economics of the ibid system.

Initially, it was said that *Jatropha curcas* could even be grown on wasteland with minimal care and minimal requirement of water and nutrients [34], but without commercial yield [41]. From experiences with Jatropha projects, it is now emerges clearly that it performs much better with adequate access to soil nutrients and water [48]. Adding some fertilizer or manure is needed to maintain good long-term seed yields, because Jatropha is not a nitrogen-fixing crop, and substantial nitrogen is removed with the harvesting of the seeds [48]. In spite of efforts made by Indian government, its growth did not pick up [42]. According to one study the reason for this was that basic agronomic properties of Jatropha were not thoroughly understood by many [45]. However, later on, it was found that for a good and profitable yield, proper and careful agricultural practices are important, these include proper irrigation and fertilizing [46, 188]. Another study on land availability and biomass production potential, in India, also supported that biomass productivity can be increased through use of genetically superior planting material, application of fertilizer and manure, by adoption of soil and water conservation practices along with water application in the areas with less rainfall [189].

Incorporating all the above mentioned practices, would lower the values for Net Energy Balance (NEB) and Net Energy Ratio (NER), by virtue of all being energy intensive. Therefore, a viability study is required to find out the suitability of this high input (with adoption of the best available management practices, which include proper irrigation, pruning, weeding, and use of fertilizer and water, etc.) Jatropha green diesel production system.

Against the above backdrop, initially a detailed discussion of various challenges of Jatropha green diesel production system and suitable agronomical practices has been attempted, followed by the calculation of NEB and NER keeping the suitable practices into consideration.

5.2. Challenges of Jatropha Green diesel production system

Properties of *Jatropha curcas*, like; ability to resist drought [88, 89], ability to control soil erosion, toxicity to animals [94, 190, 92, 47], ability to grow on marginal soil [94] and most important of all, the biodiesel production from its non- edible seed oil [96], had made it the most promising option for biodiesel production for India [28].

However, *Jatropha curcas* potential, for producing energy from marginal land without large inputs, has recently created a hype of attention, resulting in the planning of huge areas of plantation in Asia, Africa and America [94].

If we look at the Indian biodiesel industry, with an aim to serve two important purposes i.e. reduce crude oil import by its in part substitution with biofuel, and thus, save foreign exchange and help to move towards stricter emission norms, in the year 2003, Planning commission of India launched the National Mission on Biodiesel [191]. It was an initiative of Indian Government towards sustainable development.

With a target to achieve 20% blending by the year 2011-12 by beginning with 5 % blending in 2006-07, the mission was proposed in two phases [191].

a. **Phase-I:** It consisted of Demonstration Projects, and was supposed to be implemented by the year 2006–07.
b. **Phase-II:** Demonstration projects were to be followed up by phase-II, which was supposed to be a self-sustaining expansion of the programme beginning in the year 2007 leading to production of bio-diesel required in the year 2011-12.

But the set target could not be achieved [192]. Phase-I, also known as demonstration phase , targeting 0.4 Million hectares (Mha) of waste land for Jatropha plantation with an objective to develop a self-sustainable cycle reaching up to retailing of biodiesel, failed, As a result, lead to the failure of phase-II targeting 20% blending of petro-diesel by 2012 [26]. A few reasons, which led to the failure of the national biodiesel mission, are [26]:

1. Appropriate agencies for Jatropha plantations could not be identified. Phase-I of the mission failed to attract sufficient number of demonstration project.
2. Moreover, the plantations failed due to which even the transesterification facilities could not be set up.
3. According to Biodiesel Purchase policy the public sector oil marketing companies were to buy biodiesel (B100) through their

selected purchase centers. Since the identified purchase centers were very few in numbers, procurement of biodiesel on mass scale was not possible.

4. Adequate policy and financial support to meet the targets of Phase-I were lacking.

5. Biodiesel purchase price was supposed to be inclusive of any taxes and duties, and transportation cost for delivery of biodiesel at the purchase center. The initial uniform purchase price fixed for biodiesel was Rs. 25 per liter, which was unrealistic. Moreover, no institutional mechanism was developed to determine realistic prices.

All of the above mentioned failures can be divided into three broad categories, i.e.:

1. Implementation failure

a. Non-identification of appropriate agencies to carry out demonstration project

b. Non-identification of purchase centers

c. Non-establishment of transesterification facilities

2. Agronomical failure

a. Plantation failure

3. Policy failure

a. Lack of proper financial support

b. Unrealistic biodiesel purchase price

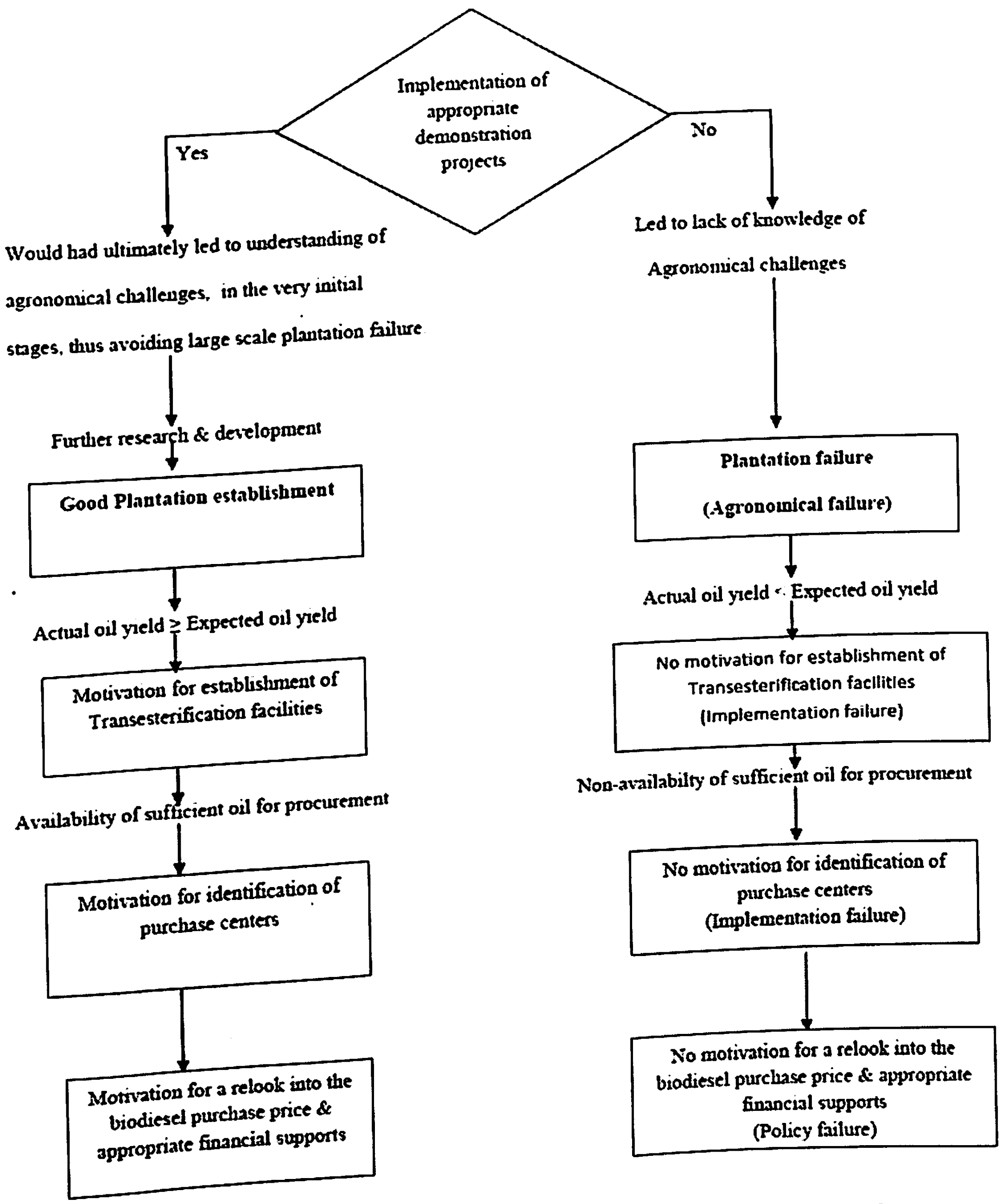

Figure5. 1: Importance of the Agronomical Practices in deciding the future of National Biodiesel Mission of India

Though the agronomical failure seems to be less prominent than the rest two, it is important to note that all the other types of failures revolve around it. Agronomical failure was one of the major reasons for the failure of the entire biodiesel mission. It is clear from the Figure 5.1 that only if proper demonstration projects would had been carried out, it would have had led to a better understanding of agronomical challenges of Jatropha biodiesel system in its very initial stages, and thus, avoided the large scale plantation failures and its further consequences.

There is a surprising lack of scientific knowledge about basic agronomic properties [102]. According to one study the basic agronomic properties of Jatropha were not thoroughly understood by many [94]. Although the oil yield of this species is better than any other non-edible oil yielding plants, the lack of agronomic practices defame this species for further exploitation. Furthermore, data on the growth performances and yield of *Jatropha curcas* plantations is very scarce [193].

The growing and management practices are not well documented [94, 47]. The main knowledge gaps are situated in the cultivation part, mainly concerning water requirements, growth and yield response to input [194]. Jatropha being cultivated rather recently, little is known about its profitable plantation management techniques, especially those related to the resource requirements, like, fertilizer application, irrigation or pruning etc [195].

Major constraint for the extended use of *Jatropha curcas* seems to be the lack of knowledge on its potential yield under sub-optimal and marginal conditions [94]. Many authors have mentioned about the biophysical limits of the species, but the data provided by them is based on generalizations of scattered observations, rather than on systematic research. Yet this knowledge is crucial, as Jatropha should still be considered a wild and undomesticated plant showing great variability in productivity between individual plants [194].

Jatropha is widely described in literature as a hardy tree that grows in a wide range of physiographic and climatic conditions. It is a vigorous, drought and pest tolerant plant that can grow in barren, eroded lands under harsh climatic conditions [27, 98]. Jatropha has been known to grow on lands unsuitable for economically viable agriculture and thrives under heterogeneous edaphic conditions. The plant is also known to tolerate high rainfall of over 1200 mm [98].

Earlier *Jatropha curcas* was said to grow even on wasteland and that too with minimal care and minimal resource requirements [34], but the plantations failed to give commercially viable yields [41]. It was also said that it could grow on any kind of soil with minimum inputs and management [127]. However, in due course of time, it was found that for a good and profitable yield, proper and careful agricultural practices are important, these include proper irrigation and fertilizing [46, 47].

From experiences with Jatropha projects, it is now clear that it performs much better with adequate access to soil nutrients and water [48]. Adding some fertilizer or manure is needed to maintain good long-term seed yields, because Jatropha is not a nitrogen-fixing crop, and substantial Nitrogen is removed with the harvesting of the seeds [48]. It is largely promoted as a crop grown on marginal and wastelands. Seed yields of Jatropha reported in literature are in the range from 0.2 tons to 12 tons per hectare, depending on production conditions [27].

Another study on land availability and biomass production potential in India also supported that biomass productivity can be increased through use of genetically superior planting material, application of fertilizer and manure, by adoption of soil and water conservation practices along with water application in the areas with less rainfall [189].

The success of Jatropha production will depend on its viability as a commercial crop. There is a need for the development of a package of practice for optimization of commercial cultivation of Jatropha [27].

5.3. Suitable agronomical practices

Over the years, through the experience of researchers and scientists, better and suitable agronomical practices for Jatropha cultivation have evolved Various agronomical practices suggested for sustainable development of Jatropha biodiesel system have been discussed below.

5.3.1. Seed management techniques

Studies have been undertaken to improve the performance and quality of Jatropha seedlings by proper seed management techniques. It has been observed that soaking of seeds for 24 hours in water or for 2 to 3 minutes in boiling water, before sowing them, reduces their germination period from about 10-15 days to 7-8 days [27].

Removal of seed coat also accelerates water imbibitions, and germination occurs within 48 hours. However, in practice, removing seed coats for large scale plantation is not feasible, and therefore, use of intact-seeds is recommended [196]. Application of plant growth substances, increase the growth of seedlings [27, 196] from intact-seeds. Few effective growth substances are potassium nitrate (KNO_3), indole-3-butyric acid (IBA) and naphthalene acetic acid (NAA) [196].

5.3.2. Soil requirement

It is normally claimed that *Jatropha curcas* is well adapted to marginal soils preferably sandy soils. However, it is important to note, that in spite of good and deep root system, the plant may fail to grow well in sandy soils with low nutritional contents. The results have shown that clay-loam soils, with higher nutritional content than sandy soils, might be more suitable for plant development, while sandy-loam soils with lower nutrient content are more suitable for obtaining good seedlings than clay-loam soils. Therefore, while establishing *Jatropha curcas* plantations on poor soils, proper care, especially about the nature of soil and the additional fertilizer requirement, must be taken care of or else the plantations may fail to develop well [197].

Moreover, well-drained soils with pH 6-8 are preferred [198]. Though Jatropha has also been established in high sodic soils with pH as high as 11, but with poor yield. However, sodic and degraded lands of India can be explored for the production of energy plants like *Jatropha curcas*, but it might require some calcium and magnesium fertilization. Appropriate requirements of fertilizer can only be established through proper experimental evidences [94].

5.3.3. Plant propagation

Jatropha plants established from cuttings normally have lower longevity and lower drought resistance, because they develop pseudo-tap root which penetrate the soil to about half the depth of a tap root developed from seed, and thus, these plantations suffer tree loses during dry spells, especially at the initial stages of establishment. Therefore, plants established through cuttings are not normally recommended for large-scale commercial plantations under rain fed conditions [27].While Jatropha plantations established from seeds, develop tap roots which reach greater depth into the soil, and help plantations to adapt to arid or semi-arid conditions. Seeds must be collected from 8 to 15 years old trees, because it is this period when the trees mature completely and seed production is optimum [27].

There are basically two ways of propagating Jatropha from seed. These are; the production of seedlings in nurseries or in situ seeding where seeds are sown directly into planting fields [27]. Although seeds sown directly into fields have lower rate of survival, yet they are preferred over transplants for long term plantations [198, 27]. Jatropha plants established by direct seeding method develop deeper tap root systems which increase the survivability and longevity of the plants [27, 199].

5.3.4. Spacing

Competition for water between the roots of the adjacent plants requires optimal spacing between the plants, which is dependent on rainfall. Wider spacing is required in semi-arid environments in comparison to sub-humid environments. However, spacing is a tradeoff between biomass and fruit production. Moreover, fast canopy closures due to narrow spacing also result in competition for light. Competition for light and water results in lower fruiting. Close spacing is appropriate only when Jatropha is planted for live-fencing or hedges for soil conservation. When the plantation is done with the aim of oil production for biodiesel, seedlings should be planted wide enough to obtain high quantity of seed in the mature stage, but close enough to avoid unacceptable loss of photosynthetic capacity in the young stage. Thus, optimum spacing can be recommended only after minimum 5 years of continuous growth and yield observations, and also in different environmental conditions and using different provenances [94]. The best available practice at this moment is to start with a densely spaced block plantation (2 m *2 m spacing) and gradually remove the rows or individuals (thinning) according to the plant performances. It was observed that with increasing spacing, seed yield per plant increased significantly, whereas the seed yield per hectare decreased [94].

5.3.5. Fertilizer

Jatropha has been largely promoted as a crop suitable for production on waste or marginal lands with little or no requirement for use of fertilizers. Though Jatropha grows on these lands but the yield is very low, may be as low as 0.2 tons per hectare, and uneconomical. Fertilizer should be applied judiciously to realize yield potential of above 5 tons per hectare. Like all other crops, Jatropha responds to nutrient application. Proper application of both macro and micro nutrients are essential for optimization of seed yield in Jatropha [27].

On degraded sites Jatropha responds better to organic than inorganic fertilizers in terms of seed yield [27, 94]. For high biomass production both nitrogen and phosphorous containing fertilizers should be applied. *Jatropha curcas* seed cake itself is a rich source of nitrogen and other nutrients, and has been found to enhance plant growth and biomass [94].

5.3.6. Mycorrhiza

Jatropha forms a symbiotic relationship with the fungi Mycorrhiza. Mycorrhiza is a non-pathogenic fungus that forms permanent association with Jatropha in the rhizosphere. This fungus converts phosphorous into forms that can directly be absorbed by roots of the plants and can offers up to 50% reduction in phosphorus fertilizer requirement. Mycorrhiza also improves the uptake of other nutrients by plants. Therefore, especially in areas with low phosphorous, Jatropha should be inoculated with Mycorrhiza [27].

TERI's researchers have found that mycorrhizal bio-fertilizers not only enhance uptake of nitrogen and phosphorous but by doing so also provide tolerance and strength to the plants to withstand the adverse conditions. Inoculation of mycorrhizal bio-fertilizers converts the chemical laden site to a lush green plantation of *Jatropha curcas* [200].

5.3.7. Water requirement (Rainfall and irrigation)

Though *Jatropha curcas* is adapted to semi-arid conditions and can survive with rainfall as low as 200 mm per annum, but have been found to give higher yields with higher rainfall of up to 1200 mm [198]. *Jatropha curcas* is also said to have a good drought tolerance mechanism, however, under favorable soil moisture conditions Jatropha could use large amounts of water for luxurious growth and high yield [201].

The observed precipitation preferences indicate that Jatropha is not common in regions with arid and semi-arid climates. Plantations in arid and semi-arid areas hold the risk of low productivity. This is in contrast with popular claims on preferred climate and with the limiting rainfall levels stated in various literatures. Production sites with 900–1200 mm rainfall can double the seed yield (5 ton dry seed/ha/yr), than semi-arid regions with 200 mm to 300 mm rainfall (2 to 3 tons dry seed /ha/yr). It indicates that plantations in arid or semi-arid regions show low productivity and need additional irrigation [194].

Therefore, though *J. curcas* can grow without irrigation in a broad range of rainfall regimes, from 250 up to 3000 mm per annum, to achieve high biomass and optimum yield and to standardize the agronomic practices, irrigation at regular interval is one of the very important requirements [94]. Flowering in Jatropha is induced during the rainy season. When irrigated, Jatropha produces seed throughout the year. Seed yield under rain fed conditions is just about 40% of that under irrigation [27]. Moreover, rain fed plants showed lower Chlorophyll b, carotenoid and protein content in leaf as compared with other trials indicating lower physiological performance in absence of water/irrigation [94].

5.3.8. Temperature requirement & Frost sensitivity:

The natural climatic conditions of Jatropha are more humid and have a higher mean minimum daily temperature of the coldest month than it's commonly believed site requirements, and therefore, point towards cautious selection of plantation sites [194]. Best growth conditions are found at altitudes below 500 m and in annual average temperatures higher than 28 °C [198].

Jatropha plantations in regions with frost risk hold the risk of damage due to frost [198]. Although it can recover from slight frost, but will have lower seed production. Severe frost can even cause death of the plant. Given the tendency of the natural range towards warmer climatic conditions with longer return periods of damaging frost events, this is an underestimated risk [194].

5.3.9. Pruning

According to Behera et al, pruning the main branch in the dormancy phase (when leaves are shed) at 30–45 cm height from ground, helps in the production of more branches and to stimulate plentiful and healthy inflorescence, thus, eventually enhancing the quality and quantity of seeds and fruits [94].

However, contrary to the above study, results of another study by Ghosh et al revealed drastic reduction of fruit yield after pruning. This loss can partially be made up by application of paclobutrazol (PBZ), and thus serving its only purpose of keeping the plant height within harvestable distances [202].

Thus, the above two contrary studies compel for further research into it, to optimize the pruning process, which might prove to be a very important issue in standardizing the agronomical practices.

5.4. Genetic diversity of *Jatropha curcas* germplasm (Challenges)

Very little work on provenance trials and genetic resources of *J. curcas* has been reported so far. Though *J. curcas* grows widely in India and several collections of the plant are also maintained, pedigree and provenance records are not available, which otherwise would had helped in analyzing the diversity within the available collections to shortlist the parental lines for adaptability trials and further improvement of Jatropha plants [95].

Thus, apart from the knowledge of basic agronomical practices, research on *Jatropha curcas* germplam improvement is also important because genetically modified and improved Jatropha seed quality will further complement the benefits of improved agronomical practices by increasing the oil yield per seed.

5.5. Possible benefits of improved agricultural practices & germplasm improvement

5.5.1. Environmental benefits

Use of biodiesel has lower emissions in comparison to petroleum based diesel. Biodiesel has lower emissions of unburned hydrocarbons, carbon dioxide, carbon monoxide, sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, ozone-forming hydrocarbons, and particulate matter (75–83%). Reductions in net carbon dioxide emissions are estimated at 77–104 g/MJ of petroleum diesel displaced by biodiesel. More is the amount of biodiesel in its blend with diesel; more is the reduction in the emissions [38, 31]. Though, the NO_x emissions are slightly more with the use of biodiesel, but can be controlled with the help of antioxidants [26].

5.5.2. Economical & Social development

If the Jatropha based biofuel projects are planned and handled carefully, can facilitate economic and social development in India. Indigenous production of renewable energy can cut-off a large amount of import bills and also offer large number of employment opportunities, thus, creating income base for many households in India.

5.5.3. Resolution of land issues

With world's 15 percent population, food security is one of the major concerns for a country like India [37]. In spite of vast land areas, India does not produce enough edible oils and import them to meet the food requirements [6, 26]. In reality, the 13.4 million hectares of waste land identified by Indian government for meeting the targets of its National

Biodiesel Mission may not be available for Jatropha plantation since much of it is already occupied or used by the poor villagers [192]. According to Pandey et al, the overall productivity of Jatropha biodiesel system can be increased manifold (from 3.75 MT /ha assumed by Planning Commission of India to about 11.25 MT/ha at its full potential), by proper care and careful agricultural practices i.e. high input practices with proper allocation of resources at right time [31]. This would decrease the amount of land required, and also solve the problem of much talked about land availability problem in India.

5.6. Other important challenges

No attention was paid to address the technological issues related to usage of biodiesel in existing petro-diesel engines. One of the micro-missions should have addressed the technological issues likely to be encountered by the users of biodiesel in engines, few being oxidation during storage, and problem in cold starting [26].

The presence of about 78.9 % unsaturated fatty acid methyl, and contamination by even a trace amount of different transition metals commonly found in metallurgy of storage tanks and barrels, like iron, nickel, cobalt, copper and manganese, increase its rate of oxidation and thus make Jatropha oil based biodiesel relatively unstable on storage. The residual products like acids, aldehydes and insoluble gums, formed from degradation of biodiesel cause engine problems like filter clogging, injector coking, and corrosion of metal parts [127]. Moreover, biodiesel being a mild solvent dissolves the sediments normally present in old tanks used for petro-diesel fuel, and this further increases the problem of instability [26].

Since stability of biodiesel is very important, antioxidants like phenolic antioxidants namely 2, 6-ditertiarybutyl hydroxytoluene, bis-2, 6-ditertiarybutyl phenol derivative, and aminic antioxidant octylated butylated diphenyl amine, should be used during storage, and also to ensure proper fuel quality during entire distribution process [127]. The antioxidants are also very effective in controlling the NO_x formations during biodiesel combustion, due to very high temperature in the combustion chamber of the engine. They do, however, have significantly more CO and HC emissions [26].

Further, due to the increase in the viscosity of the biodiesel at low temperatures, the fluidity of the biodiesel is affected, which leads to the problem of cold starting. Thus, to overcome this problem some heating arrangements should be made in the fuel lines [26].

5.7. Life cycle Energy Balance

5.7.1. Goal & Scope

All the activities in the production of biodiesel are energy intensive, due to the virtue of which they also generate greenhouse gases, and therefore, a viability study is required to find out the suitability of the crop as a biodiesel feedstock. Many studies have already been done on different feedstocks for biodiesel [203, 204, 205, 206, 207, 113, 208], and most of them [204, 205, 206, 208] have used either Net Energy balance (difference of energy output and energy input) or Net energy ratio (ratio of energy output to energy input) or both of them, as indicators for estimating the viability of the systems. In the same manner there are viability studies already done on Jatropha [43, 44].

However, most of them have considered low input (with minimal care and minimal use of materials) Jatropha cultivation system. Many of them have even shown these indicators to be positive, yet the values are very less. We need to find out if we can further increase the values for these viability indicators i.e. Net energy balance and Net energy ratio, by using a high input (with adoption of the best available management practices, which include proper irrigation, pruning, weeding, and use of fertilizer and water, etc.) Jatropha cultivation system. An increase in the input of fertilizer and irrigation decreases the energy use efficiency [209]. And this increase can only be compensated by higher energy returns which are possible only if the yield can be increased to a much higher extent. For the same, we have compared the results of the current study with two previous studies done by Achten et al and Prueksakorn et al [43, 44] on low input Jatropha biodiesel system and one previous study on Palm oil biodiesel system which also includes Coconut biodiesel system [205].

Therefore, with reference to the background stated above this case specific life cycle study aims at finding out the life cycle energy balance and greenhouse gas emissions from the energy use for a small scale (1 hectare) but high input Jatropha green diesel system. The functional unit of the study is one hectare.

5.7.2. System Boundary

The system includes Jatropha cultivation and harvesting, oil extraction, oil and seed cake processing, and end combustion of green diesel production and its end use in transportation. Focus is mainly on primary agricultural practices [210]. Non-renewable energy requirement for only fertilizer use during Jatropha cultivation has been included as fertilizer production is highly energy intensive process. The non-renewable energy requirements for items, with many years of useful life, have not been considered in this study. Instead of artificial pesticides, bio-pesticides were used during the cultivation of Jatropha. Though, genetically modified seeds were not used, yet proper care was taken during selection of seeds to see that they are of the best quality. Figure 5.2, shows the system boundary for Jatropha green diesel production system.

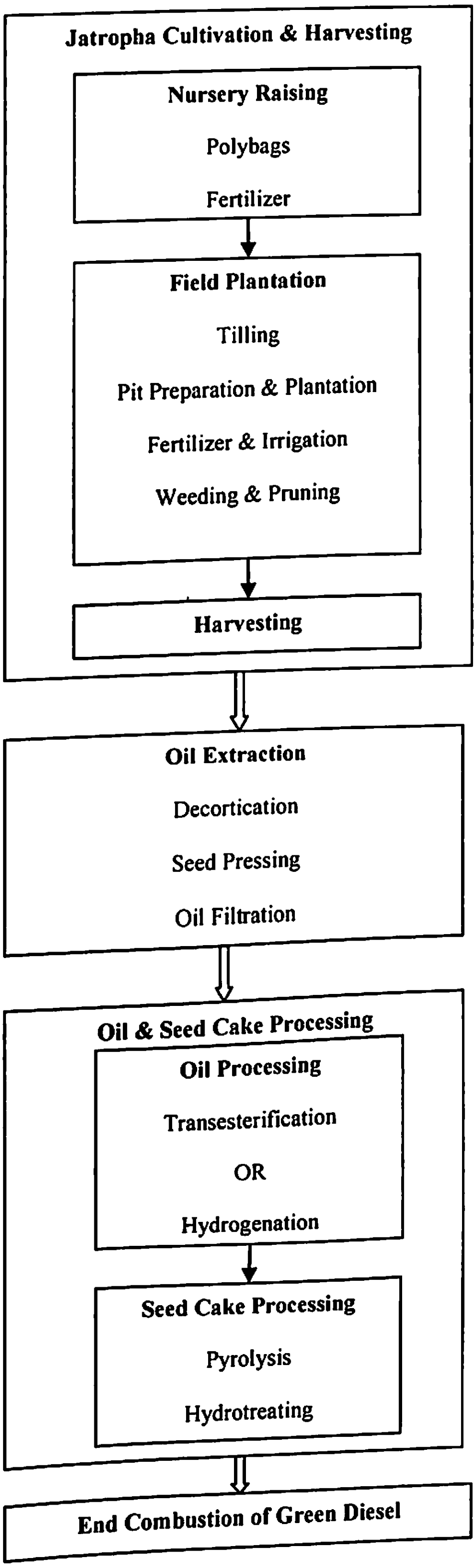

Figure5. 2: System boundary of Jatropha green diesel production system

5.7.3. Methodology

Life cycle Assessment (LCA) has been used for the analysis of energy balance and greenhouse gas emissions from the energy use for Jatropha based biodiesel production and its use in internal combustion engine for transportation. In LCA, a product is followed from its cradle to its grave. Natural resource use and pollutant emission are described in quantitative terms [85]. This study incorporates all the major activities and various inputs and outputs in every stage of Jatropha biodiesel production. The entire life cycle has been divided into four major stages:

i. Jatropha cultivation & Harvesting
ii. Oil extraction
iii. Oil & Seed cake processing
iv. End combustion of green diesel

5.7.3.1.Method of data collection

Agreed, that a lot of research has already been done on Jatropha, however, the documentation on every aspect of it is not proper. Therefore, the data and the facts about Jatropha biodiesel have been taken from three sources, i.e;

i. Various studies and research papers.
ii. The detailed information about various inputs during Jatropha cultivation stage has been taken from a primary data collected from 100 acres of plantation, in Ettayapuram village of Tamil Nadu, by a company called Bharat Jatropha Garden Estate Pvt. Ltd.
iii. Parallel experiments were undertaken in Biodiesel lab at University of Petroleum and Energy Studies, Dehradun, India for various biodiesel related inputs/outputs and properties.

5.7.3.2. Assumptions

a. CO_2 emissions from every stage of Jatropha life cycle have been considered, while N_2O emissions have only been considered from fertilizer use.
b. Greenhouse gas emissions from human activities i.e. from physiological activities of human beings at work have not been considered as our major concern is the use of depleting fossil fuels and electricity use.
c. Greenhouse gas emissions from only mineral fertilizer have been considered and not from organic fertilizer.
d. Per kWh of only the direct electricity use has been made equivalent to 10.69 MJ.
e. According to Indian Centre for Science and Environment in 2007–2008, 78% of India's urea production came from natural gas as the feedstock and rest from fuel oil and naphtha contributing 11% each [211]. Since the maximum urea in India is produced from natural gas so the assumed 100% urea production is from natural gas.
f. Electricity production has been assumed to be from 100% fossil fuel fired power plants in India. Fossil fuel share in electricity generation in India is 64%. Coal is by far the most important fuel source for power generation, with 52% of electricity generated in coal-fired power plants and rest from natural gas (11%), oil (1%), hydro (23%), nuclear (3%), and renewable (10%) [212].
g. The initial temperature of Jatropha seed cake during pyrolysis has been considered to be at 20 °C.
h. Hydrogenation is a part of hydrotreating, therefore, the energy consumption for hydrogenation has been assumed to be same as that for hydrotreating, and it has also been assumed that entire energy input is in the form of electricity.

i. Specific heat for Jatropha seed cake was assumed to be same as that of cellulose.

j. Offgas contains 80% of propane [213], therefore, the calorific value of offgas was assumed to that of propane.

5.7.4. Calculations and parameters considered for study

The various parameters considered for this study are given in Table 5.1 and calculation methods are given in Table 5.2.

Table5. 1: Various Parameters Considered for Study

Parameters	Value	Unit	References
Area under study	1	hectare	
Weight of one polybag used in nursery raising	10	gram	
Spacing between Plants	2*2	meters	
Plant Density	2500	Per hectare	
Density of Diesel	0.850	kg/liter	
Density of methanol	791.8	Kg/m^3	
Emission factor /ton Plastic (Land filled)	0.04	$MTCO_2E$ (Metric ton carbon dioxide equivalent)	[214]
Specific energy consumption for Urea production from natural gas from the best available technique.	20.9	GJ/ MT.	[211]
The average CO_2 emission during Urea production from the various plants surveyed by Centre for science and environment.	0.61	$MTCO_2$/MT of urea	[211]
CO_2 emissions from diesel at oxidation factor of 0.99	10.1	kg/gallon	[215]
1 US gallon	3.785	liters	
Calorific value of Diesel	44000	kJ/kg	[128]

Parameters	Value	Unit	References
According to Ernest Orlando Lawrence Berkeley National Laboratory in 2001-02 the average energy consumed per MT of fertilizer produced in India (nitrogen and phosphorous fertilizers)	34.20	GJ/MT of fertilizer	[216]
Effective CO_2 Emission Factor for fuel oil	77.4	$MTCO_2/TJ$	
Effective CO_2 Emission Factor for naphtha	73.3	$MTCO_2/TJ$	
The world average is 2.1 $MTCO_2/MT$ ammonia for natural gas feedstock and 4.1$MTCO_2/MT$ ammonia for other feedstocks. And since natural gas forms 50% of feedstock and rest as another 50% so the average is	3.1	$MTCO_2/MT$ ammonia	[211]
Average specific energy consumption for ammonia from all the feedstocks	10.9	GCal/MT	[217]
CO_2 emission from electricity	980	gCO_2/kWh of electricity produced	[212]
Fossil fuel energy per 1kWh electricity, considering the conversion efficiency(calculated as per the given data in the literature)	10.69	MJ	[218]
Calorific Value of Naphtha	10500	kCal/kg	[219]
Energy consumed in Hydrogen production	50.9	kWh/kg of Hydrogen	[220]
Hydrogen required for hydrogenation/kg algal oil	1.5	wt% of algae oil	[213]
Lower heating value of Hydrogenated oil (LHV)	44	MJ/kg of hydrogenated oil	[113]
Heating value of gas obtained during pyrolysis	12	MJ/kg	[221]
Specific heat of cellulose	1.5	$J°C^{-1}g^{-1}$	[222]
Density of hydrogen at NTP	0.0899	Kg/m^3	[223]
Hydrogen required for hydrotreatment /kg pyrolysis oil	400	NL(normal liter)	[224]
Average energy consumed in hydrotreating/hydrogenation process	0.32	kWh/kg of oil processed	[220]
Heating value of gas obtained during pyrolysis and liquefaction	12	MJ/kg	[221]

Parameters	Value	Unit	References
Calorific value of Naphtha	10500	kCal/kg	[219]
Calorific value of Propane	10792777.3	kCal/ton	[225]

Table5. 2: Various Calculation Methods

Parameters	Calculation method
Calculation for CO_2 emissions from FAME	The CHN (Carbon, Hydrogen and Nitrogen content) analysis, conducted in biodiesel lab at University of Petroleum and Energy Studies, gave 0.78 kg of Carbon/kg of FAME (green diesel obtained via transesterification). The formula used for CO_2 emissions is: Carbon dioxide emission from fuel combustion = Fuel combusted * Carbon content coefficient* Fraction oxidized * (44/12) where 44 is molecular weight of CO_2 and 12 is molecular weight of carbon. If we consider fraction oxidized = 1 (The use of a 1.00 fraction oxidized for fuel combustion follows the guidance from Chapter 3 of the 2006 IPCC, guidelines for National Greenhouse Gas Inventories [226]). CO_2 emission from 1 kg of Green diesel = 1 * 0.78 *1 * (44/12) =2:86 kg of CO_2
Calculation for CO_2 emissions from Hydrogenated oil	Hydrogenated oil have following chemical structure C_nH_{2n+2} [113], which gave 0.75 kg of carbon/kg of hydrogenated oil. Considering the formula for CO_2 emissions and fraction oxidized same as that mentioned for FAME above, CO_2 emission from 1 kg of Hydrogenated oil = 1 * 0.75 * 1 * (44/12) =2.75 kg of CO_2.
Calculations for direct N_2O emissions from fertilizer applied	Nitrous oxide emissions = FC * EC FC is the Fertilizer Consumption; EC is the Emission Coefficient = 17.68 kg/ton of fertilizer consumed [227] . The emission coefficient represents the percent of nitrogen applied as fertilizer that is released into the atmosphere as nitrous oxide.

Parameters	Calculation method
Calculation for NEB and NER	NEB = Total Energy Output -Total Energy Input NER = Total Energy Output/Total Energy Input
Calculation of heating value of char	The experimental results have demonstrated an increasing of the LHV of char concurrently with the increasing of the pyrolysis process temperature [228]. A significant linear correlation there is between the pyrolysis temperature and HHV of the char. The equation to calculate relationships between temperature and the char yield is [228]: $HHV = 0.0069T + 24.68$ [MJ/kg] Heating value of char produced at around 500 °C was estimated to be 28 MJ/kg.
Energy required for pyrolysis	The energy required for pyrolysis can be calculated with the following equation [229] Energy for pyrolysis (J/g)=Specific heat of biomass* (temperature rise in biomass)* amount of biomass

5.7.5. Jatropha cultivation & Harvesting at the identified site

A. Nursery raising

1) Polybags

Black poly-ethylene poly bags (weight per bag was 10 g) filled with soil (Equal quantity of sand, humus and soil, well mixed) were used to grow plantlets from seeds and cuttings in the nursery. It was observed that if watered every 3 days, it accelerated the germination and prepared the plants to be planted in the fields just at the age of 3 months. With good quality seeds, the germination rate was about 70%.

At 70% germination rate number of polybags required for getting 2500 well germinated plants was estimated to be 3500 with total emission of 0.0014 $MTCO_2E$ (metric ton carbon dioxide equivalent), if land filled.

2) Fertilizer

Along with sand, humus and soil, 25 kg (0.025 MT) of Urea was also used for the nursery raising for plantation in field of one hectare. Therefore, energy required for 0.025 MT of Urea was estimated to be 0.52 GJ with 0.02 MT of CO_2 emissions. The direct nitrous oxide emission from the use of Urea was estimated to be 0.44 kg.

B. Plantation in field

At the age of 3–4 months, the small plantlets were planted in the prepared field, at the beginning of the rainy season, with spacing of 2*2 m with plant density of 2500 per hectare.

1) Tilling

Field preparations involved tilling and weed removal. Tilling loosened the soil for plantation as well as uprooted the weeds. It was found that to till one hectare of land, a tractor normally took 2 hours and consumed 12 liter of diesel. Therefore, the total energy consumed was estimated to be 0.45 GJ and with 0.03 MT of CO_2 emissions.

2) Pit preparation and plantation

After the field was tilled and weeds were removed, pits were dug. It was seen that 150 pits could be dug per day per man, working for 8 hours a day. So, 2500 pits required 133 man hours. Thereafter the plantlets from the nursery were planted in these pits. In 8 man hours, 300 plants could be planted. Accordingly, it took total of 67 man hours to plant 2500 plants. Since both the activities of pit preparation and planting were done manually, no fossil energy was consumed. Even if plantation is done on a large scale, due to availability of inexpensive labor in India, it can still be done manually.

3) Fertilizer

For initial 2 years fertilizers were used every 6 months and once every year after fruiting. The mineral fertilizer used was Di Ammonium Phosphate (DAP). 500 g of cowdung (gobar), mixed with 50 g of DAP, was fed per plant. Thus, for 2500 plants total of 0.88 MT of DAP and 8.75 MT of cowdung was required.

A lot of energy is consumed to produce fertilizers, which further depends on capacity utilization, feedstocks, plant age and technology. Energy use for 0.88 MT of DAP was evaluated to be 30 GJ. The share of various feedstocks used to produce fertilizer in India is Natural gas (50): Naphtha (25): Fuel oil (10): External ammonia (15) [215]. Based on these values the share of each of the feedstock in production 0.88 MT of fertilizer, and CO_2 emissions from them was evaluated which is given in Table 5.3. The direct Nitrous oxide emission from the use of DAP was estimated to be 15.47 kg.

Table5. 3: Energy Share and CO_2 Emissions from each Feedstock in Production of 0.875 MT of Fertilizer {Calculated based on data given in reference number [215]}

Feedstock	Energy required (GJ)	Amount of CO_2 emitted (MT)
Natural Gas	15	0.71
Naphtha	7.5	0.55
Fuel oil	3	0.23
Ammonia	4.5	0.31
Total	30	1.8

4) Irrigation

Irrigation was done with the help of a pipe attached to water tankers. For large scale plantation drip irrigation was found to be very costly, as a lot of pressure is required to maintain the water flow in the larger area. Excluding 4 months of rainy season, a minimum of 16 times irrigation was done for initial 2 years and two times every year later on.

The size of pipe used to deliver water was 2.5 inch and10 liter of water was given to every plant. Almost 5 liter got wasted from moving from one plant to another, so an average of 15 liter was considered per plant. Total 37,500 liter of water per irrigation was estimated for one hectare of Jatropha plantation with 2500 plants. Accordingly, in the initial 5 years, 22 times irrigation was done. 5 liter of diesel was consumed by the tanker per irrigation thus a total of 110 liter (93.5 kg) of diesel was consumed during the initial 5 years. Therefore, total energy input was estimated to be 4.11 GJ with 0.3 MT of CO_2 emissions.

5) Weeding, pruning and harvesting

Weeding was regularly done, till the plants became 3 months old. Even before planting in fields, the weeds were removed by tilling. Pruning was also done on a regular basis, after the plants became 3 years old. It gave rise to many new branches and thus, more fruits.

Harvesting was labor intensive and was done manually. Considering that all the fruits of Jatropha do not ripe at the same time, mechanical harvesting was not found to be efficient. The ripe fruits of yellow and black color were picked by hands.

It was observed that one person could harvest at rate of 8 kg of dry seeds/hour. Therefore, to harvest 22,625 kg of seeds, a total of 2828 hours of man work was estimated. Table 5.4 gives the total yield per hectare for the initial 5 years.

Table5. 4: Total Yield Per Hectare for Initial Five Years from Jatropha Plantation in the Identified Site

Plantation Year	Seed yield/plant (kg)	Average yield/Plant (kg)	Average yield/hectare (kg)
First	nil	Nil	nil
Second	0.2 to 0.4	0.3	750
Third	0.5 to 2	1.25	3125
Fourth	2 to 4	3	7500
Fifth	4 to 5	4.5	11250
Total Yield/hectare(kg)			**22625**

5.7.6. Oil extraction carried out in the biodiesel lab

1) Decortication

After the Jatropha fruits were harvested they were decorticated i.e. fruit shells were removed to extract the seeds. Decortication was done mechanically, for which a decorticator (made by Indian Institute of Technology, New Delhi) of 1.5 kW and capacity of 150 kg/hour was taken. Therefore, the total time to decorticate all the seeds was estimated to be 151 hours with energy use of 226.5 kWh (2.42 GJ) and 0.22 MT of CO_2 emissions.

2) Seed pressing

It was found that after decortication the weight of the seeds became 60% of the original weight of corticated seeds. Therefore, at 60% of original weight, the weight of 22,625 kg corticated seeds was estimated to be 13,575 kg. Thereafter, the seeds were pressed for oil extraction. For this purpose a screw press expeller of 5.5 kW with capacity 50 kg/hour was taken. The oil content of Jatropha seeds in a literature is given to be 38%

[230]. Therefore, at 100% extraction efficiency the oil yield should be around 5158.5 kg. But with the screw press used, we obtained the oil yield of 4126.8 kg i.e. the extraction efficiency of almost 80%, and that too when the seeds were pressed twice. It was estimated that it would take almost 543 hours (not considering the reducing weight of the seeds after each round of pressing) with energy use of 2986.5 kWh (31.9 GJ) and 4.39 MT of CO_2 emissions.

3) Filtering of oil

After the above process, the oil was filtered using a filter press of 1.5 kW with capacity of 600 kg/hour. Total time for filtering was estimated to be 7 hours with energy use of 10.5 kWh (0.11 GJ) and 0.01 MT of CO_2 emissions.

5.7.7. Oil & Seed cake processing

A. Oil processing

The most commonly used method for oil processing is transesterification. In fact, there is another process, called hydrogenation which forms green diesel with much better properties than the FAME/ green diesel obtained via transesterification process. Detailed comparison of properties of green diesel obtained from both is given in Table 3.3 of Chapter 3.

1) Oil processing via Transesterification

Energy use for transesterification of 1 kg of Jatropha oil was evaluated experimentally, and then was used to estimate energy use for transesterification of 4126.8 kg of oil. Table 5.5 gives the total energy use during various steps of oil processing for converting it into biodiesel.

Carbon dioxide emission from 22 GJ of energy use during oil processing was estimated to be 1.87 MT of CO_2. Further, at 95% conversion efficiency, the total biodiesel yield was expected to be 3920 kg.

Table5. 5: Energy Use during Various steps of Oil Processing via Transesterification for converting it into Green diesel

Various steps in Oil processing for converting it into biodiesel	Total Energy Input per unit kg in KJ	Total Energy Input for 4126.8 kg in GJ
Energy consumption for Transesterification	2888	11.92
Energy consumption for washing	259	1.07
Energy consumption for drying	2256	9.31
Miscellaneous energy for pumping unit	1.7	0.01
Total Energy Input		22

2) Oil processing via hydrogenation

Energy use and hydrogen required for hydrogenation of 1 kg of Jatropha oil was considered to be same as that for a study done on algal oil [213]. The amount of hydrogen required for hydrogenation of 4126.8 kg of Jatropha oil was estimated to be 61.9 kg. Table 5.6 gives the total energy use during various steps of oil processing via hydrogenation for converting it into green diesel.

Table5. 6: Energy Use during Various steps of Oil Processing via Hydrogenation for converting it into Green diesel

Various steps in Hydrogenation	Energy Input (GJ)
Energy consumed in hydrogen production	11.34
Energy required for hydrogenation	14.12
Total energy input	25.46

At 78 % conversion efficiency [213], the total green diesel yield was estimated to be 3218.9 kg. Along with diesel this process also produces 2% i.e. 82.54 kg of naphtha and 6% i.e. 247.6 kg of offgas [213].

The energy content of 82.54 kg of naphtha was estimated to be 3.62 GJ, and 247.6 kg of propane was estimated to be 11.14 GJ. This 14.76 GJ of energy can be used to produce electricity required for hydrogenation process. Therefore, the effective total energy input during hydrogenation process was estimated to be 10.7 GJ. The total CO_2 emission from electricity uses (1320.58 kWh for hydrogenation) was estimated to be 1.29 MT.

B. Seed cake processing

The 9448 kg of seed cake left after oil extraction can be used as fertilizer, or can be used to produce biogas [129]. Since the current work is focused on green diesel production, therefore, apart from the above two uses, it can also undergo pyrolysis to produce bio-oil, char and gas. The pyrolysis oil can further be upgraded to form green diesel.

The amount of gas, liquid, and solid products produced after pyrolysis depend on the reaction parameters [231]. Depending on the pyrolysis time or heating rate, it is of two types, i.e., slow and fast pyrolysis [229]. Slow pyrolysis forms more of char while fast pyrolysis dramatically alters and shifts the reaction to form more of liquid bio-oil [229, 232].

The yield of bio-oil during fast pyrolysis (energy provided was in the form of electrical energy) is maximum at 500 °C [231]. Therefore, in the current study the product yield from pyrolysis of seed cake was estimated at 500 °C. The ratios in which oil, gas and char are obtained at 500 °C are 64.25: 31.86: 3.89 respectively [231]. Therefore, it was estimated that pyrolysis of 9448 kg of seed cake would produce 6070.34 kg of bio-oil, 3010 kg of gas and 367.5 kg of char.

The bio-oil also contains about 15 % wt water [232] and higher oxygen content, which decrease its heating value to about 15- 19 MJ/kg. Moreover, it is not suitable for direct application in diesel engines, and thus, needs to be further upgraded [224]. In their pure form, pyrolysis oils are not suitable for use in modern diesel engines. The high viscosity of the oil may be a major factor in carbon deposits in the combustion chamber and exhaust ports. A reduction in viscosity greatly reduces engine operation problems [231].

One of the technologies used for upgrading is catalytic hydrotreatment, which is carried out at about 200-400 °C and 100-200 bar pressure. The Ru/C catalyst was found to be superior with yield of about 60 wt% upgraded oil [224]. Moreover, hydrogenated oil has heating value of 44 MJ/kg i.e. almost more than twice the heating value of bio-oil obtained via pyrolysis. Even the calorific value of Jatropha oil cake is only about 13.56 MJ/kg [231].

The amount of hydrogen required for upgrading 6070.34 kg of bio-oil was estimated to be around 218.5 kg. Moreover, with 60% conversion efficiency the amount of upgraded oil obtained was estimated to be around 3642 kg. Table 5.7 shows the total energy uses during various steps of green diesel production from Jatropha seed cake.

Table5. 7: The Total Energy uses during Various Steps of Green Diesel Production from Jatropha Seed Cake

Various steps in conversion of Jatropha seed cake to green diesel	Energy Input
Energy required for pyrolysis (GJ)	20.19
Energy consumed in hydrogen production (GJ)	40
Energy required to upgrade bio-oil i.e. for Hydrotreatment (GJ)	20.77
Total energy input (GJ)	80.96

The energy content of 3010 kg of gas obtained during pyrolysis was estimated to be 36.12 GJ and 367.5 kg of char was estimated to be 5.88 GJ. This 42 GJ of energy can be used to produce electricity required for pyrolysis and hydrotreatment. Therefore, the effective total energy input during entire process was estimated to be 38.96. Carbon dioxide emission, from electricity uses (1888.89 kWh for pyrolysis and 1942.5 kWh for hydrotreatment) during the entire process, was estimated to be 3.75 MT.

5.7.8. End combustion of Green diesel

Experimentally, it was found that combustion of 1 kg of green diesel (FAME) obtained via transesterification gave 41,238 kJ (0.04 GJ) of energy output. Thus, the total energy output from 3920 kg of green diesel obtained via transesterification was estimated to be 161.65 GJ. And from calculation, the total CO_2 emissions were found to be 11.21 MT (11,213 kg).

From literature review, it was found that combustion of 1 kg of green diesel (hydrogenated oil) obtained via hydrogenation gave 44 MJ [113] of energy output. Thus, the total energy output from 3218.9 kg of green diesel obtained via hydrogenation was estimated to be 142 GJ. And from calculation, the total CO_2 emission was estimated to be 8.9 MT (8852 kg).

Since the green diesel (Upgraded bio-oil) obtained by pyrolysis of Jatropha seed cake oil was also assumed to be upgraded via hydrotreatment, its calorific value was assumed to be same as that of the green diesel obtained via hydrogenation i.e. 44 MJ. Thus, the total energy output from 3642 kg of green diesel obtained via hydrogenation was estimated to be 160.25 GJ. And from calculation, the total CO_2 emission was estimated to be 10 MT (10015.5 kg).

5.7.9. Results and discussion

Two separate tables for stage wise energy input/output and CO_2 emissions per hectare during first five years of Jatropha life cycle were made. Table 5.8 includes oil processing via transesterification process and Table 5.9 includes oil processing via hydrogenation process. It is clear from Tables 5.8 and 5.9 that green diesel production via both the processes have equal values for NER, while CO_2 emissions are less for biodiesel production via hydrogenation process.

Table5. 8: Stage wise Energy input/output and CO_2 emissions per hectare during first five years of Jatropha life cycle (for oil processing via transesterification)

Stages	Sub-stages	Energy input/output (GJ)	CO_2 emissions (MT)
Jatropha Cultivation	Nursery raising including use of polybags and fertilizer	0.52	0.02
	Tilling,	0.45	0.03
	Fertilizer during field plantation	30	1.8
	Irrigation	4.11	0.3
Oil Extraction	Decortication	2.42	0.22
	Seed pressing	31.9	4.39
	Filtering of Oil	0.11	0.01
Oil processing	Transesterification	22	1.87
Total Energy use/ CO_2 emissions		91.51	8.64
Total energy output during end combustion of Biodiesel		161.65	11.21
NEB /Total CO_2 emissions		70	20
NER		1.77	

Table5. 9: Stage wise Energy input/output and CO_2 Emissions per hectare during first five years of Jatropha Life Cycle (for Oil Processing via Hydrogenation)

Stages	Sub-stages	Energy input/output (GJ)	CO_2 emissions (MT)
Jatropha Cultivation	Nursery raising including use of polybags and fertilizer	0.52	0.02
	Tilling,	0.45	0.03
	Fertilizer during field plantation	30	1.8
	Irrigation	4.11	0.3
Oil Extraction	Decortication	2.42	0.22
	Seed pressing	31.9	4.39
	Filtering of Oil	0.11	0.01
Oil processing	Hydrogenation	10.7	1.29
Total Energy use/ CO_2 emissions		80.21	8.06
Total energy output during end combustion of Biodiesel		142	8.9
NEB /Total CO_2 emissions		61.79	16.96
NER		1.77	

Though, both the processes have equal values for NER, yet, as mentioned earlier, green diesel obtained via hydrogenation process has much superior quality in comparison to green diesel obtained via transesterification process. Therefore, the LCA, including hydrogenation process, will be used to carry on the further analysis.

This section has been discussed in two parts. Initially, in order to fulfill the first part of the first objective i.e. to find out if the values of NEB and NER can further be increased by using a high input Jatropha cultivation system. NEB and NER have only been discussed for oil processing stage via transesterification process. Seed processing has not been included in this part. It has been done so that the results of this study can be compared to previous similar kind of case specific studies on LCA of low input Jatropha green diesel production system. This would bring the current study at the same platform as that of the previous studies.

In the second part of the results and discussion, NEB, NER and CO_2 emissions have been calculated for entire life cycle of Jatropha green diesel production system. It includes oil processing via hydrogenation and also includes the seed processing for green diesel production.

A. Comparison with previous studies

In a similar kind of case specific LCA of Jatropha biodiesel, a small scale, but low input Jatropha biodiesel system on wasteland in Allahabad, India was studied. This study evaluated life cycle energy balance for Jatropha biodiesel system over the rotation period of 20 years. It considered non-renewable energy requirement which included construction of all the machineries used in the Jatropha biodiesel production along with fertilizer, electricity and diesel production and use. The management practices included use of inorganic fertilizers only before the plantation establishment, while the biomass residues, produced during its life cycle, were brought back to the field. Irrigation was practiced only in extreme conditions when monsoon was late. The average yield was expected to be 1695 kg dry seeds per hectare, 275 kg crude Jatropha oil per 1000 kg seed with production of 97 kg of Jatropha biodiesel per hectare. Considering the energy content of only Jatropha biodiesel and excluding that of co-products, the net energy gain was 78.2 kJ per FU (release of 1 MJ in a car engine fueled by Jatropha biodiesel), and net energy ratio was 1.35 [43].

When this was compared with the current study, it was found that average yield per hectare of the current study was eight times to that of the literature study with low input system. Even if we include the non-renewable energy requirement given in this literature, the energy balance remains higher.

Another study was done on energy analysis for Jatropha plantation system for biodiesel production in Thailand. The management practices included use of fertilizer once every year with irrigation. Details of irrigation were not given in the literature. For one hectare perennial plantation over a period of 20 years, the total energy use was about 940 GJ. Total energy output, including all the co-products like crude glycerin, peel, seed cake and wood was 5660 GJ. While that from biodiesel alone was less than 1500 GJ [44]. The net energy ratio of this study was 1.42, which was found to be lesser than that of the current study.

As per our analysis, with the passage of time the NEB and NER will increase for the current study, as the energy use during Jatropha cultivation stage will decrease because of lesser fertilizer and irrigation requirements in the ensuing years. Thus, widening the gap between the values of NEB and NER for the current study and the two studies mentioned above.

Studies of another full chain energy analysis of biodiesel production, but this time from Palm oil, clearly showed that even if the NEB and NER of biodiesel from Jatropha were lesser in comparison to those of Palm oil and Coconut oil, yet when energy content of the co-products were also considered, Jatropha had the highest value for both the indicators in comparison to the rest two [205]. Table 5.10 shows the NEB values for all the compared studies with the information of the year and country done.

Table5. 10: NEB values of the Compared sSudies

Year of Study	Plant	Country	Crude Oil yield (kg/ha)	NER (considering energy yield from biodiesel alone)	References
Current Study	Jatropha	India	2052 (in the 5th year)	1.77 (for initial 5 years)	
2010	Jatropha	India	466 (mean yield over 20 years)	1.35 (for 20 years' lifetime)	[43]
2010	Jatropha	Thailand	1932 (in the 6th year)	1.42 (for 20 years' lifetime)	[44]
2009	Palm	Thailand	2800 (mean yield over 25 years)	2.42 (for 25 years' lifetime)	[205]

B. Net energy and CO_2 emissions result (LCA includes oil processing via hydrogenation as well as seed processing)

Table 5.11 shows stage wise energy input/output and CO_2 emissions per hectare during first 5 years of Jatropha life cycle. Total energy input during first 5 years of Jatropha plantation was estimated to be 119.17 GJ. Figure 5.3 shows that the maximum energy input was during seed cake processing stage followed by Jatropha cultivation and oil extraction, which have almost equal energy input. The main factor resulting in excessive energy use during processing of seed cake was energy consumed during hydrogen production for up-gradation of bio-oil produced from pyrolysis of seed cake. During Jatropha cultivation stage the most energy intensive activity was the application of chemical fertilizers, as fertilizer production in itself is a very energy intensive process.

Table5. 11: Stage wise Energy input/output and CO_2 emissions per hectare during first five years of Jatropha life cycle (for oil processing via Hyrogenation)

Stages	Sub-stages	Energy input/output (GJ)	CO_2 emissions (MT)
Jatropha Cultivation	Nursery raising including use of polybags and fertilizer	0.52	0.02
	Tilling,	0.45	0.03
	Fertilizer during field plantation	30	1.8
	Irrigation	4.11	0.3
Oil Extraction	Decortication	2.42	0.22
	Seed pressing	31.9	4.39
	Filtering of Oil	0.11	0.01
Oil processing	Hydrogenation	10.7	1.29
Seed cake processing		38.96	3.75
Total Energy use/ CO_2 emissions		119.17	11.81
Total energy output during end combustion of Biodiesel		302.25	18.9
NEB /Total CO_2 emissions		183.08	30.71
NER		**2.54**	

The main factor resulting in excessive energy use during oil extraction was seed pressing, as the entire activity was done twice to extract the maximum oil from the seeds, yet could achieve only 80% extraction efficiency. It consumed almost 93% of the total energy input during oil extraction stage. During oil processing stage hydrogen production alone consumed almost 50% of the total energy use of the oil processing stage, while pyrolysis and hydrotreatment consumed together consumed the rest

50%. It was estimated that that end combustion of the entire green diesel produced during first five years of Jatropha plantation, would release almost 302.25 GJ of energy, giving net positive energy balance of 183.08 GJ and net energy ratio of 2.54.

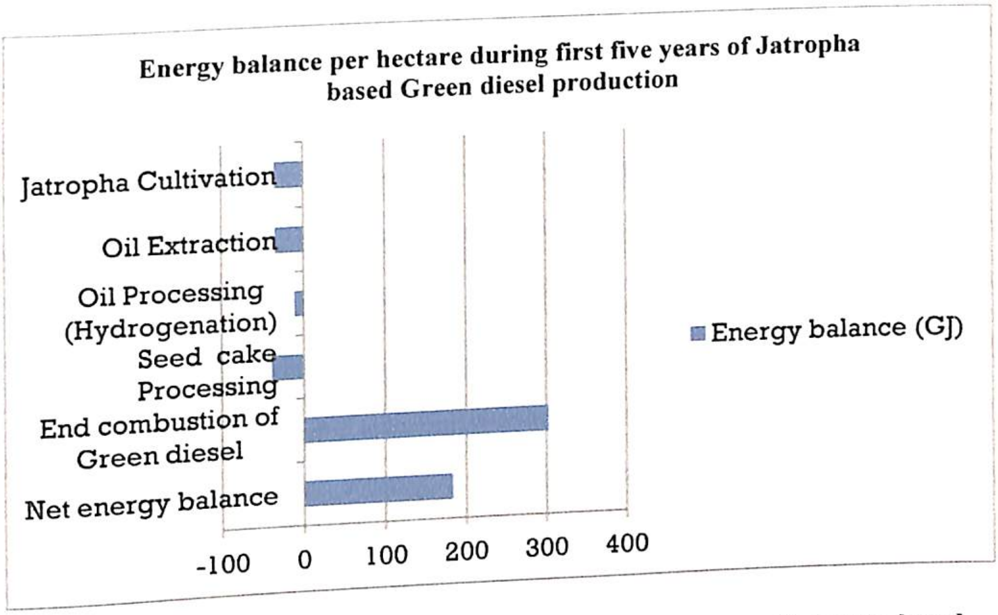

Figure5. 3: Energy balance per hectare during first five years of Jatropha based biodiesel production

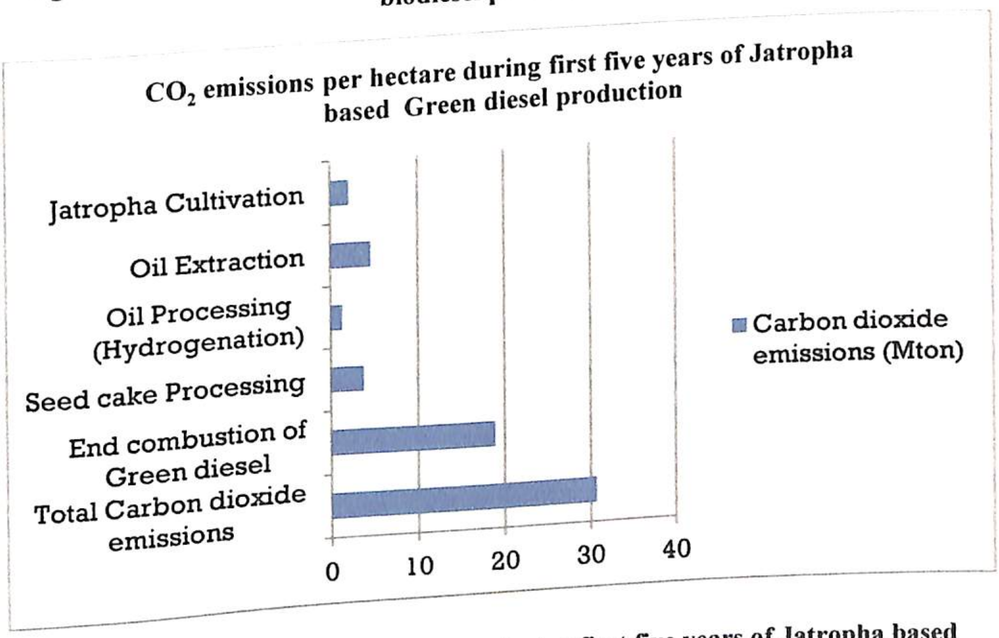

Figure5. 4: CO_2 emissions per hectare during first five years of Jatropha based Green diesel production

Figure 5.4 shows that end combustion of biodiesel emitted maximum carbon dioxide followed by oil extraction stage. Despite of almost equal energy input, oil extraction stage emitted more CO_2 than Jatropha cultivation stage. It was so, because all the activities in this stage consumed a lot of electricity, which in India is produced from fossil fuels with a major share of coal in it. The major share of CO_2 emissions during Jatropha cultivation stage came from the use of chemical fertilizers. Since fertilizer production is a very energy intensive stage so emissions should have been very high but it was not so, because the maximum amount of fertilizer produced in India is from natural gas, which is a clean fuel.

The overall life cycle energy balance for first 5 years of biodiesel production from Jatropha was found to be positive, and will remain for the rest of Jatropha life. Our analysis showed that both NEB and NER will increase in the further years as the energy use during Jatropha cultivation stage will decrease because of lesser fertilizer and irrigation requirements.

5.8. Cost of Green diesel production

All costs for green diesel production from Jatropha were estimated based on vendor quotes, prior literature studies and present market costs. With the assumption that capital cost has 20 years of life, the operational cost was also estimated for over 20 years.

It is clear from Tables 5.12 and 5.13 that operational cost over 20 years is much more than the capital cost. The highest contributor to the operational cost is the man power wages, which is almost 80 % of the total operational cost and 50% of the overall cost. According to the current study, the cost per kg of green diesel production from Jatropha is ₹ 62.43. This cost can be further brought down by using genetically superior seeds for plantation, which would produce more seeds with more oil content per seed.

Table5. 12: Capital Cost Investment over 20 years, for Green Diesel Production from Jatropha

Capital cost	Rate	Cost (₹)
Land (1 hectare for cultivation & 0.5 acres for nursery)	₹125000/acre	371250
Machinery (Decorticator, screw press expeller, filter press)		918000
Hydrotreating unit (2 units)	10 kg/day	45000
Pyrolysis unit	15 kg/day	17000
Total capital cost (20 years life)		**1351250**

Table5. 13: Operational Cost Investment over 20 years, for Green Diesel Production from Jatropha

Operational cost	Rates	Cost (₹)
Tilling cost	₹ 500/acre	1250
Cost of nursery raising	Approximately ₹ 1/plant (Inclusive of all inputs)	3500
Fertilizer	DAP at ₹ 650/50 kg and compost gobar at ₹ 2/kg	90750
Manpower (1skilled, 1 semiskilled)	₹ 100/day for semi-skilled and ₹ 150/day for skilled labor	1825000
Hydrogen	₹ 75/kg	177887
Electricity	₹ 5/unit	162072
Diesel uses	₹ 42/liter	11424
Total operational cost (over 20 years)		**2271883**

Table5. 14: Total invest over 20 years, for Green diesel production from Jatropha

Total Capital cost (₹)	**1351250**
Total operational cost(₹)	**2271883**
Total cost (₹)	**3623132.96**
Total green diesel production (kg)	**58036**
Cost /kg of green diesel produced (₹/kg)	**62.43**

5.9. Concluding Remarks

During first 5 years, the balance energy available for useful work was found to be 183.08 GJ, which was 60.5% of the total energy produced by Jatropha based biodiesel during that period, while rest 39.5% of it was consumed during Jatropha based green diesel production.

The net energy balance and net energy ratio can further be increased by manufacturing such a screw press which may provide almost 80% extraction efficiency at very first pressing or by using better and more efficient oil extraction methods. Further, if the plantation field is nearer the nursery, the polybags can totally be avoided. The decreased energy input will automatically take care of the greenhouse gas emissions.

Since, the production of chemical fertilizers is energy intensive, a further study is required to find out the effect on the productivity of Jatropha plants, if chemical fertilizers are totally or partially replaced with organic fertilizers. Even the seed cake, formed during the end of biodiesel production from Jatropha, can be used as organic fertilizer.

When the values for NEB and NER of the current study were compared with the values of previous low input Jatropha biodiesel systems, current study values were found to be higher than previous studies. It can be observed that these values will further increase on including the energy content of the co-products formed during the life cycle, which is very well supported by the study done on the Palm oil and Coconut oil. A few of the co-products include wood, seed cake and seed husk. The wood content, seed cake and seed husk can be increased by regular pruning as it gives rise to more branches and thus more seeds, which is further enhanced by proper fertilizer and irrigation practices. While our analysis also showed that both NEB and NER will increase in the further years, as the energy use during Jatropha cultivation stage will decrease because of lesser fertilizer and irrigation requirements.

It has been found that excessive use of Nitrogen fertilizers increase Nitrous oxide emissions, which have very high global warming potential [233]. But it can be reduced by better utilization of Nitrogen fertilizer and increased use of organic fertilizers. Appropriate crop management practices, which lead to increase in N use efficiency and yield, hold the key to N_2O mitigation. Application of nitrate (NO_3–N) fertilizers in crops with aerobic conditions and ammonium (NH_4–N) fertilizers in wetland crops also helps reducing the N_2O emission. Another innovative technology is the use of nitrification inhibitor that curtails the nitrification process, thus reducing soil emissions [234].

There are many oil processing techniques available, like hydrogenation, transesterification using base catalyst, acid catalyst, bio-catalyst and catalyst-free supercritical alcohol method. The production of green diesel, using a biocatalyst and catalyst-free supercritical alcohol method, eliminates the disadvantages of the alkali process by producing product of very high purity with less, or no downstream operations of washing and drying, which is a very energy intensive process. But the biocatalyst process has not yet been implemented in an industrial scale due to certain constraints, like enzyme inhibition by methanol, exhaustion of enzyme activity and high cost of enzymes. Super critical process takes place at very high temperatures, thus requiring more energy [29]. So, further research needs to be done to overcome such problems, and come up with a less energy intensive oil processing technique.

It can be concluded from the results that there is a huge potential for increasing the overall productivity of Jatropha biodiesel system by adopting high input practices with proper allocation of resources at right time and with proper care.