

EXECUTIVE SUMMARY

Depleting energy resources, growing energy demand and escalating prices of oil and petrol has led to an increased interest in renewable energy sources. Because of the world energy crisis, many countries, especially those lacking conventional fuel resources, have started to take a series of measures to resolve this problem.

When it comes to concern over these issues, India is not secondary to any other nation. Even the recent oil and gas discoveries in India have failed to keep pace with the energy demand. With high rate of economic growth, and 15% of the world's population, it is currently dependent on imports for 68% of its oil use and is expected to become the fourth largest net importer of oil in the world by 2025, behind the United States, China, and Japan.

The most feasible way to meet the growing demand for energy is by utilizing alternative fuels, which should be technically feasible, economically competitive, environmentally acceptable, and easily available. One such fuel that exhibits great potential is biofuel. Hydrocarbons can be replaced to some extent by other compounds including ethanol and biodiesel.

Biodiesel fuels are attracting increasing attention worldwide as a blending component or a direct replacement for diesel fuel. In comparison with the conventional diesel fuels, biodiesel is 100% renewable. It has better exhaust gas emission quality and is biodegradable. Rapeseed and Sunflower in Europe, Soybean in USA and Sugarcane in Brazil are being used as raw materials for producing biofuels. However, for the country like India with world's 15% population, food security is a major concern which restricts these options, as most of the biofuels used today are from food plants which are cultivated on fertile lands. Considering that India

consumes five times more diesel than gasoline fuel, it is of paramount importance that biofuels, particularly biodiesel, should get more attention in India. Moreover, biodiesel has been recognized as the most suitable fuel for diesel engines applications.

After experimental studies, *Jatropha curcas* was thought to be a promising biodiesel crop by planning commission of India. Moreover, in the recent years, “algae for fuel” concept has gained renewed interest for production of green diesel, due to their high oil productivity.

However, a few viability studies, already done on *Jatropha* have not taken care of the recent research on it. They have considered low input (with minimal care and minimal use of materials) *Jatropha* cultivation system. None of the studies have adopted the further changes in agronomical practices of *Jatropha* and have done viability studies on 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.

Further, a few viability studies, which have worked on LCA of algae, have got very low or negative values for net energy balance, have either not included the entire value chain or have considered only one of many available culture, harvesting, extraction and oil processing techniques.

It also needs to be brought out that, as per researcher’s knowledge, till date there is no literature which has done a comprehensive feasibility study for *Jatropha* and Algae.

Therefore, this study aims to do fresh viability studies on both the crops, and also do a detailed comparison of the two, on the basis of four broad parameters, which include agronomical practices and challenges, technical suitability, environmental acceptability and economic competitiveness,

and find out the more suitable energy crop between the two, for green diesel production in Indian context.

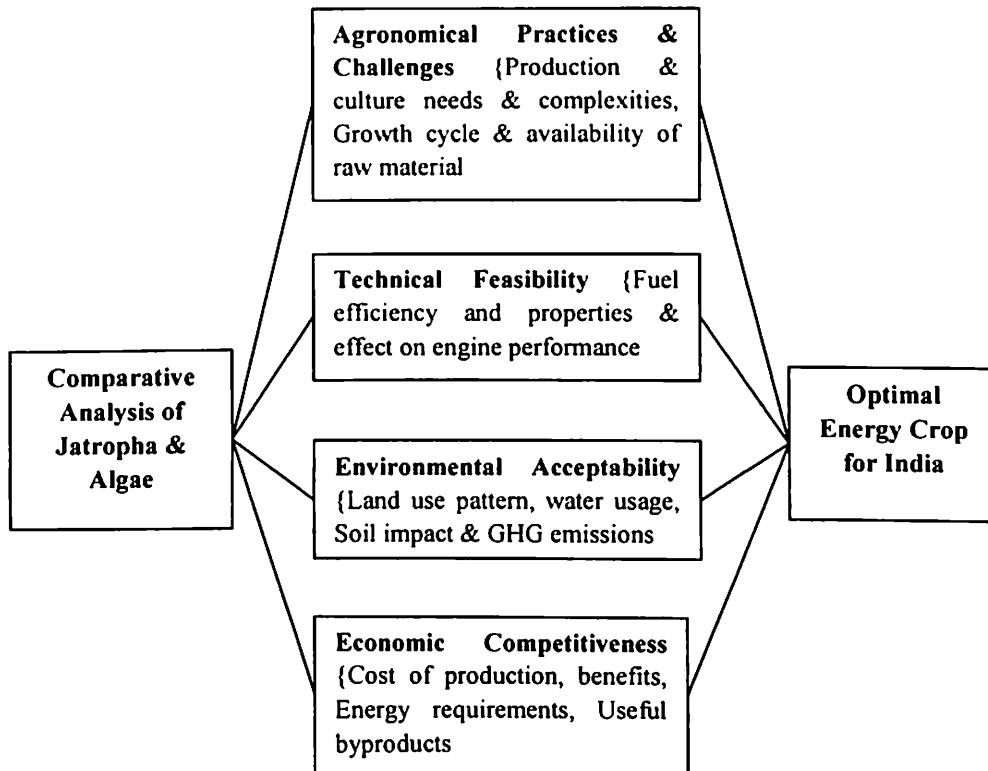
Research Objectives

- i. To find out if the values of Net Energy Balance can further be increased by using a high input *Jatropha* cultivation system, and also study its effect on environmental acceptability and economic competitiveness of *Jatropha* as energy crop in Indian context.
- ii. To find out if the value of Net Energy Balance for algae can further be increased or made positive by using a combination of many available agronomical practices and recent technological advancements, and further study its impact on the economic competitiveness and environmental acceptability of the energy crop.
- iii. Find out the more optimal energy crop between the two i.e. *Jatropha* and Algae, in Indian context, when compared on the basis of parameters, like, ease of agronomical practices, technical viability, economic competitiveness and environmental acceptability.

Present research comprises of all three types of research methods; library, field, as well as laboratory research. And as conclusive research tends to be quantitative in nature, same has been adopted for the current study due to its extensive relevance to quantitative study.

In order to attain the first two objectives, which have been aimed at finding out the values for NEB and NER for *Jatropha* and algae green diesel production systems, Life cycle assessment has been used. Research framework used to achieve the third objective, i.e. comparative analysis of the two energy crops, *Jatropha* and algae, has been shown in following Figure:

Research Framework



According to the current study, when the values NEB and NER, over five years, for high input Jatropha green diesel production system were compared to the previous studies, it was found that these values were more than the NEB and NER values of the previous studies. Moreover, these values were expected to increase further with the passage of time. Furthermore, when the energy inputs and outputs of green diesel production from Jatropha seed cake were added, it increased NER by almost 1.4 times.

For algae it was found that, even on including the entire value chain and with the adoption of best available agronomical practices and recent technological advancements, the values for NEB and NER did not come out to be positive.

Finally, when the two energy crops were compared on the basis of four broad parameters i.e. agronomical practices, technical viability, economic competitiveness and environmental acceptability, the study concluded that in the present scenario and technological availabilities, Jatropha is more optimal energy crop for green diesel production. Algae still has a long way to go.

In spite of high values of NEB and NER, the success of Jatropha as an energy crop will depend only on its viability as a commercial crop. There is need for the development and adoption of a package of practices/strategies for optimization of commercial cultivation of Jatropha and realize its full potential as an energy crop.

Moreover, though the oil production of algae is far more than that of Jatropha and algae has a huge potential as an alternative source of renewable energy, yet research and development in the area of green diesel production from microalgae has to go a long way to come out with technologies, which can further reduce the huge energy requirements during green diesel production from microalgae.

The thesis consists of seven chapters. The first chapter, *Introduction*, talks about the importance of energy in India and worldwide. It establishes the need for the study of renewable energy sources with special focus on green diesel or biodiesel. It also elucidates the importance of Jatropha and algae for production of green diesel.

The second chapter, *Literature Review and Research Methodology*, discusses about the methodological approach adopted for comparing Jatropha and Microalgae as an energy crop. It focuses on the gap between the current viability studies and the required viability studies for production of green diesel from Jatropha and algae. It is followed by the research problem, objectives of the study, research questions, scope of the study and a detailed research methodology to meet the set objectives.

The third chapter, *Value Chain of Jatropha*, outlines the various stages in the value chain of *Jatropha curcas* for biofuel production. It also provides a comprehensive understanding of each and every stage along with all possible methodologies and technologies developed till date for the production of green diesel. Once the value chain is in place, this chapter would build up the base for the further life cycle study for the calculation of net energy balance and net energy ratio for *Jatropha* green diesel production system. Each and every stage of the value the chain has influence on the LCA result.

The fourth chapter, *Value Chain of Algae*, outlines the various stages in the value chain of algae for biofuel production. It also provides a comprehensive understanding of each and every stage along with all possible methodologies and technologies developed till date for the production of green diesel. Once the value chain is in place, this chapter would build up the base for the further life cycle study for the calculation of net energy balance and net energy ratio for algae green diesel production system. Each and every stage of the value the chain has influence on the Life Cycle Assessment (LCA) result.

The fifth chapter, *Life Cycle Assessment of Jatropha Green Diesel Production System*, discusses in detail the various challenges of *Jatropha* cultivation and *Jatropha* green diesel production system. It talks about the 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 measures 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.

The sixth chapter, *Life Cycle Assessment of Algae Green Diesel Production System*, based on the value chain and various agronomical

practices and the techniques of green diesel production as reviewed in chapter 3, will aim to find out if the net energy balance can further be increased by using a combination of many available agronomical practices and the techniques of green diesel production from microalgae. It also talks about the cost economics of the best route.

The seventh chapter, *Comparative Study of Jatropha and Microalgae Based Green diesel Production System*, provides a detailed comparative analysis of green diesel production from Jatropha and microalgae on the basis of four parameters agronomical practices and challenges, technical suitability, environmental acceptability and economic competitiveness. While doing so, this chapter also compiles the entire thesis and its results.