

## **CHAPTER 2**

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### **LITERATURE REVIEW & RESEARCH METHODOLOGY**

#### **2.1.Introduction**

This chapter 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.

#### **2.2.Literature Review**

Production of suitable feedstocks is an important dynamic in the biofuels industry [27]. It is essential for biofuel production to develop feedstocks. It is also not easy to find a proper feedstock in the first phase of development [22]. The total number of oil-bearing species range from 100 to 300, and of them, 63 belonging to 30 plant families hold promise for bio-diesel production [25].

Raw materials contribute to a major portion in the cost of biodiesel production [6]. The choice of raw materials depends mainly on its availability and cost [6]. In every country at present, biodiesel is made from different variety of feed stocks that are available and cultivable domestically [28].

Many developed countries, such as USA and those belonging to European community are using edible oil-seed crops such as soybean, rapeseed, groundnut, sunflower for production of bio-diesel [25, 6]. In fact, they even have surplus amount to export. Hence, edible oils such as soybean and rapeseed are used in USA and European Nations, respectively.

Similarly countries with coastal area, such as, Malaysia and Indonesia have surplus coconut oil, and that is utilized for the synthesis of biodiesel. Brazil, being the largest sugarcane producer in the world, produces ethanol which is used to run 40% of its fuel powered cars [6] .

However, shortage of raw material to produce biodiesel is a major constraint [25]. Developing countries like India, already having dearth of huge quantity of edible oil (6.31 million tons) for consumption, cannot afford to use edible oils for bio-diesel production [25, 28]. India even though with a vast land area including coastal area does not produce enough edible oils and has to import these to meet the food requirements [6, 26]. Looking into this, a Planning Commission committee on development of biofuel, which submitted its report in 2003, noted that biodiesel in India has to be made from non-edible oil seeds [28]. Government of India launched “National Mission on Biodiesel” with a view to find a cheap and renewable liquid fuel based on vegetable oils [25]. More than 75 non-edible feed stocks, few being *Pongamia Pinnata*, Neem, Rubber, Rice Bran, Castor and *Jatropha Curcas*, were identified in India, whose fuel characteristics were found to be within the specification of biodiesel standard of USA, Germany and European Standard Organization [28]. Moreover, in the existing scenario, when most of the cultivable area has been occupied by conventional cultivated crops, plant species which can grow in wastelands under less favorable environmental conditions need to be promoted [39].

### **2.2.1. Review on *Jatropha***

After experimental studies, done by Planning commission of India, *Jatropha curcas* was thought to be promising choice for production of economically feasible biodiesel in India [28]. In the year 2003, the planning commission of India, launched a National Mission on biofuel

with special focus on plantation of *Jatropha* on wastelands to meet the country's energy demand [40].

Not only in India, but *Jatropha* has been widely accepted as a potential agricultural solution for subtropical and tropical locations and grown for large-scale cultivation for production of biodiesel [39]. Now many developing countries, especially those in South America, Africa and south Asia, including Mali, Nicaragua, Tanzania and Zimbabwe, have begun their *Jatropha* projects [22].

Currently there are over 60 energy plants recorded around the world. But only over 10 species have been studied and are known by people, of which *Jatropha curcas* is the most promising oil plant [22]. It is because of its hardiness, easy propagation, drought endurance, high oil content, low seed cost, short gestation period, rapid growth, adoption to wide agro-climatic condition, bushy/shrubby nature and multiple uses of different plant parts [25].

However, the initial experiences with *Jatropha* projects broke many myths associated with it. Initially it was said that *Jatropha* could even be grown on wasteland with minimal care and minimal requirement of water and nutrients [34]. But none of the projects gave any commercial yield [41], and in spite of efforts made by Indian government, its growth did not pick up [42]. The studies done on *Jatropha* (one in Allahabad in India [43] and another in Thailand [44]; which used net energy balance as indicator for estimating viability of *Jatropha* cultivation systems, gave very low values for Net energy balance. According to Behera et al the reason for failure 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, 47, 31]. From experiences with *Jatropha* projects, it is now clear that it performs

much better with adequate access to soil nutrients and water. Adding some fertilizer or manure is needed to maintain good long-term seed yields. This is because *Jatropha* is not a nitrogen-fixing crop, and substantial nitrogen is removed with the harvesting of the seeds [48].

### **2.2.2. Review on Algae**

Search for raw material for biodiesel production is not limited to vegetable oils only [6]. In recent years, 'Algae for fuel' concept has gained renewed interest with increase in demand for use of renewable energy sources, rocketing energy prices all over the world [49] and potential for high productivity feedstock for advanced fuels [50]. Algae's potential as a feedstock is dramatically growing in the biofuel market [51]. Researchers are developing algae that produce oils, which can be converted to biodiesel [4].

In United States, researchers are of the opinion that even surplus vegetable oils will not be enough to meet the future demand of biodiesel, and hence have tried algae as a raw material for biodiesel production. Algae, convert carbon dioxide into sugars and proteins, in presence of sunlight [6].

Today research is focused on the cultivation of microalgae rich in lipids in order to produce biodiesel [52]. Though, macroalgae also produce lipids but the percentage of oil content in macroalgae species studied so far, is not as high as those achieved by microalgae [53].

Research on the utilization of algae for biofuel production started more than 50 years ago [54]. Probably the most significant effort regarding biofuel production from microalgae was made by the US Department of Energy's Aquatic Species Program (ASP) that took place from 1978 to 1996. The program was a response to the early and mid 70's energy crisis, and focused on the production of biodiesel from high lipid-content algae grown in ponds, utilizing waste CO<sub>2</sub> from coal fired power plants. The

program included a broad range of research activities: collection and screening of potential species, biochemistry and physiology of lipid production, genetic engineering, algae production in wastewater treatment to systems analysis of the outdoor production [55]. Although the conclusion of the long-running ASP was that the biodiesel production from microalgae was unlikely to succeed, but circumstances have now changed. The need for security of energy supply, recognition of the need to reduce greenhouse gas emissions [56], and rising crude oil prices [57] have generated renewed interest in using algae as an alternative and renewable feedstock for fuel production [58, 59].

The characteristics that drive interest for its utilization are: high biomass yield when compared to terrestrial plants [50, 55] and high utilization of CO<sub>2</sub>. Algal biomass can be utilized as an energy source in co-firing, gasification, anaerobic digestion, or production of biofuel [55]. Microalgae have higher photosynthetic efficiency [15] owing to their simple cellular structure [60, 51]. They have rapid growth [51, 61, 15, 62], and can be harvested on a continuous basis throughout the year [60, 63]. They also have higher rates of oil production (oil content can exceed 80% by weight of dry biomass) [60]. They can be cultured in salty or waste water [64, 61, 62, 65]. It simultaneously leads to waste water treatment, during which they absorb nitrates and phosphates and release oxygen [61]. They absorb CO<sub>2</sub> [63], thus, biofuels from algae can be coupled with flue gas CO<sub>2</sub> mitigation [65, 60].

Microalgal biofuels are produced from the oil content of the algal cells [66]. It is this oil that can be extracted and converted into biodiesel [51]. Not all algal oils are adequate for making biodiesel, but suitable do commonly occur [35]. Therefore, one of the most important decisions in obtaining oil from microalgae is the choice of algal species to use [35, 67].

Considering that biodiesel is produced from oil content, biofuels ultimately derive their energy from the sun through photosynthesis [68]. Knowledge of the regulation of oil synthesis has suggested ways to produce triacylglycerols in abundant non-seed tissues [68]. Further, the algae oil content and composition is strongly dependent on the metabolic status of the cells [69]. Several studies have shown that the quantity and quality of oil within the cell can vary as a result of changes in growth conditions [70], such as temperature, light intensity [69, 71], cell culture density, pH and alkalinity, contamination by other microorganisms [52] and nutrient media characteristics, which include concentration of nitrogen, phosphates, and iron [71, 69]. The possibility of oil accumulation, through manipulation of environmental culture conditions, has a great potential in oil production. The culture conditions of the microalgae can be optimized in order to maximize lipid synthesis [72]. In general, microalgae are photoautotrophic organisms [52], but some microalgae species grow utilizing organic compounds as energy or/and carbon sources [73, 52, 74] to generate adenosine tri-phosphate (ATP) [52]. As discussed above, due to this ability algae can also be cultivated using photoautotrophic (or photosynthetic), heterotrophic, or mixotrophic growth [73, 74]. Photoautotrophic and mixotrophic growth are influenced by light intensity and by carbon source concentration, while heterotrophic growth is influenced only by the organic substance concentration [52]. Algae can be cultivated in open ponds, such as, open raceway ponds or in closed systems such as photobioreactors [75, 54]. Photobioreactors provide better control over the culture conditions affecting algae growth [56, 76, 74]. The use of such large quantities of fertilizer for microalgae cultivation raises questions about their environmental impact [52]. Algae have a large water foot print in terms of energy returned on water invested [77]. Recycling harvest water reduces water uses and use of waste water reduces fertilizer requirement [50, 78, 79, 80]. Most of the studies done on

Life cycle assessment of algae for energy balance calculation, have either found very low [81] or even negative values for net energy balance [82, 83, 84].

### **2.3. Inference drawn from the Literature review**

From the above review on Jatropha and algae, following inferences can be drawn:

#### **I. Jatropha**

- Adoption of proper and careful agricultural practices, which mainly include an increase in the input of fertilizer, and proper irrigation, will decrease the energy use efficiency. And, this can only be compensated by higher energy returns which are possible only if the yield can be increased to a much higher extent.
- Since all the activities in the production of biodiesel are energy intensive, due to the virtue of which they also generate more greenhouse gases, and thus, affect the environmental acceptability.
- With the increased inputs it will also affect the economic viability.

#### **II. Algae**

- Most of the literature is focused on Algae culture techniques and the ways to increase lipid content.
- There are a very few literature works which have worked on LCA for energy balance, or have done comprehensive economic analysis, or environmental feasibility.

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.

In the light of the above review study, on Jatropha and algae, the researcher has identified certain research gaps, research questions and research objectives. These are set out in the succeeding paragraphs.

#### **2.4. Research Gap**

1. A few viability studies, already done on Jatropha [43, 44] 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.
2. A few literature works, which have worked on LCA of algae and 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.
3. As mentioned earlier, till date there is no literature which has done a comprehensive feasibility study for Jatropha and Algae.

#### **2.5. Research Questions**

- What impact would high input Jatropha cultivation system have on Jatropha as an energy crop?
- What combinations of many available agronomical practices and recent technological advancements will further increase or make net energy balance for algae positive, and what will be its impact on economic competitiveness and environmental acceptability of algae as an energy crop?



- Which energy crop, between the two i.e. Jatropha and Algae, will be the more optimal energy crop in India context when compared on the basis of parameters, like, ease of agronomical practices, technical viability, economic competitiveness and environmental acceptability?

## **2.6. 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.

## **2.7. Research Methodology**

Present research comprises of all three types of research methods; library, field, as well as laboratory research. Library research method includes collection and analysis of historical records and documents. Field research includes collection of information outside of a laboratory, library or workplace. The approaches and methods used in field research vary across disciplines. It includes observation, questionnaire, and interview etc.

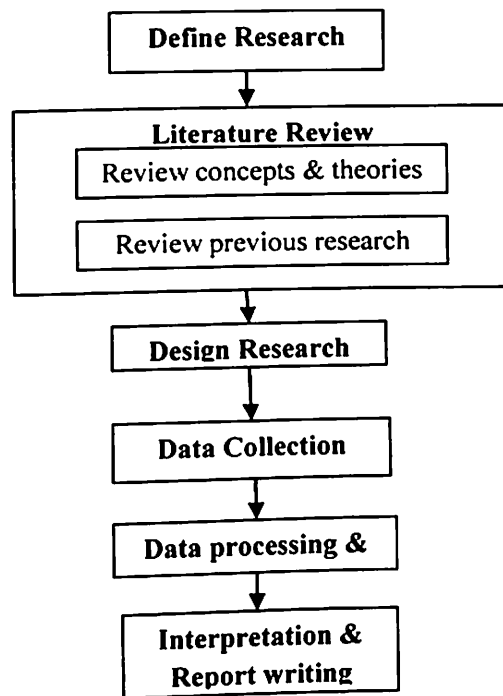
Laboratory research is conducted in a room or building equipped for scientific experimentation or research.

In the current study, the value chain of Jatropha and algae, required for further LCA and viability study, has been established with the library research method. Even the entire LCA and viability study of algae has been done with the help of library research method. Field research method was used to get detailed information about various inputs and outputs during Jatropha cultivation stage, from a plantation in Ettayapuram village in Tamil Nadu. While, laboratory research method was adopted for studying the properties of green diesel obtained from Jatropha as well as the various inputs and outputs during green diesel production from Jatropha oil.

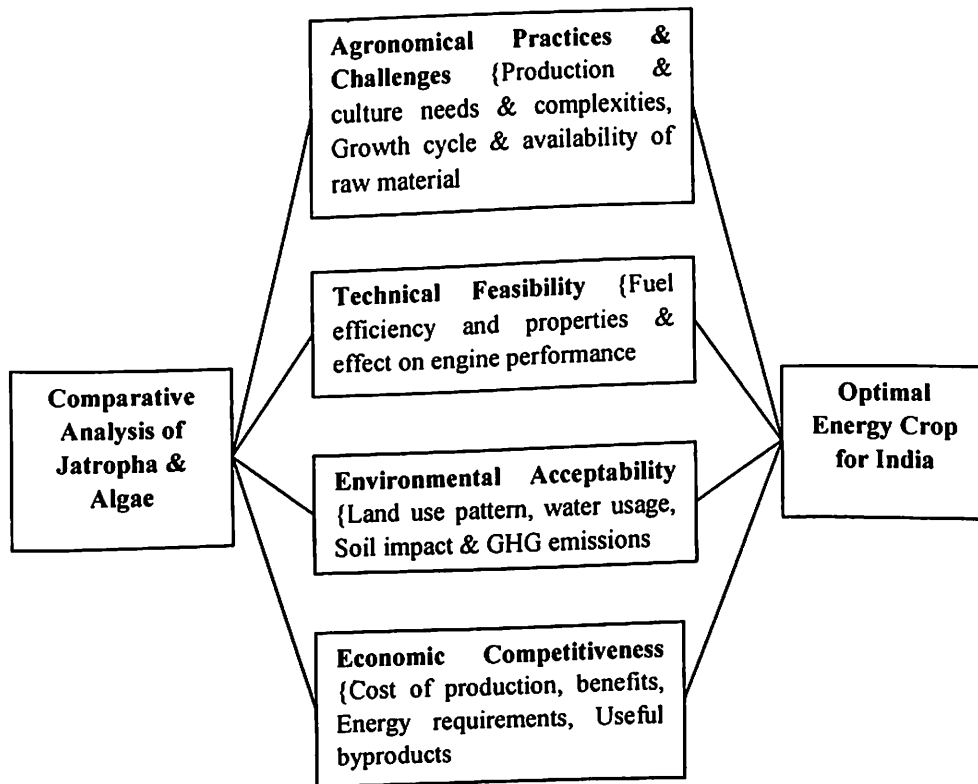
As conclusive research tends to be quantitative in nature, that is to say in the form of numbers that can be quantified and summarized, same has been adopted for the current study due to its extensive relevance to quantitative study.

The flow chart shown in Figure 2.1, gives a brief overview of the research process. Research process consists of series of actions or steps necessary to effectively carry out research and the desired sequencing of these steps.

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. The methodological framework of Life cycle assessment has been explained later in sub section 2.7.1. Research framework used to achieve the third objective, i.e. comparative analysis of the two energy crops, Jatropha and algae, has been shown in Figure 2.2.



**Figure2. 1: Research Process Flowchart**



**Figure2. 2: Research Framework**

### 2.7.1. Life Cycle Assessment

Energy analysis, i.e. to achieve first and second objective, has been carried out within the methodological framework of the Life cycle Assessment (LCA). It is a systematic environmental management tool used for quantifying the input out inventory of a product system throughout its life cycle stages, and projecting the environmental performance based on a selected functional value of the product [84]. In LCA, a product is followed from its cradle to its grave. Natural resource use and pollutant emission are described in quantitative terms [85].

According to ISO 14000 series (ISO 14041-43), the technical framework for the LCA methodology includes four phases: (1) goal and scope definition; (2) inventory analysis, (3) impact assessment; and (4) interpretation.

Owing to the variety of biomass feedstock for bioenergy processes, along with the debates on the final environmental benefits or drawbacks of such systems, LCA has been increasingly applied as a useful tool to analyze and compare various biofuel production technologies from a life cycle perspective. In some cases, the primary focus of the LCA investigation is on the energy demands (e.g. Jorquera et al., 2010 [86]) and CO<sub>2</sub> emissions of the process chain (e.g. Stephenson et al., 2010 [87]), especially when the LCA is applied for comparing bioenergy products.

Therefore, LCA has been used for the analysis of energy balance and greenhouse gas emissions from the energy use for *Jatropha* and algae based green diesel production, and its use in internal combustion engine for transportation. The study incorporates all the major activities and various inputs/outputs during every stage of *Jatropha* and algae based biodiesel production.

### **2.7.2. 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. And moreover, since microalgae biofuel industry is still in infancy, data on large scale algae production is lacking. Therefore, the data and the facts about Jatropha and algae based biodiesel have been taken from the following sources:

- i. Various studies and research papers.
- ii. The detailed information about various inputs during Jatropha cultivation stage has been drawn 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.
- iv. For algae laboratory observations and published data of known industrial processes have been used and extrapolated.

### **2.8. Concluding Remarks**

The extensive literature review carried out in this chapter; supports the rationale of choosing Jatropha and algae for green diesel production in the Indian context. It also supports the need for doing fresh viability studies, based on NEB and NER values, for Jatropha and algae.

It is apparent from the foregone literature review that biofuel projects today are characterized by agronomical and technological changes and challenges posed by new production and conversion processes, thereby also affecting their environmental acceptability and economic viability. Therefore, further study is required to include the impact of these changes

on the viability of energy crops. Accordingly, the purpose of this study is to consider the new agronomical and technological changes and challenges, and thus, establish their impact on environment and economics of both *Jatropha* and *Algae*. Also carry out a detailed and systematic comparison, along their value chain.

Lest it remains unstated, the research methodology gives an overall view of the research work and process to meet the set objectives.