Introduction
1.1. ENERGY

Energy is the capacity for doing work (EIA, 2006). Energy has always been the key to man’s greatest goals and to his dreams of a better world. It is said that the caveman started along the path to civilization after he had utilized the energy in fire for heat and light and the energy in his body, for food and survival.

Energy is **one of the major building blocks of modern society.** Energy pervades all sectors of society: economic, labor, environment, international relations *etc.*, in addition to our own personal livings *i.e.*, housing, food, transportation, recreation and more. Thus energy, environment and economic development are closely linked.

1.1.1. Energy resources and their importance

The energy supplies can be divided into renewable energy and nonrenewable energy resources. **Nonrenewable energy** is the energy obtained from static stores of energy that remain bound unless released by human interaction. Examples are fossil fuels (coal, oil sands, shale oil and heavy oil) geothermal gas hydrates, natural gas and nuclear fuels. This type of energy is initially an isolated energy potential and external action is required to initiate the supply of energy for practical purposes. This type of energy is also called finite energy or conventional sources of energy (Ozgur, 2008).

**Renewable energy** is the energy obtained from virtually inexhaustible sources of energy, occurring in natural environment like solar energy, wind energy, energy from biomass, wave energy, tidal energy and hydroelectric power. This type of energy is passing through the environment, irrespective of there being a manmade device to intercept and harness the power. This is also referred to as nonconventional energy (Saxena *et al.*, 2008). One of the major renewable alternative sources is the ‘**bioenergy from biomass**’ (Fig. 1.1).
As the demand for the world’s fossil fuel increases, their price rises. Interest has rightly given to the development of renewable energy sources. Renewable sources of energy offer the most potential energy conservation and development option for the future. The use of renewable energy sources can meet considerable energy demand of several villages in a country (Gang liu et al., 2008). If an integrated energy system suitable to specific locations and needs is developed, the major problem of carrying energy to the remote rural communities can be solved to some extent by harnessing the available renewable energy potential in those areas. Amongst the renewable sources of energy, ‘biomass’ is one of the most potential energy sources.

1.1.2. Energy from biomass (Bioenergy)

Organic carbon based materials of plants and animals are called biomass. This biomass may be transformed by physical, chemical and biological processes to ‘biofuel’.
Biomass can be considered as a renewable energy source because plant life renews and adds to itself every year. It can also be considered a form of solar energy as the latter is used indirectly, to grow these plants through photosynthesis (Baratieri et al., 2008).

By photosynthesis, solar energy can be converted into biomass which in turn can be stored and used as fuel in various forms (Table 2.1). In chemical form, **biomass is the stored solar energy** and can be converted into solid, liquid and gaseous energy carriers (Plaz et al., 1982).

So far the only use of plant material as fuel is in the form of burning fire wood. Currently, a number of thermal conversion systems are in various stages of development. These include pyrolysis, gasification and hydrogenation. All these processes require feed stock of relatively low water content and operate at high temperature (Tiwari and Ghosal, 2005).

The dry matter of biological material cycling in the biosphere is about 250x10^9 tons/year, incorporating about 100x10^9 tons/year of carbon. The associated energy bound in photosynthesis is 2x10^{21} J y^{-1}. Of this about 0.5% by weight is the biomass used for human food. The use of biofuels, when linked carefully to natural ecological cycles may be nonpolluting and sustainable. The energy obtained from the biofuels is called the 'bioenergy' (Nijaguna, 2002).

### 1.1.3. Biomass energy types

Out of several sources of renewable energy, energy from biomass has been an important source since time immemorial. Biomass resources fall in to three categories (Baratieri et al., 2008).

1) Biomass in its traditional solid mass form (wood and agricultural residues) to be burnt directly for getting energy.

2) Biomass in nontraditional forms converted into liquid fuel (alcohol and biodiesel) to be used as fuels in engines.

3) Biomass anaerobically fermented to obtain gaseous fuel (called biogas) for domestic and industrial usage.
1.1.4. Sources of biomass for fuel conversion

The main biomass sources are as follows:

1. **Forest resource**: Wood and saw dust.

2. **Agricultural residues**: Rice husk, bagasse, groundnut shells, coffee husk, straws, coconut shells, coconut stalks, jute sticks etc.,

3. **Land crops**: (Containing lignocellulose materials) Trees of *Eucalyptus*, poplar, firs, pines, *Leucaena*, starch crops like maize and cassava and sugar crop like cane and beet.

4. **Aquatic plants**: Unicellular algae, multicellular algae and water weeds.

5. **Waste**: Municipal sewage sludge, animal waste, industrial waste (distillery, sago and tannery wastes etc.,)

1.1.5. Pros and cons of bioenergy

Production of energy from biomass has been regarded as one of the most important ways of resolving the energy crisis. Recycling of animal excretions for conversion to energy has long been practiced (Van Buren, 1979). However, increasing demand for energy necessitates the use of other biomass, like plant materials and agricultural residues for better conservation of energy and minimization of pollution. Biomass occupies a unique position for generating clean fuel and it is one of the desirable energy options for a developing country like India with enormous biomass resources (Lahiri, 1999). Scientists are trying to explore the advantages of biomass energy as an alternative energy source as it is renewable and free from net CO₂ emission and is abundantly available on earth.

**Pros of Bioenergy**

- Storage of solar energy in chemical energy forms, which is available to a certain degree whenever desired
- Large potential supply for transport, fuel and electricity generation
- Linked with established agriculture and forestry
- Encourages integrated farming practices
- Efficient use of byproducts, residues and wastages
• Environmental improvement by reducing the level of carbon dioxide
• Economically moderate costs and planning for future is possible
• Plantation can be located on semiarid land not needed for crop
• There is no problem of waste disposal

Cons of Bioenergy

• May lead to soil infertility and erosion,
• May compete with food production,
• Due to low energy density, large land requirement, transport and storage problems, bioenergy becomes uneconomical.

1.1.6. Biogas

Bioenergy, in the form of biogas, which is derived from biomass, is expected to become one of the key energy resources for global sustainable development (Lahiri, 1999). Some ecologists recommended that it makes more sense to use animal manure as a fertilizer and crop residue to feed livestock, retard soil erosion and fertilize soil (Miller, 2003).

The byproduct of anaerobic digestion of organic materials is commonly referred to as ‘biogas’ because of the biological nature of gas production. Biogas technology refers to the production of a combustible gas (called biogas) and a value added fertilizer (called slurry or sludge) by the anaerobic fermentation of organic materials under certain controlled conditions of temperature, pH, C/N ratio, etc. Methane is the main constituent (63%) of biogas. The other major constituent is carbondioxide (30%) (Singh, 1987). It is known by various names such as biofuel, sewerage gas, klar gas, slude gas, fool’s fire, ‘will-o-the wisp’ of marsh lands and even fuel of the future (PinkMonkey Online Study Guide – Biology, July, 2008).

Biogas requires the lowest financial inputs per kWh of output. In addition biogas is one of the most ‘mature’ technology in terms of years of use and number of units installed, and has the potential to alleviate some of the more pressing problems in developing countries (Kishore and Srinivas, 2003). The biogas slurry, rich in nutrients but low in carbon content, can be used as a natural biofertilizer, preferable to other inorganic fertilizers (Chakraborty et al., 2002).
1.1.7. Benefits of biogas

The benefits derived from biogas are many.

a) Economic (Ranade et al., 1991)

- Generation of energy (heat, light, electricity); utilization of methane as a source of hydrogen in fuel cells to generate electricity (Tiwari and Ghosal, 2005).
- Transformation of organic wastes into high quality fertilizer, which can be easily assimilated by plants.
- Contribution to the better image of farming community, by reducing odour, pathogens and weeds from the manure, apart from producing an enhanced fertilizer.
- Conservation of more than 4 tons of fire wood and 32 litres of kerosene from each biogas plant annually.
- Protection of as much as 0.3 acre of forest each year, by a single biogas system (with a volume of 100 cubic feet).

b) Environmental (Chakraborthy et al., 2002)

- Biogas production from biomass is considered as carbon dioxide neutralization and no addition of gases into the atmosphere.
- Workload reduction especially for women in fire wood collection and cooking in rural areas.
- Home protection mainly from smoke and ash, maintaining it more hygienic.

c) Health (Caius, 1986)

- Eradication of problems like respiratory illness, eye irritation, asthma, dizziness, headache and burning of skin etc.,
- Elimination of pathogenic bacteria (Salmonella typhi, S. paratyphi, Vibrio cholerae and Shigella dysentriae) from the biomass fermentation during the anaerobic process.

1.1.8. Energy farming (Energy plantation)

‘Energy farming’ is defined as growing crops specifically for production of fuels or energy as a main subsidiary product of agriculture, silviculture and aquaculture. The crops grown in the energy farming system are called ‘energy crops’, and are planted and harvested
periodically. The cycle of planting and harvesting over a relatively short time period assures that the resources is used in a sustainable fashion (Tiwari and Ghosal, 2005).

Energy crops can fulfil one or more market values. The whole plant is used as feed stock and for production of electricity or liquid fuels or both. For example Alfalfa is being evaluated for its potential to yield both energy and feed from a single crop (Grohmann et al, 1992).

Energy crops contain significant quantities of one or more of the four important energy rich compounds namely oils, sugars, starches, and lignocelluloses. Oils are from soybean and nuts; sugar from sugar beets, sorghum and sugar cane and starches from corn and cereal crops. Sugar cane crops are used for food, feed and power generation purposes. The lignocellulosic sources are bamboo, sugar cane, bagasse and switch grass (Miles et al, 1995).

1.1.9. Types of energy crops

Energy crops are conveniently divided into woody energy crops, herbaceous crops (herb and shrub) and aquatic energy crops.

Woody crops, grown on a sustainable basis are harvested on a rotation of 5-7 years. A few examples of woody energy crops were Eucalyptus globulifera, Ficus benghalensis, Dendrocalamus strictus and Erithrina indica. The herbaceous energy crops are Phaseolus trilobatus, Sesbania aegyptiaca, Crotolaria juncea and Cucumis melo. whereas the shrub energy crops are Jatropha glandulifera, Clerodendron enerme, Ipomoea carnea and Tecoma gracillis (Reddy, 1994).

Apart from the terrestrial plants, aquatic plants are being utilized for energy production. The aquatic algae Spirulina platensis contain protein, carbohydrates, lipids and are rich sources of hydrocarbons. Many varities of aquatic weeds are also used for energy production viz., Eichhornia, Juncus, Typha, Salvinia, Pistia, Lemna and Hydrilla (Chaturvedi, 1993).

Among the nonconventional sources of energy, forest biomass plays a significant role in solving the fuel wood crisis. Biomass from natural forests and energy plantations will serve as dependable and renewable energy resources in future (Shukla and Chandel, 2006).
Tabernaemontana divaricata is a petrocrop and hence a renewable source of energy. The old leaves, roots, flowers and stem contain 7.1, 6.2, 4.8 and 3.7 per cent hydrocarbons respectively. (Behera et al., 1994). Euphorbia lathyris was projected as a potent source of petrocrop plant in arid zones (Calvin 1982). Pedilanthus tithymaloids was evaluated as an incessantly renewable and potential source of hydrocarbon. This plant grows profusely in marginal waste lands in northern and eastern India without any agricultural management. The plant is having huge amount of hydrocarbon and is used as a petrocrop (Srilekha et al., 1996). Calvin (1982) discussed Euphorbia lathyris to be a kind of “energy farm” capable of producing a mixture of reduced terpenoids which can be converted into gasoline-like substances. The most interesting and attractive species is Copaifera multijuga, which produces the light yellow oil (Copaiba oil) that is obtained from its heart wood by tapping (Alencar, 1982).

The latex bearing plants viz, Plumeria alba, Calotropis procera, Euphorbia nerrifolia, Mimusops elengi and Nerium indicum were evaluated as potential renewable sources of energy and chemicals (Kalita and Saikia, 2004). The plant parts (leaf, stem, bark, etc.) consist of oils, polyphenols, hydrocarbons, crude protein, α-cellulose, lignin and ash. According to Kalita and Saikia (2004) among the latex bearing plants, the highest gross heat value was exhibited by Calotropis procera (6145 Cal/g).

1.2. CALOTROPIS – A POTENTIAL SOURCE OF BIOGAS

Calotropis (Asclepiadaceae) is a perennial shrub with a long history of traditional medicine. The chief features of this plant are

- It is distributed in tropical and subtropical area
- The plant is found up to 900 metres elevation and is distributed throughout the country
- The plant grows very well in a variety of soils and different environmental conditions
- It does not require cultivation practices
- It is one of the few plants not consumed by grazing animals (Ravindra Sharma, 2003).
- It thrives on poor soils particularly where overgrazing has removed competition from native grasses
• Some times this plant is the only survivor in some areas, where nothing else grows
• It is a drought tolerant (able to grow in scarcity of water) and pioneer vegetation in desert soil.
• Presence of latex, extensively branched root system and thick leaves with waxy coverage are the xerophytic adaptations.

In spite of all the above mentioned advantages the plant has some toxic metabolites
• The alkaloids present in its latex (asclepin, calotropin, calacctin, uscharidin, giganteal and proceragenin) act as pest repellents (Rathod, 1998).
• The plant possesses proteolytic activity and is resistant to phytopathogens (Cleverson et al., 1996).
• The synthesis of secondary metabolites by the plant destroys a variety of microorganisms (Caius, 1986).

Its latex content and easy availability draw attention towards its use in biomethanation. For the successful utilization of any biomass as a source of biogas, its methanogenic potential alone is not sufficient. The residue left after the process must be properly managed for its sustainability. In order to implement this, the characteristic features of the residue especially assessment of the toxicity is inevitable.

Already attempts have been made (Prateek Shilpkar, 2007; Traore, 1992 and Mahamat et al., 1989) to evaluate the methanogenic potential of Calotropis. But there is no study so far reported on the level of toxicity of the residue.

Hence, the present study is focussed on assessing the production potential of biogas (methane) and changes in some phytochemicals during biomethanation. Evaluation of toxicity in terms of rhizoplane and rhizosphere bacteria and antimicrobial potential of the plant have been examined. In order to study the reduction of toxicity, some secondary metabolites of the plant viz., terpenoid, flavonoid, steroid and alkaloid were estimated before and after biomethanation.
Aim and Objectives
1.3. AIM

The aim of this study is to assess the reduction of toxicity during biomethanation of *Calotropis*, to utilize the plant as a source of energy and the residue as fertilizer.

1.4. OBJECTIVES

i) To evaluate the biogas potential of *Calotropis*.

ii) To quantify certain phytochemical components (cell wall elements and macronutrients) of *Calotropis* biomass before and after methanogenesis.

iii) To study the bacteria of rhizoplane and rhizosphere of *Calotropis*.

iv) To find out the antagonistic activity of *Calotropis* against the rhizosphere bacteria (*Escherichia coli, Staphylococcus aures, Pseudomonas aeruginosa* and *Bacillus subtilis*).

v) To assess the secondary metabolites viz., terpenoids, flavanoids, steroids and alkaloids of *Calotropis*, quantitatively before and after methanogenesis.

1.5. SCOPE

- Biomethanation of *Calotropis* biomass will be a solution to the energy crisis.
- Biogas from *Calotropis* will be a pollution free and environmentally safe fuel.
- Fuel cost will be economical. Hence it will be an advantage to the weaker section of the society.
- Maintenance of carbon dioxide equilibrium in the atmosphere by promoting *Calotropis* growth is a possible solution to global warming.
- The plant is available in all seasons and at all places and does not require cultivation practices enabling to assess its production. This will help the policy makers on energy and fertilizers.
- Detoxified slurry will be a good manure to promote agricultural economy.
- Cow dung can be spared from biogas production and be used as a farmyard manure to improve the soil fertility for achieving cost effective agriculture.