

Hydrocarbon Plants as New Sources of Alternative Energy with Special Reference to *Euphorbia Cotinifolia*: A Review

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Abstract:

The latex producing plants belonging to families Euphorbiaceae, Asclepiadaceae, Apocynaceae, Urticaceae, Convolvulaceae, Sapotaceae were reviewed for their suitability as petrocrops. Latex is a milky fluid secreted by lactiferous canals found in roots, stems, leaves and fruits of all flowering plants. The milky sap is a rich source of triterpenes as secondary metabolites. The latex of such plants contains hydrocarbons of high molecular weight. The entire plant of *Euphorbia cotinifolia* (family Euphorbiaceae) is known to contain latex which is a rich source of hydrocarbons and thus a valuable potential source for bioprospection for biofuel. This review focuses on currently available and relevant information among petrocrops and their biochemical pathways. Further, it discusses biotechnological approaches in different petrocrops and their suitability as biofuel.

Keywords: Latex, secondary metabolites, *E.cotinifolia*, petrocrops, biofuel

I. INTRODUCTION

Development in industrialization and urbanization has increased demand for energy. In order to meet these energy demands, dependency on conventional energy sources like- coal, petroleum and natural-gas led their sustainability in danger (Saxena *et al.*, 2009). For achieving sustainability, bio-based economy is possible through combined efforts of science and commercial enterprise, government-legislation and broad public support.

At world level, there are many threats to uninterrupted energy supply for energy importing countries as energy is crucial for economic development, social stability and geopolitical security of every country. The growing competition for limited energy resources accompanied with dynamic economic growth and population increase brings about a rise in energy demand. The key energy considerations are: - (a) Security- is regarding future availability of oil and gas and (b) climate- concern for climate change (Adelman *et al.*, 2004).

According to international energy outlook (IEO 2011), worldwide consumption of petroleum and other liquid fuels will increase from 85.7 million barrels per day in old years to 112.2 barrels per day in 2035. The world largest potential renewable energy resource is biomass resources which reduces carbon dioxide emissions and offers a promising renewable energy source, which can make a major contribution to world energy economy. The work on hydrocarbon yielding plants was initiated by Prof. Melvin Calvin (kumar, 1984) on the seeds of *Euphorbia lathyris* at university of Rajasthan, Jaipur. In 1982 at University of Rajasthan, Department of Science and Technology granted a research project on hydrocarbon yielding plants which was then practically demonstrated in 1985 on five hectare land. The successful demonstration of the project led its name to Energy Plantation Demonstration Project for fifty hectare in semi- arid region of Rajasthan and was made a centre to conduct investigations. It has been carried out on yield of hydrocarbon production by plants which could be converted to petroleum like substance and used as its substitute (Kalita *et al.*, 2008).

The objective of this review is to discuss some of the hydrocarbon yielding plant species that were investigated as energy-crops belonging to certain plant family like *Anacardiaceae*, *Apocynaceae*, *Asclepideaceae*, *Asteraceae*, *Convolvulaceae*, *Euphorbiaceae*, *Fabaceae*, *Meliaceae*, *Moraceae*, *Papaveraceae* and *Sapotaceae*.

II. ANACARDIACEAE

Size and Distribution:

The family consists of about 77 genera and 600 species. It is mostly tropical in distribution but also found in temperate regions of America and Eastern Asia. There are 22 genera and 110 species have been reported from India. The larger genera of this family are *Rhus*, *Semecarpus*, *Mangifera*, *Schinus*, *Anacardium*, *Pistacia*, *Spondias* and *Cotinus*. Few Indian genera are *Mangifera*, *Rhus*, *Anacardium*, *Spondias*, *Buchanania* and *Lannea* (Pandey and Mishra, 2008).

Characteristics of Anacardiaceae Family:

Usually trees or shrubs, rarely climbers or woody vines, containing resin ducts with plenty of gum and acrid juice. Its leaves are usually alternate, simple or pinnately compound, exstipulate or stipules obscure. Inflorescence is axillary or terminal panicles. Its flowers are uni- or bisexual, bracteates, pentamerous, actinomorphic, hypogynous, rarely perigynous or epigynous: small and numerous. Fruit is usually a drupe with resinous mesocarp. Seed contains curved embryo with very little or no endosperm (Pandey and Mishra, 2008).

Some of the species have been identified as potential biofuel- crops. They are:-

- 1) ***Rhus copallinum*** (Shining Sumac, Winged Sumac and Black Sumac):- It is native to Eastern North America and occurs in dry woods, sand hills, roadsides, abandoned fields and disturbed areas in the Eastern US. Winged sumac is a fast growing and short lived deciduous shrub or small tree about 20 ft tall with an irregular crown spreading to 10 ft. Its leaves are alternate, pinnately compound, 15-30 cm long, have wings between each of 7-15 dark green lance shaped leaflets. Its leaves turn brilliant orange-red in autumn. Its flowers are small, greenish-yellow, borne in compact terminal panicles. Its fruit is a drupe containing single seed. The plant has been studied as a potential biofuel crop by Gehring and Johnson in 1984. They extracted the oven dried stem tissue with ether and found the extract to be 0.31 mg per gram dry weight of stem tissue, cyclohexane soxhlet extract was 0.16 mg per gram and methanol (ether and 87.5% methanol) soxhlet extract was 0.42 and 8.23 mg per gram dry weight of stem tissue and further, chemical analysis by Dogan and Akgul, 2005, showed the presence of major fatty – acids as oleic, linoleic and palmitic acids. They are also reported low content of polyunsaturated fatty acids (www.academia.edu & Dogan and Akgul, 2005). Min et al., (2008) observed the hydrolysable tannins (Gallotannin, Ellagitannin) with molecular weight of 152 Da in the plant species.
- 2) ***Rhus glabra*** (Vinegar tree, Red sumac, Scarlet sumac):- It is a deciduous shrub native to North America found in all 48 mainland states of USA and in Southern Canada. The plant grows in thickets, waste ground, open field and roadsides. It is a shrub or small tree 6-15 feet high. Its leaves are pinnately large with lanceolate, leaflet serrate and green on top, whitish beneath. Its leaves turn bright red in fall. Its inflorescence is arranged in dense panicles of greenish- red with small, five petaled flowers which bloom in June and July. Its fruit is edible, large, erect, cluster of small bright red berries. In 1986, the plant was identified as alternative energy source with yield of 8.65% hexane, 31.51% MeOH extract and total yield obtained was 40.16% respectively (Adams, et al., 1986).
- 3) ***Rhus tribolata*** (Skunbrush, Stinking sumac, Three- leaved sumac):- It is broadly distributed throughout Western North America, from Saskatchewan and Alberta South to Texas and California and into Mexico. It is an upright arching shrub, 0.5-2.5 m tall, forming rounded mound like or upright thickets. Its crown diameter is often greater than the plant height. Its leaves are alternate, compound, deciduous with three unstalked leaflets variable in size, shape and margin. Its leaflets are ovate to rhomboid, more or fewer wedge shaped at the base, coarsely toothed, usually shiny-glabrous above. Foliage in summer is green, which becomes orange or reddish in the fall. Its inflorescence is borne in dense cluster of yellowish to whitish, small flowers on short lateral shoots opening before the leaves. Its flowers are both bisexual and unisexual borne on the same plant. Its fruit are red at maturity, sparsely hairy and each containing single nutlet. Active compounds found in the leaves are tannic and Gallic acids whereas fruits contain only tannic acids. Adams recognized the plant as an alternative energy source or chemical feedstock with polar extracts of 43.3% dry weight (Adams et al., 1986).
- 4) ***Rhus ovate*** (Sugar bush or Sugar sumac):- It is an evergreen shrub to a small tree, native to California and grows in chaparral, dry canyons, Southern California, Arizona and Baja California. It has thick reddish twigs which range from 2-10 m and 6-30 ft tall giving it round appearance. Its foliage is rich dark- green, leathery with ovate, alternate leaves that are folded along the mid- rib. Its inflorescence occurs at end of the branches consisting of small, 5-petaled flowers with white to pink petals and red sepals which may be bisexual or pistillate. Its fruit is reddish, sticky drupe. It was an identified as an alternative energy source with yield of 3.87% hexane, 36.20% MeOH extracts and total yield of 40.07% respectively (Adams et al., 1986).
- 5) ***Rhus michauxii Sargent*** (Dwarf sumac, Flame leaf sumac, winged sumac):- It is native to United States and found in open woods, glades, roadsides, railroads thickets and prairies. The branching of the plant is woody, single or multiple from baser, reddish, glabrate with lenticels. Its leaves are alternate, odd pinnate, petiolate, rachis between leaflets winged. Its leaflets are 5-11, sessile, elliptic- lanceolate, entire, acute to acuminate, slightly oblique at base. Its inflorescence ends in terminal thyrse with greenish-yellow flowers which bloom in May- November. Carr, et al., (1985) examined the plant for energy producing potential and also analyzed yield in fractions referred to as oil 7.0%, polyphenol 20% and hydrocarbon 0.4% respectively (georgiawildlife.com/sites/default/files/uploads/wildlife & Miller, et al., (2004))

III. APOCYNACEAE

Size and Distribution:-

Family Apocynaceae comprises 300 genera and 1400 species of mostly distributed in tropical and subtropical regions. From India about 29 genera and over 85 species have been reported. Some of the larger genera reported were *Rauwolfia*, *Tabernaemontanna*, *Parsonsia*, *Aspidosperma*, *Prestonia*, *Strophanthus*, *Apocynum*, *Plumeria*, *Vinca* and *Catharanthus* (Pandey and Misra, 2008). Some Indian genera are *Apocyanum*, *Catharanthus*, *Nerium*, *Plumeria*, *Tabernaemontanna*, *Thevetia*, *Rauwolfia* and *Vincia* (www.bokus.com/bok/9788180521768/taxonomy-of-angiosperms & Sharma et al., 1986).

Characteristics of Apocynaceae family:-

Apocynaceae or dogbane family is a family of flowering plants which include trees, shrubs, herbs, woody twiners or even succulent with milky sap in lactiferous vessels. Leaves are simple, exstipulate, opposite decussate or sometimes alternate or whorled, entire, rarely stipulate. Inflorescence is a panicle, cyme or raceme; flowers are solitary, usually dichasial cyme. Flowers are bracteate, bracteolate, complete, hermaphrodite, actinomorphic, pentamerous,

hypogynous but rarely perigynous or epigynous. Fruit usually a pair of follicles or a berry, drupe, capsule or 2 indehiscent mericarps. Seeds often flat with straight embryo and a crown of hairs (Sharma et al., 2011).

Species of dogbane family with milky sap yields oil, polyphenol and hydrocarbon content. Some of the species identified are:-

- 1) **Aganosma cymosa** (Sellakkodi):- It is commonly found on hill slopes, limited to peninsular India and Bengal. It is a climbing shrub with pubescent branchlets having elliptic, ovate, obtusely acute and subcoriaceous leaves. Its inflorescence is terminal corymbose cyme with fragrant pale yellow / white flowers. It was reported by Augustus and Seiler in 2011, that an extractable yield of chemical constituents of whole plant sample had 0.5% ash, 20.0% lignin, 1.7% carbohydrate, 10.3% oil content and total yield (protein+ oil+ polyphenol+ hydrocarbon+ ash+ lignin+ carbohydrate) was 36.9%. The gross calorific value of oil and hydrocarbon from whole plant sample was reported as 29.3 and 35.8 MJ/ Kg dry weights respectively (Augustus and Seiler, 2011).
- 2) **Allamanda cathartica** (Golden trumpet vine, Allamanda vine):-It is native to Brazil. It is tropical twining vine with bright to light green, deeply veined whorled leaves, with coarse texture. It has large, bright yellow and trumpet shaped flowers which bloom almost throughout the year. Its milky sap is considered poisonous. The phytochemical survey of peninsular Malaysia by Rahmani, et al., (1985) revealed the presence of triterpenes / steroids on screening of the plants. It was reported by Augustus and Seiler in 2011 that an extractable yield of chemical constituents of whole plant sample had 0.7%ash, 57.7% lignin, 2.3% carbohydrate content and total yield was 68.7% respectively. The gross calorific value reported by Augustus and Seiler of oil and hydrocarbon from whole plant sample was 30.8MJ/Kg and 33.0 MJ/Kg dry weights.
- 3) **Alstonia scholaris** (Indian devil tree, Milk wood pine, Satavan):- It is native to China, Indian subcontinent, Southeast Asia and Australia. It is an evergreen, tropical, 40 m tall elegant tree with greyish rough bark having whorled branches that come out of the same point. Its leaves are dark –green, leathery, rounded and form 4-7 whorls. It has white, funnel shaped flowers which boom in October. Its flower fragrance is very similar to that of *Cestrum nocturnum*. The plant was screened as potential alternative crop for renewable energy by Augustus et al., 2003. They revealed the presence of cis- polyisoprene (natural rubber) hydrocarbon fractions in the plant. Qualitative and quantitative studies of various phytochemicals and physical constant values involving moisture content, ash and extractives were carried out by Khyade and Vaikos 2009. They recorded the presence of alkaloids, commarins, flavonoids and phylobatannin, reducing sugars, simple phenolics, saponins and tannins.
- 4) **Calotropis procera** (Giant Milkweed, Sodom apple, Calotrope):- It is native to Saudi Arabia, Middle- East, India and introduced in South America. Its native habitat is hot deserts, but in isolated wet places. It is shrub with oppositely arranged leaves covered by a coating of dense wool like hairs that peel off in small sheets. It has woody trunk with corky bark. Corolla of its flower is cupped upward with petals that are pale green below and pale lilac above. Its leaves, flower and root contain high amount of protein with 11.7%, ash 10.9% with varying quantity of alkaloid and contain calotropin and calotropagin in leaves (Khairnar,2011).Peoples and Lee (1982) evaluated the plant as source of high quality of hydrocarbon i.e. biocrude. Further, its potentiality as an alternative source of energy was reported by Manikandan and Arumugam, (2010) on biocrude yield having 3.97% oil, polyphenol 4.86% and hydrocarbon 3.16% respectively.
- 5) **Calotropis gigantea** (Giant rubber bush, king's crown, gigantic swallow- wort):- It is a common waste land weed which originated in India and is most abundant in tropics and sub- tropics. It is a large shrub which looks like small tree having clusters of waxy flowers that are either white or lavender in color. It has oval light green leaves with milky stem. Their flower consists of five pointed petals with small elegant crown rising from the center which holds the stamens. Their flower lasts long so used in floral arrangements. Its fruit is follicle which on drying disperses seeds by wind. Rama Murti and Seshadri (1943) reported that its latex contains resinol as esters and two new alcohols alpha calotropeol and beta calotropeol (smaller amount of beta amyryn), cardiac poisons similar to usharin and calcium oxalate. Sharma and Swarup (2003) selected it as one of the most energy rich crop and its biocrude was hydrocracked to hydrocarbon fuels by Bhatia et al., (1989).
- 6) **Caralluma attenuate** (Kundeti kommu):- It is commonly distributed in tropical jungles near foot hills of India. It is a perennial herb, with branched angular fleshy green stems on which leaves are reduced to scales. Its corolla is banded as purple on the lower part as dark with purple fringes. Its stem is edible and used for the treating gum problems. Augustus and Seiler (2011) reported the yield of 3.4% hydrocarbon, 6.6% protein with gross calorific value observed in oil fraction was 33.4 MJ/Kg of dry weight.
- 7) **Carissa carandus** (Caranda, Christ's thorn, and Karaunta):- It is cultivated throughout India (also grow wild). It is a dichotomously branched evergreen shrub that grows 2-3 meters high with numerous, rigid branches spreading with two straight, sharp, simple / forked thorns, up to 5 cms in length on the axils and nodes. Its leaves are smooth, ovate or oblong – ovate, with prominent veins rounded/ notched at the base and blunt- tipped. Its flowers are white or pale rose, fragrant, two or three clustered. Study on triterpenoidal constituents of fresh leaves of the plant by Siddiqui et al.,(2003) had led to isolation of four pentacyclic triterpenoids including one new constituent carissin and two previously known triterpenoids (Siddiqui et al.,2003). It was observed by Augustus et al.,(2002,2003) that this plant species had a high hydrocarbon yield of 1.7%, the polyphenol fraction being 7.7% and oil content as 5.8%; so it was considered as an alternative crop for production of renewable energy.
- 8) **Cascabella thevatia** (yellow oleander, captain cook tree and oleander):-Previously it was known as *Thevatia peruviana* that originates from tropical America and is widely cultivated throughout tropics as an ornamental,

also in tropical Africa. All parts of the plant produce milky exudates which are highly toxic as they contain cardiac glycosides. It has leathery, narrow and long leaves with quite short petioles of 4 mm long tapering into the attenuate leaf bases. Its flowers are usually yellow; bell shaped about 7 cms long present throughout the year. Botanical survey of India (2004) revealed that kernels of plant yield upto 67% of non-drying oil. Schmelzer et al., 2008 revealed its seed contains 57-63% oil and after purification consist mainly of 6% oleic acid, 16% palmitic acid, 11% stearic acid & 7% linolenic acid and 5% linoleic acid.

- 9) **Nerium indicum** (Sweet-scented oleander):- It is cultivated as an ornamental plant in the gardens. It is large, erect, evergreen shrub with white latex. Its leaves are arranged in threes, 10-15 cm long, linear-lanceolate with tapered ends. Its inflorescence ends in terminal cymes with pink or white flowers. Its root contains bitter glycosides, ferulic acid, neriodorin, neriodorein, karabin, potassium salts in excess whereas bark contains scopoletin and scopolin besides this it also contains tannins, red coloring matter, aromatic oil, wax, flobefin, yellow colored stable oil and oleandrin. The research at North East Institute of Science and Technology (NEIST), Jorhat, had conducted experiments on chemical constituents of the plant biomass in different parts of the plant which revealed the yield in leaf as 2.10% oil, 4.21% polyphenol, 0.34% hydrocarbon; in stem 3.71% oil, 6.23% polyphenol, 1.36% hydrocarbon; in bark 3.24% oil, 8.25% polyphenol, 1.78% hydrocarbon and the whole plant yield was 3.24% oil, 7.54% polyphenol and 1.45% hydrocarbon respectively Kalita and Saikia., (2010).
- 10) **Nerium oleander** (karavira):- It is planted in sub-tropical and tropical regions of the world. It is large, evergreen scented shrub that grows 2-6 m tall having thick, leathery, dark green, narrow, lanceolate leaves with entire margin which occurs in pairs or in whorl of three. Its inflorescence end in cluster of white pink or red colored flowers that bloom from June to October. Its fruit is long narrow capsule the work done by Sultana in 2009 on the chemical constituents of fresh, uncrushed leaves of the plant reported ten pure compounds among which two new constituents i.e. nerizoside and neridiginoside were reported and eight known constituents ursolic acid, oleandrin, odoroside-H, neritaloside, nerigoside, oleanolic acid, oleandrigenin and 14, 16-dianhydrooleandrigenin were revealed. It was reported by Augustus et al., (2011) the gross calorific value of whole plant sample were: 15.9 (red flower variety) and 16.5 (white flower variety) MJ/kg; of oil were 33.2 (red flower variety) and 32.7 (white flower variety) MJ/Kg (dry weight) respectively.

IV. ASCLEPIDACEAE

Size and Distribution:

The family includes 250 genera and 1800 species growing in subtropical and tropical regions of the world. In India 300 species belonging to more than 53 species were found. Common forms met in the country are species of *Calotropis*, *Pergularia*, *Dischidia* (in Assam), *Hemidesmus*, *Cryptostegia*, *Gymnema*, *Leptadenia* etc (Pandey and Misra, 2008).

Characteristics of Asclepideaceae family:

Plants are herbs and shrubs usually twining with opposite exstipulate leaves. Stem usually exudates milky juice/sap (latex) when broken. Leaves are simple, usually entire, mostly paired and opposite / in whorls of 4 rarely alternate with very small or absent stipules. Flowers are bisexual, 5-merous, perfect, regular, actinomorphic, complex flowers, solitary usually in clusters. Inflorescence is terminal, axillary or extra-axillary, cymose, often condensed and umbel like, occasionally a raceme like bostrychium. Fruit is a pair of follicles. All plant parts, especially, seeds and latex are often poisonous.

Due to high calorific content of latex some species of milkweed family has been considered as potential energy crop. Some of the species identified were:

- 1) **Asclepias curassavica** (Mexican butterfly weed, blood-flower and scarlet-milkweed):- It has pantropical distribution and is native to American tropics. It is an evergreen perennial shrub that grows 1 m tall, having pale grey stems with milky sap. Its leaves are lanceolate or oblong-lanceolate with acuminate or acute tips and are arranged oppositely. Its inflorescence ends in cymes of 10- 20 flowers each are purple or red with yellow or orange corona lobes. The plant flowers nearly year round. Its fruit are long fusiform shaped follicles having flat seeds with silky hairs. Emon and Seiber (1985) evaluated the plant as potential renewable source of fuel or chemical feedstock. They reported 4590 cal/g in leaves with 41.20% of organic carbon, 4219 cal / g in stems with 41.18% organic carbon, 46663 cal / g in latex having 48.03% organic carbon with 50% of cardiac glycoside. Groeneveld et al., (1990) reported cardenolide in aerial parts and voruscharin as major compound in the latex whereas in other tissues 15- 20% of Uscharidin was reported. Sharma et al., 1994 reported that 8.4% hexane and 12.0% methanol extract yield from leaves and total extractable were 20.4%.
- 2) **Asclepias linaria** (Pineneedle milkweed, needle-leaf milkweed):- It is a native to Arizona. It is a perennial sub-shrub, herb/ forb that grow 5 ft tall. It has dark green, narrowly linear leaves which densely line the stems resembling pine needles. Its inflorescence is umbel like that ends in clusters of white flowers that bloom in spring summer. Its seed capsule is tear drop shaped about 2 inches long. Important components of oil fractions reported by Abbot et al., (1990) were triterpenes alcohol and esters, wax and natural rubber whereas fatty-acid triglycerides were nearly absent. In 1985 Carr et al., surveyed the plant and reported the plant as hydrocarbon crop with yield of 7.7% ash, protein 8.5%, oil 8.7%, polyphenol 11.7% and hydrocarbon fractions 1.9%

respectively. The hexane soluble or oil fraction yield of 6.94% on dry plant basis was revealed in the plant by Abbot et al., (1990).

- 3) ***Cryptolepis dubia*** (Wax leaved climber, nagbel):- Its native range is china, Indian- subcontinent and Indo China. It is a twining, evergreen, glabrous shrub used as a folk medicine in South East Asia. Its leaves are leathery, simple, oppositely arranged and shining acuminate. Its inflorescent is cymes which are very shortly peduncle, paninulate with white and tubular flowers. Its fruit is long, straight, rigid follicle with compressed seeds. Dutta et al., (1978) isolated an alkaloid- b Buchananine from the stems of the plant. Pandey et al., (2007) purified a novel serine protease cryptolepain from the latex of the plant. It was reported by Kamolrat Photi, (2005) the oil and hydrocarbon yield of 3.42%, 0.68% and polyphenol fraction of 5.68% respectively.
- 4) ***Hemidesmus indicus*** (kshirini):- It is found in South Asia and occurs over greater part of India, from upper gangetic plain eastwards to Assam and in some places in central, Western and South India. It is a slender, prostrate or semi erects lactiferous and twining shrub. It has numerous slender stems which are thickened at nodes with short-petioled, opposite, elliptic-oblong to linear lanceolate leaves. Their flowers are greenish outside and purplish inside which are arranged in sub sessile axillary cymes. Its root extracts were phytochemically analyzed by Rajan et al.,(2011) and reported the presence of alkaloids, steroids, terpenoids, flavonoids, phenolic compounds, tannins, lignins, proteins, carbohydrates, amino acids and reducing sugar in aqueous extract whereas in alcoholic extract only steroids, flavonoids, phenolic compounds, tannins, lignin, inulin, cardiac glycosides, proteins, carbohydrates, amino-acids and reducing sugars, Kamolrat Photi, (2005) determined the plant with biocrude fractions of 3.52% respectively.
- 5) ***Sarcostemma acidum*** (Soma, Somlata and Moon plant):- It is distributed in various parts of India, dry rocky places in Bihar, Bengal, Konkani, Deccan, TamilNaadu and Kerala. Its stem is trailing or twining, rarely erect, succulent with woody base. It is a leafless bush of green succulent branches that grows upwards with flowers like those of onion. Its leaves are reduced to minute scales and soon lost. Its inflorescence is cymes umbel like sessile, terminal or extra-axillary. Augustus and seiler (2011) exhibited high content of carbohydrate with 6.9% and hydrocarbon with 3.6% and gross calorific value of 36.5 MJ/ Kg dry weights.

V. ASTERACEAE

Size and Distribution:

The largest family of flowering plants comprises about 1,528 genera and 23,840 species growing worldwide. In India, some 138 genera and 708 species are found. Common wild forms found are *Ageratum*, *Eclipta*, *Eupatorium*, *Parthenium*, *Triodex*, *Vernonia*, *Xanthium* etc. and cultivated ones are *Aster*, *Calendula*, *Centaurea*, *Chrysanthemum*, *Dahlia*, *Helianthus*, *Lactuca*, *Tagetus*, *Zinnia* etc. Large genera of the family are *Senecio* (1470 species), *Vernonia* (1050 species) and *Eupatorium* (590species) (Pandey and Misra, 2008).

Characteristics of Asteraceae (Compositae) family:-

Asteraceae (Compositae) are mostly herbaceous but shrubs, trees and climbers do exist. Leaves can be alternate, opposite or whorled, simple, often deeply lobed or incised, conduplicate or revolute with dentate or entire margins. Inflorescence is specialized capitulum called as calathid or calathidium. The capitulum is a contracted raceme composed of numerous individual sessile flowers called florets all sharing the same receptacle. The florets have five petals fused at the base to form corolla tube and they may be either actinomorphic or zygomorphic. Disc florets are usually actinomorphic; ray florets are always highly zygomorphic. Fruit is achene-like and is called cypsela.

There are some species of asteraceae which showed hydrocarbon content and has potential as biofuel. They were:-

- 1) ***Aster umbellatus*** (flat-topped aster):- It grows in moist thickets, swamp borders and woods. It is a perennial herb distributed in USA and Canada. Its stem is usually hairless below its inflorescence, long, toothless, stalkless leaves along the stem which tapers at the ends. Its inflorescence is flat topped, densely branched cluster of flower heads (umbrella like) with white rays that tends to curve downward or backward which blooms from August to September. Carr et al., (1986) analyzed the percent yield on moisture- free plus ash- free sample weight basis. They extracted the yield of 5.0% ash, 1.9% oil, 9.7% polyphenol, 0.8% hydrocarbon and protein with 4.3% respectively.
- 2) ***Baccharis bigelovii*** (Bigelow's false willow):- It is a perennial subshrub native to United States, having floral region in North America specifically in states of Arizona, new Mexico and Texas. It grows on dry rocky ground in coniferous forests. Its stem are slender, erect, striate-angled, short petiole, glabrous and resinous. It has obovate to oblanceolate leaves with irregularly incised to coarsely serrate, glabrous, gland-dotted and resinous margins. It has corymbiform flower heads with campanulate, staminate and pistillate involucre. Its flowers from August-November. Jakupovic et al., (1990) showed the presence of sesquiterpenes and diterpenes from the aerial parts of the plant. Adams et al., (1986) reported the yield with hexane 4.24%, MeOH 33.07% and total yield was 37.31% respectively.
- 3) ***Arnoglossum reniforme*** (Great Indian plantain):- it is native to United States habituated in rich woods, north or east facing slopes, ravines, bluffs along streams. Its stem are erect, simple, herbaceous but stout, hollow, angled, ribbed with vertical striations, glabrous, reddish- purple at the base. Its leaves are alternate, petiole, and glabrous, with shallow adaxial groove which is reddish at the margins, irregularly dentate, green above and silvery- green below. Its inflorescence ends in terminal corymbiform flower heads, each subtended by a minute bract. Their involucre is 1 cm tall, cylindrical, whitened and glabrous. Ray florets are absent and disc florets are

typically 5 per flower head. The plant blooms from may- September. Carr et al., (1985) reported the yield of 4.1% from the plant.

- 4) ***Pityopsis graminifolia*** (Narrowleaf silkgrass):- It is native to US and distributed from Delaware to Ohio, South to Georgia, Texas and Mexico. It is a perennial herb with its native habitat in dry, open sandy sites. Its leaves are silvery grass like, 1 ft. long, topped by 2 inch clusters of bright yellow, daisy like flowers. Its stem is mostly decumbent having linear, no leaf stalk and usually curved (often folded) leaves. Disc flowers are yellow, bisexual in nature and ray flowers are numerous and yellow in color. It blooms in the period of summer and autumn. Its fruit is an achene. The plant was identified as rubber producing species by Carr and Bagby (1987) with 0.4- 0.7% of hydrocarbon.
- 5) ***Lapsana communis*** (Nipplewort):-It is an annual herb that grows in full sunlight shade, moist to dry conditions, in loamy or gravelly soil, gravelly bars of rivers, and edges of yards, mesic woods, sheltered waste areas, roadsides and stream banks. It is an uncommon plant that occurs primarily in North East Illinois and is adventives from Eurasia. Its stem is erect, simple or branched, glabrate to sparsely or densely pilose with stipitate- glandular hairs. The central stem is often reddish- green, slightly ridged, covered with white glandular hairs particularly in lower part. Its lower leaves are alternate and each leaf has a large terminal lobe and two small side lobes resembling a pair of a pair of elongated “nipples”, which are separated from each other by narrow portion the leaf blade that is little broader than central vein. It blooms in the period from mid-summer to early fall. Each ray floret is replaced by a curved achene, which are without any tufts of hair. Carr and Bagby (1987) reported the yield of oil with 6.1% dry ash- free plant sample basis.
- 6) ***Liatris aspera*** (tall blazing star, rough blazing star, button snakeroot):- it is native to United States and found mid to eastern United States. It is herbaceous, erect, with slightly zigzag, glabrescent stem at base, lined with short, narrow, bright green leaves which are alternate, petiolate below and sessile above. Its leaf blades are linear elliptic, entire, sparse pubescent with minute punctuations, acute, tapering at the base down the petiole. All leaves are with single mid rib. Its inflorescence ends in terminal spike with sessile flower heads typically subtended by one reduced leaf (bract). Its ray florets are absent and disc florets are +/-30 per head. It has long, glabrous corolla tube externally, pubescent at base internally, whitish at base, pinkish near the apex expanding towards the apex. It blooms in the period from august to November. Carr et al., (1986) reported the yield with 4.7% oil, hydrocarbon 0.2% and polyphenol with 22.7% on a moisture –free plus ash –free sample weight basis.
- 7) ***Liatris punctata*** (dotted blazing star, dotted gay feather):-it is a perennial plant native to United States which prefers sun, dry and sandy prairies. It is 10-40 cm tall with erect , unbranched may be solitary but usually in clusters bears very narrow, grass like, numerous leaves crowded along the hairless stem covered in dots of resin. Flowers are rounded pink to purple heads, tightly packed in a spike like cluster up to 10 inches long. It blooms in the period from July- September. Its fruit are achenes, hairy, 10-ribbed, with pappus of white, feathery bristles. Mead et al., (1992) reported sesquiterpenes lactones in the species in addition to known alkaloids new alkaloids new pyrrolizidine alkaloid, punctanecine were traced from roots of the plant. Carr et al., (1986) reported the yield of 8.0% oil, polyphenol 10%, hydrocarbon0.1% and crude protein was 7.5% on moisture-plus ash- free plant sample weight basis.
- 8) ***Lactuca serriola*** (prickly lettuce):- it is most commonly a weed of nurseries, orchards, roadsides and agronomic crops throughout the United States. It is an annual or biennial weed with erect, hollow, light green to white stem emerging from the central rosette and the branches in upper portion of the plant. Its leaves are alternately arranged along the stem with their bases that clasps the stem. Most of the leaves are distinctly lobed and have prickles that occur along the leaf margins, mid-vein and lower leaf surfaces. Its stem and leaves when cut discharge the milky sap. Many flowers are produced in the upper portion of the plant that branches outwards and resembles a cone. Its flower is composed of 5 to 12 yellow toothed petals. Its fruit is an achene containing single seed. Lactuca members were characterized with sesquiterpene lactones and cis-1, 4-polyisoprene rubber (Lebeda et al., 2004; Bushman et al., 2006). Adams et al., (1986) reported the yield of 4.48% hexane, 33.7% MeOH and total extract yield with 38.25% of dry weight.
- 9) ***Solidago erecta*** (showy goldenrod, willow-leaf golden rod):- it is native to US and is rarely distributed in Escambia region. It is a perennial herb which prefers to grow at the margins of fresh and brackish marshes, edge of pinewood and thickets. Its leaves are slightly toothed, smooth and widest beyond the middle with rounded or blunt tip having wedge shaped base with blade extending down and appears winged. Its basal leaves are lance like on long stalks. Its flowers are pale, seen as interval clusters along the stem having symmetrical 6-9 female ray florets with bisexual disc flowers. Its fruit is an achene. Carr and Bagby (1987) identified the plant with 0.4- 0.7% of hydrocarbon and as rubber producing species.
- 10) ***Verbesina alternifolia*** (Wingstem):- It prefers full sun to light shade and moist to mesic conditions. It is native to United States. It is a perennial herb, 3 m tall, unbranched, winged central stem with scattered white hairs between the ridges. It has alternate, lanceolate to narrowly ovate leaves with rough texture having smooth/slightly serrated margins and white hairs along the major veins on the underside. Its apex is composed of daisy- like composite flowers with ragged appearance. Its flower has 2-10 yellow ray florets and disc florets are greenish- yellow, prominent, numerous, projecting outward. Its flower blooms from late summer to early fall. Its fruit is broad, flat and winged achene each with two slender awns which get distributed to some extent by wind. Carr and Bagby (1987) identified the plant with 0.4- 0.7% of hydrocarbon and as rubber producing species.

VI. CONVULVACEAE

Size and Distribution:

It is the family of flowering plants, which includes some 50 genera and about 1200 species is widespread in tropical and subtropical regions of the world. Some 20 genera and 177 species are found in India. Common forms met in the country are *Convolvulus*, *Evolvulus*, *Ipomea*, *Argyria*, *Porana* etc. (Pandey and Misra, 2008).

Characteristics of Convolvaceae family:

Most of the local species are vines, plant is herbs, shrubs, trees and some are parasitic. Stem of vines is with no tendrils, juice in stem is milky. Leaves are simple and alternate, entire or lobed, no stipules. Flower is perfect, regular (actinomorphic), often with 2 bracts, 5 sepals, sometimes lobed, showy bell like corolla, stamens often joined to corolla, ovary superior, 1 pistil. Fruit usually a capsule, sometimes a berry/ nut.

Some species of family with colorful funnel-shaped were identified as potential petrocrops. They were:

- 1) *Argyreia nervosa* (Elephant creeper, holzrose and silver morning glory, vidhara in Sanskrit):- it is native to Indian sub- continent and introduced to numerous areas worldwide, including Hawaii, Africa and Caribbean. It is a perennial, beautiful woody flowering vine that reaches 30 ft length and grows well in full sun on a trellis. Its leaves are large, downy and have velvety white hairs. Its flowers are purple on inside fading lighter at the ends. Modi et al., (2010) reported the presence of various alkaloids, glycosides, falconoid glycoside and steroids in its phytochemical analysis.
- 2) *Convolvulus arvensis* (bine weed and wild morning glory):- it is native to Europe and Asia. It is climbing perennial vine which spreads by rhizome and seed. It is prostrate weak- stemmed plant that can twine and form dense tangled mats. Its stems can grow to 1.5 m or longer and its underground rhizomes range from 5 cm to 2.6 m long. Its leaves are extremely variable (round, ovate or oblong may be even linear). It has long funnel like corolla, generally white to very pale pink. The microchemical screening tests by Sher et al.,(2011) in different parts of the plant reported that its root contain alkaloid, mucilage, anthraquinone derivatives, saponins, tannins, starch, fat, protein and cellulose; stem part contains mucilage, anthraquinone derivatives, calcium oxalate, saponins, starch, fat, protein, cutins and cellulose; leaf consists of mucilage,calcium oxalate,tannins, starch, fat, protein, cutins and cellulose and flower contains alkaloid, mucilage, anthraquinone derivatives, calcium oxalate, tannins, starch, fat, protein and cellulose. Adams et al., (1986) reported the yield of plant species in hexane as 1.95% MeOH as 30.76% and total extract yield with 32.71% of dry weight.
- 3) *Ipomea aquatica* (water spinach, water morning glory, Chinese spinach):- it is found throughout the tropical and subtropical regions of the world and is cultivated throughout Southeast Asia, also grows wild in fresh water aquatic habitat. It is a semi- aquatic tropical trailing vine with milky sap grown as a leaf vegetable that grows in water or on moist- soil. Its stem is 2-3 m or more long, rooting at the nodes which are hollow and can float. Its leaves vary from typically sagittate to lanceolate. It has trumpet shaped flowers which are usually white in color with mauve in the centre. Its fruit is oval or spherical capsule, woody at maturity holding 1-4 grayish seeds which are often short hairy. The phytochemical screening by Sivaraman et al., (2010) from fresh leaf extracts showed the presence of alkaloids, carbohydrates, proteins, sterols, phenols, flavonoids, gums and mucilage, glycosides,terpenes and tannins. It was reported by Kameoka et al., (1992) that its oil contains 58 volatile components of which 49.14% were terpenoids. The percent of crude protein content was 23.6% and 27.6% crude fiber content as 15.5% and 14.0% which were similar to as reported by Bruemmer et al., (1979).
- 4) *Ipomea purpurea* (morning glory):- it is native to tropical America, introduced from South America as an ornamental plant. It is an annual vine 10 inches long that branches occasionally. It can climb fences and adjacent vegetation through its twining stems, in open areas it sprawls across the ground in all directions. Its stem is terete, light green to brown, slightly too moderately pubescent and non –woody. Its leaves are alternate, cordate to cordate- orbicular, smooth along margins and nearly hairless along their upper surfaces, with light green to brown petioles which are nearly as long as the blades. Its flower occurs at the axil of the leaves with funnel form corolla. Its flower booms once during the morning and lasts only a single day which is replaced by globoid seed capsule with dark colored and wedge shaped seeds. Saito et al., (1995) isolated six acylated cyaniding glycosides from violet – blue flowers.
- 5) *Ipomea leptophylla* (bush morning glory, big root morning glory, wild potato vine):- it occurs throughout the tropical and subtropical regions of the world and comprises annual and perennial herbaceous plants, shrubs and small trees. It is very drought tolerant due to its large root system (also called man root) with habitat in plains and dry banks especially in sandy or gravelly soils. Most of its species are twinning climbing plants. Its stem is glabrous, entirely thick, bushy and branching. Its leaves are narrow, linear to narrowly lanceolate, willow like and short stalked. Its inflorescence occurs at axil of leaves with cluster of 1-3 flowers. It has funneled shaped, pinkish or lavender to purplish –red corolla. Its fruit are desiccated capsules, which are egg shaped, completely elongated and flat. Barnes et al., (2003) identified the organic soluble extract from the leaves which resulted in two new resins of glycosides. Adams et al., (1986) reported the yield in hexane as 4.36% MeOH 13.97% and the total extract yield was 18.33% of dry weight.

VII. EUPHORBIACEAE

Size and Distribution:

The family comprises 321 genera and 7770 species widely distributed in tropical and subtropical regions of the world. In India, it is represented by 70 genera and some 450 species with common forms being *Acalypha*, *Bischofia*,

Croton, *Euphorbia*, *Jatropha*, *Phyllanthus*, *Putranjiva*, *Manihot*, *Emblica*, *Ricinus* etc. major genera of the family are *Croton* (720 species), *Phyllanthus* (500 species), and *Acalypha* (350 species) (Pandey and Misra, 2008).

Characteristics of Euphorbiaceae family:-

The family includes large number of annual herbs/shrubs/trees. Almost all plants have latex which is either milky / watery. Leaves are stipulate / exstipulate, petiolate, alternate, simple entire / deeply lobed / trifoliately compound with unicostate / multicostate reticulate venation. Stipules are modified into pair of spines / glandular hairs. Flowers are unisexual arranged in cymose manner, monoecious/ dioecious, incomplete & hypogynous; bracteates, ebracteolate, pedicellate flowers.

The short descriptions of some species of Euphorbiaceae family having the potential as hydrocarbon yielding plants are:-

- 1) ***Baliospermum solanifolium*** (danti, red physic nut, wild castor):- It is distributed throughout greater parts of India, Burma, Malaya and Nepal. Its leaves are simple, sinuate, toothed and variable in shape and size. Its upper leaves are small (8-12 cms long) while lower ones are large (10-30 cms long). Its flowers are small, numerous, unisexual in axillary racemes with male flowers above and few female flowers below. The phytochemical studies by Mali and Wadekar (2008) revealed the presence of four phorbol esters in roots while the preliminary studies showed the presence of flavonoids, glycosides, sterols and absence of steroids, saponins and terpenoids, whereas the seeds reported the presence of glycosides and terpenoids and leaves showed the presence of steroids, terpenoids, flavonoids and absence of alkaloids and saponins (Mali and Wadekar, 2008).
- 2) ***Croton bonplandianus*** (ban tulusi, three leaved caper):- it is perennial herb found in wastelands and roadside areas. It is grown abundantly in rural areas of Malda and west Bengal. As, normally crotons are popular foliage but this is a wild species of croton. It is often called as ban tulusi (jungle tulusi) due to resemblance of its leaves and flower cymes to that of tulusi. It is a small annual herb, 1-2 ft tall with alternately arranged leaves which are 3-5 cms long, lance shaped with toothed margin. Its inflorescence is a long raceme (3-8 cms long) born at the end of the branches with small white flowers. Its flower has 5 sepals and 5 petals, numerous long stamens protruding out. It's flowering and fruiting time is September to December. Its stem and branches are used as fuel. Sharma and Mbise (1988) yielded good quantity of biocrude which can be hydrocracked to petroleum oil and also reported that the plant is rich in nitrogen, phosphorous and potassium. Sharma et al., (1994) reported the yield in hexane extract from leaves with 10.1%, stem with 3.3% whereas from methanol extract 2.6% yield in leaves and 15 % in stem and total yield from leaves and stem were 12.7% and 18.3% respectively.
- 3) ***Euphorbia antisiphilitica*** (candelilla, wax plant):- it is a species of spurge that is native to trans-pecos of Texas, southern New Mexico in United States. It is shrubby and has densely clustered, erect, leafless stems that are covered in wax to prevent transpiration. It contains white sap which may irritate the skin. Schneider et al., (2009) revealed high unsaponifiable fraction, consists largely of n-alkanes; most abundant hydrocarbons (50-57% wt.) found were nonacosane ($C_{29}H_{60}$), hentriacontane ($C_{31}H_{64}$), tritriacontane ($C_{33}H_{68}$), hentriacontane with 35-45%. Next to hydrocarbons sterols (beta- sitosterol, small amount of other steroids as campesterol) and fatty alcohols were part of unsaponifiable fractions. Carboxylic acids and ester of 28-29% (Hydroxyl esters, simple esters, lactones and part of which are monoesters) were responsible for acid and ester value (Schneider et al., 2009). Scora et al., (1995) identified hydrocarbon composition ranged from C_{14} to C_{38} (values of C_{14} , C_{15} , C_{16} were too small to be analyzed) from stem part of candelilla. The largest component was hentriacontane (C_{31}) at 76 to 80% of the total hydrocarbon fraction followed by tritriacontane (C_{33}) at 9-12% and nonacosene (C_{29}) at 4 to 5%. Kumar et al., (2008a) revealed the presence of free acids (7-9%), alcohols, sterols and natural resins (12-14%) and mineral matters. He reported best extraction results in hexane with 8.5% and methanol extract of hydrocarbon yield with 27.5% respectively.
- 4) ***Euphorbia acanthothamnus*** (Greek spiny spurge, Aegean spiny spurge):- it is also called thorny bush in Greek. It is an endemic, perennial spiny cushion like shrub which grows mainly in limestone areas, with many spiny branches which flowers from March to June. Its leaves are elliptical, 2 cm long with cup like bracts. The data given by Magaris and Vokou in 1985 for the plant with special characteristics of having stored content of hydrocarbon which gives its possibility as energy crop as well as an alternative and renewable energy source.
- 5) ***Euphorbia antiquorum*** (ancient euphorbia, fleshy spurge):- It is widespread throughout peninsular India and is cultivated in Lantau Kowloon, New Terr, tropical Asia and south- north China. It is one of the largest armed trees, 3-8 m tall and 5-7 cms in diameter with succulent tree lets fruticose. Its stem is 3-4 angled, triangular teeth at margins. Its leaves are obovate or obovate oblong, entire, glabrous and fleshy, arranged alternately at apex of younger branches or teeth's. Its leaves are insignificant and fall of quickly. Its petiole is much shorted having 2-5 mm long spiny stipules; two membranous bracteal leaves are present which are nearly as large as inflorescences. Its inflorescence is solitary at the leaf axils. Its flowers throughout the year. The plant has abundant milk (latex) with pungent and lingering odour. Sake et al., (2013) determined the lipid content in plant sample and proximate analysis was done.
- 6) ***Euphorbia dendroides*** (tree spurge):- it is widely distributed in the Mediterranean basin, from Iberian Peninsula to Egypt and grows in semiarid and Mediterranean climates. It is a perennial small tree / large shrub, 2m high which grows on the slopes of valleys and cliffs in hilly areas. It blooms from December to May. Ivana et al., (2011) isolated seven new diterpenoides from the plant. Margaris and Vokou (1985) reported the plant as one of the energy rich crop due to stored content of hydrocarbon so can be used as alternative renewable energy source.

- 7) ***Euphorbia dentate*** (toothed spurge and green poinsettia):- it is native to Great Plains region and is widely distributed from Massachusetts to Virginia and west to Arizona, but only limited locations in Idaho have been reported. It is a dicot annual herb with erect / somewhat erect stem of 20-50 cms high. Its leaves are hairy, few cms long, pointed, widely to narrowly lance shaped and generally with toothed margins. It has cream / yellowish staminate / pistillate flowers which are few cms wide. Buchanan et al., (1978) evaluated the plant rich in protein and oil contents but do not produce natural rubber. They reported the percent yield of crude protein 16.7%, polyphenol fraction 3.5% and of 9.68% oil fraction yield.
- 8) ***Euphorbia escula*** (commonly known as leafy spurge, wolf's milk):- it has its wide distribution in USA, Europe and Italia. It is native to central and southern Europe and eastward through most of Asia north of Himalaya to Korea and eastern Siberia. It is herbaceous perennial spurge that grows 1-1.2 m tall, with several stems branched from the base. Its stem is smooth, hairless or slightly hairy with small, lanceolate, slightly wavy margin and spirally arranged leaves. Its inflorescence is umbel having small flowers with basal pair of bright yellow green petal like bracts. All parts of the plant contain toxic white milky sap, which can irritate skin. Manners et al., (1983) reported the presence of hydrocarbons, free alcohols, aldehydes, free acids, esters, triterpene and triterpene esters in epicuticular wax of the plant. Manners et al., (1987) reported the triterpenes (alpha, beta-amyrin and delta- amyrone) and unique jatropane diterpenes from root and leaf extracts of the plant. Maxwell et al., (1985) reported the presence of oil with 6.8%, hydrocarbon 0.6% on dry weight basis and total protein content averaged 12%. They also reported the calorific value from whole plant biomass with 4,407 cal/g and of oil 10,019 cal/g.
- 9) ***Euphorbia heterophylla*** (wild-poinsettia, wild spurge):- it is native to southern united states to Argentina and West Indies and is widely naturalized in India. It is an erect annual herb 1.5 m tall with hollow stem having scattered hairs. Its leaves are alternate, ovate- elliptic to rhomboid with entire margins which are slightly toothed. Its female flower is terminal, solitary surrounded by male flower enclosed in a cup shaped involucre. James and Friday (2010) reported the presence of alkaloids, saponins, flavonoid and tannins on the basis of phytochemical analysis. The work done by Buchanan et al., (1978) on the plant determined the oil-fraction with 6.62% yield.
- 10) ***Euphorbia hirta*** (dudhi, snake-weed):- It is native to India found especially on roadsides and wastelands. It is small erect/ ascending annual herb reaching up to 50cms with hairy stems its leaves are opposite, elliptical, oblong/ oblong-lanceolate, faintly toothed margin and darker on upper surface. Its inflorescence ends in dense cymes crowded together about 1 cm in diameter with numerous small flowers. Augustus et al., (2003) identified the plant with potentially useful compounds like the presence of cis-polyisoprene (natural rubber) through NMR spectra of hydrocarbon fractions. Kumar et al., (2010) reported the presence of alkanes, triterpenes, phytosterols, tannins, polyphenol and flavonoids in the plant.
- 11) ***Jatropha glandulifera*** (adalai):-it is distributed in Chengalpattu, Coimbatore, Dharampuri, Puddukotai, Ramanathapuram, Southarcot, Trichy and Tirunelveli. It is an evergreen shrub/ treelets 3-5 m tall. Its trunk is stout, branches sparsely glandular hairy with sticky transparent juice. Its leaves are simple, alternate and broad-ovate. Its flowers are greenish- yellow in color. Their flower blooms from September to November. Parthasarathy and Saradhi (1984) investigated and revealed the presence of coumarino-lignan, jatrophenolone-A and fraxetin from its roots. Augustus et al., (2003) reported the yield of 6.2% polyphenol fraction in the plant.
- 12) ***Jatropha gossypifolia*** (bellyache bush, jarak china, fignut):- it is native to Brazil and found in wastelands, forests and garden. It is bushy, gregarious shrub with reddish leaves and flowers having glandular hairs throughout. Its leaves are alternate, 10 cm wide with hairy margins, palmate, 3-5 pointed lobed and may have strong red to purple tinges. Its inflorescence ends in terminal corymbs of cluster of small 5- petaled, red-crimson/ purple colored flowers. Its capsule contains greenish seeds. It was investigated by Oduola et al., (2005) its stem latex possess the procoagulant activity and as haemostatic agent. Gubitza et al., (1997) isolated the new cyclic octapeptide (cycloglossine B (1)) was isolated together with known cyclic heptapeptide cycloglossine A from the extract of the latex. Das-B and Das -R (1995) reported the presence of alkaloid jatrophine, various diterpenoids, lignans, steroids fatty -acids and amino acids. Augustus et al., (2003) screened the plant as potential alternative crop for renewable energy and reported it with high hydrocarbon yield of 1.75%.
- 13) ***Jatropha mutifida*** (coral bush, coral plant):- it is widely cultivated and distributed in India. It is a perennial coral evergreen shrub with single trunk that grows 6-10 ft tall. Its leaves are distinctive 7 to 15 lobed, finely divided, dark green above and lighter beneath. Its inflorescence is coral like with numerous, long stalked, bright red colored flowers. Its fruit is bright yellow nut similar to *Jatropha gossypifolia*. From its stem diterpenoid multidione and new diterpenoid (15-epi-(4E)-jatrogrossidentadione acetate) has been isolated and from its latex immunologically active novel cyclic decapeptide was isolated (Das et al., 2008, 2010 and Kossai et al., 1989). Photi et al., (2005) reported the oil yield with 1.89% and hydrocarbon yield was 0.08% which was least considered.
- 14) ***Euphorbia tithymaloides*** (devil's backbone, Japanese poinsettia):- it is native of California, Brazil, Mexico and West Indies. It is a small erect shrub, with round thick zig- zag branched stem, bearing long, leathery, fleshy, green deciduous leaves and occasional small spray of red flowers. Its phytochemical studies on the leaves showed the presence of reducer's compounds, quinine, phenols/ tannins, triterpene or steroids, cycloartanol triterpene (Suárez et al., 2011). The work done by Buchanan et al., (1978) revealed 2.88% of oil yield from latex of the plant and 1.93% yield of hydrocarbon (Photi et al., 2005). De, s., et al., (1997) reported the plant as a

renewable potential source of hydrocarbons by extracting the plant in solvents like petroleum ether, benzene and ethyl acetate. They reported the ash content and heat value of whole plant (leaves and stems) with 13.75% and 7,233 cal/g; its petroleum ether residue with 15% ash content and 4,795 cal/g heat value; its benzene extract residue had 20% ash content and 4.692 cal/g heat value and ethyl acetate extract residue with 30% ash content and 3,903 cal/g of heat value.

- 15) ***Ricinus communis*** (arind):- It is native to Asia, mostly cultivated also found on roadsides, railroad, waste ground and disturbed sites. It is 5 m tall having glabrous, glaucous, entirely herbaceous stems with reddish-greenish or purplish branches. Its leaves are alternate, 30 cm broad, peltate, long-petiolate, palmately 5 to 7 lobed, toothed and glabrous. Its inflorescence is axillary racemes or loose panicles on thick peduncle having staminate, pistillate flowers which blooms from august to November. Kensa and Yasmin (2011) showed the presence of alkaloids, flavonoids, tannins, saponins, steroids, phenols, resins and carbohydrates through the phytochemical analysis. Sarbiyik et al., (2010) reported that its oil can be used as a biodiesel raw material with its high oil content and its non- edible characteristics. It yields 350-650 kg of oil per hectare and has a very high oil content of approximately 50%.
- 16) ***Euphorbia cotinifolia*** (*Caribbean copper plant*): It is native to Mexico and South America. It is evergreen shrub reach up to height 10 to 15 feet. It can be grown as a tree reaching 30 ft (9.1 m). Plant has small white flowers with creamy bracts bloom at the ends of the branches in summer. The purplish stems, when broken, exude a sap that is a skin irritant. It is a rich source of latex which has been used both as a medicine and a poison. The acetone extract showed the presence of long chain hydrocarbons in NMR Spectroscopy. Acetone extract was chosen for further studies. Phytochemical analysis of acetone extract was carried out for the detection of active secondary metabolite or different constituents such as tannins, alkaloids, flavonoids, terpenoids, steroids, carbohydrates, proteins and saponins. It will be future potential source of energy (Puri et al., 2015).

VIII. SAPOTACEAE

Size and Distribution

Sapotaceae family comprises 40 genera and 600 species widely distributed throughout the tropics. In India, 10 genera and about 52 species are found in the plains. Common examples are *Acharus sapota*, *Madhuca indica*, *Manilkara hexandra*, *Mimusops elengi*, *Sideroxylon tomentosum* (Pandey and Misra, 2008).

Characteristics of Sapotaceae family:

They are trees or shrubs with young parts often rusty tomentose. The plant contains milky sap present in the stem and in the leaves. Leaves are simple, coriaceous, alternate or rarely opposite, usually entire with or without stipules. Flowers are solitary or in cymose clusters in the leaf axils. They are bisexual, actinomorphic and hypogynous. The fruit is one to eight seeded berries often with sclerenchymatous layer.

Plant species of the family which were observed with fuel properties were:

- 1) ***Argania siderxylon*** (Argan, Moroccan Ironwood):- It is native to southwest morocco having native habitat of subtropical dry forests and valleys. It is a small, thorny tree 8-10 m tall. Its leaves are dark green, less than 2 cm long, simple, lanceolate and alternately arranged. The spines occur at the leaf axils. Its trunk is twisted, gnarled black, splayed branches which resemble a barberry or firethorn. Its flower is greenish- yellow, very small and occurs in clusters. Its fruit is oblong greenish- golden berry, 3 cm long; bear a very hard nut inside fleshy fruit containing three almonds like kernels. Nasir EI Bassam (1998) revealed endosperm of its seed contains about 68% oil which is rich in oleic acid. Its seed kernels oil contains 80% of unsaturated fatty acids. Charrouf, et al., 1992 isolated five new oleanane saponins named arganine A,B,D,E and F and two known saponins i.e. arganine C and mi-saponin A from its kernel.
- 2) ***Diploknema butyracea*** (Indian butter tree):- It is found in the Himalayas, at altitudes of 1600 m, from Uttarakhand to Sikkim, also in Andaman and Nicobar. It is a tree 25 m tall with thick, round, channeled with warts, yellowish brown or brown velvety to hairless branchlets. Its stipules are lanceshaped, brown to pale yellow pubescent which fall off early. Its leaves are yellowish- brown to brown velvety, elliptic- oblong, ovate or ovate- oblong, wedge shaped base, and blunt tip with a narrow point. Its flower is borne in clusters at the leaf axils. Its fruit is ovoid, globose to oblong, smooth, pointed tip, exocarp fleshy, 1-3 seeded. It was reported by national oil seeds and vegetable oil development board (NOVODB) in 2008 the potential oil content of 42-47% in its seeds and in kernel 60-66% oil (Kant et al.,2011). Its kernel is of high nutritional value and contains 5-20% protein, 30% carbohydrate and 3.8% ash. Its juice also has high nutritional value and is use as soft drink.
- 3) ***Madhuca longifolia*** (South Indian Mahua, Indian butter tree):- It is an Indian tropical tree found largely in central and north Indian plains and forests. Its leaves are narrower and most of them fall from February to April, during that musky- scented flowers appear. A couple of months after the flowering period the fruit opens which are fleshy, green berries, quite large and containing one to four shiny, brown seeds. Its seeds contain triterpenoids, seed fat known as Mee fat and fatty acid composition analysis showed the proportion of saturated fatty acids like palmitic and steric acid, Meet fat has triacyl glycerol (Marikkar et al., 2010). Each kernel contains 50% oil and an oil yield of the plant revealed was 34-37% (Alexander et al., 2009). Palaniappan revealed its calorific value with 36 MJ/Kg and its biodiesel calorific value was 37 MJ/Kg. It is the promising Alternative renewable fuel as it produces lesser emissions contains biodiesel, also accept [table in terms of fuel

properties. Alexander et al (2009) revealed that its press cake, after oil extraction contains >200 g/ Kg saponins measured as raw saponin and traditionally used as fertilizer.

- 4) **Mimusops elengi** (Spanish cherry, bullet wood, maulsari):- It is a lovely green small tree of the Indian subcontinent, found in tropical forests in south Asia, Southeast Asia and northern Australia. Its trunk is straight with spreading branches having small, glossy thick, dark green, oval shaped, narrow and pointed leaves. Its flowers are cream, hairy scented. Its potentiality for future energy is determined by chemical constituents of the plant biomass in different parts like leaf, stem, bark and whole plant. Rout et al., (2010) reported that its chemical composition of the extracts were rich in benzenoids (61.7%) and shade dried flowers contained high percentage of waxy materials with 59.6%. Gami and Parabia (2012) evaluated that alkaloids were absent in seeds and bark while tannins was present only in the bark of the plant. Research at NEIST (north east institute of science and technology) Jorhat extracted the plant for oil, polyphenol and hydrocarbon content in different parts and observed its leaf content with 1.36% oil, 1.46% hydrocarbon. 1.21% of polyphenol; its stem with 6.54% oil, 8.43% hydrocarbon, 3.56% polyphenol; its bark with 8.21% oil, 8.91% hydrocarbon, 3.92% polyphenol and whole plant contains 6.87% oil, 7.69% hydrocarbon, 2.42% polyphenol and gross heat value was 8,924 cal/g (Kalita et al., 2008). The study by Kalita and Saikia (2004) reported activation energy with 16.40 kJ/mol hydrocarbon fraction of the plant which was recorded as greatest.
- 5) **Tieghemella heckelii** (Blacko- nuts):- It occurs in the West African forest zone, from Sierra Leone eastwards to southern Nigeria. It is very large tree 55 m tall, sometimes much more straight and cylindrical, often swollen in lower part. It's branched spread out abruptly forming heavy, rounded crown. Its leaves are arranged in tufts at the ends of branches, spirally arranged, simple, papery or thinly leathery, glabrous, rounded, acute or acuminate at apex. Its inflorescence is fascicles of 1-4 present in the leaf axils with bisexual, regular flowers. Its fruit is large, ovoid-globose, smooth berry 8-12 cm long, yellow when ripe containing 1-3 seeds in its pulp. Its seed are broadly ellipsoid, slightly laterally compressed, with thick, woody, smooth, shining and yellowish – brown testa. Its kernel comprises of 60% oil by weight. Yellowish and semi-fluid oil consists of 51% oleic acid, 43% steric acid, 3.5% palmitic acid and 2.5% linoleic acid Gosse et al., (2002).

IX. SAPINDACEAE

Size and Distribution:

Soapberry family comprises 92 genera and 900 species widely distributed in the tropical regions of the world. In India, it is fairly represented by 24 genera and 72 species with common examples like *Litchi chinensis*, *Aesculus indica*, *Sapindus mukorossi* and species of *Acer* mainly found in western Himalayas (Pandey and Misra, 2008).

Characteristics of Sapindaceae family:

Plants are trees or shrubs, rarely woody vines. Its stem contains resin-passages with plenty of gum and acrid juice. Leaves are alternate or rarely opposite, usually pinnately compound, rarely ternate and very simple, palmately lobed or digitate, exstipulate or in climbing species often stipulate, stipules are small, regular or obliquely zygomorphic, bisexual or unisexual or polygamous, pentamerous or rarely tetramerous and hypogynous. Fruit is dry or fleshy, dry fruit may be a capsule or nut and fleshy fruit a drupe or berry. Seeds are usually arillate with curved embryo and without endosperm.

The plant species that were reported for oil and polyphenol fraction were:

- 1) **Dadonaea viscosa** (sticky hop bush, hop bushes):- It is widely distributed throughout southern hemisphere, extending to tropical areas of northern hemisphere. It occurs in all Australian states. It is evergreen, deciduous plant usually with spatulate (spoon-shaped) leaves. Its flowers are inconspicuous with no petals. Its fruit is a capsule which change color from green or cream color to a brilliant red. Qualitative phytochemical analysis of leaf extracts by Venkatesh et al.,(1998) revealed the presence of carbohydrates, flavonoids, fixed oils, proteins and amino acids, saponins, steroids and sterols, tannins, triterpenoids. It was observed by Kalita et al., (2008) about 17.1% of polyphenol fraction in the plant.
- 2) **Koelreuteria paniculata** (Golden rain tree, Pride of India, varnish tree or China tree):- it is native to eastern Asia, china and Korea. It is a small to medium sized deciduous tree with broad and dome shaped crown. Its leaves are pinnate having 7-15 leaflets with deeply serrated margin. Its inflorescence is large terminal panicles (20-40 cm long) of yellow flowers. Its fruit is three parted, inflated bladder like pod having dark brown to black seeds. Lin et al., 2002 isolated flavonoids and galloyl derivatives from seeds and reported polyphenolic compounds from fresh leaves. Mikolajczak et al., (1970) isolated and identified mixture of cyanolipids and ordinary triglycerides in seed oil. Carr et al., (1985) reported the oil content of 4.0% dry ash- free sample basis in the plant.
- 3) **Sapindus tripoliatus** (South Indian soap nut, Risht): It is a large tree that grows upto 25 m tall. Its leaflets are compound, 15 to 30 cm long, with nearly stock less leaflets which are broad, elliptic-lance shaped, smooth, pointed tipped, base slightly oblique, terminal pair longest. Its flower is greenish white, terminal, slightly velvety panicle. Its flower from November to January. Its fruit is 2-3 looped, 1.3 to 2 cm long, velvety when young, hard and smooth when mature. Chhetri et al., 2008 revealed that its oil content is very similar to the *S.mukorossi* seed kernels with average seed weight of 51.8%.
- 4) **Schleichera trijuga** (Kusum, Lac tree): It occurs naturally from the foot hills of Himalayas and Western Deccan to Sri Lanka and China. It was introduced to Malaysia and has naturalized in Indonesia. In India it occurs in

Bihar, west Bengal, central and southern India. It is a medium size to large deciduous or nearly evergreen tree of 40 m high. Its leaves are paripinnate with elliptical to elliptic-oblong leaflets which are dark-brown or grayish-green above and light brown to greenish beneath, deep purple when young. Its inflorescence is situated in the defoliated part of branch lets above leaf scars sometimes axillary consisting of simple female or sparsely branched male thyrses. Its flowers are pale –yellow or pale-green and functional unisexual. Its flowers bloom along with new leaves in February- April at the beginning of dry season. Its fruit is yellow, hard-crustaceous, smooth or slightly spiny, broadly ovoid, ellipsoid to sub globular berry and 1-2 seeded. Its seed are subglobular with brown, smooth, glabrous tests. Its seed oil is richest source of cyanolipid material which constitutes 58% of seed oil (Mikolajczak and Smith, 1971). The potential oil availability was estimated by National Oil Seeds and Vegetable Oil Development (NOVOD) Board was 25,000t/y (Vivek and Gupta, 2004).

Table 1. Energy crops belonging to different families as shown below:-

Family	Plant species
Anacardiaceae	<i>Rhus copallinum</i> L.(shining sumac)
	<i>Rhus glabra</i> L.(vinegar tree)
	<i>Rhus trilobata</i> Nutt.(Shunkbrush)
	<i>Rhus typhina</i> L.(staghorn sumac)
	<i>Rhus ovate</i> (sugar bush or sugar sumac)
	<i>Rhus virens</i> (evergreen sumac)
	<i>Schmaltzia choriophylla</i> (dwarf sumac)
Apocynaceae	<i>Aganosma cymosa</i> (sellakkodi)
	<i>Allamandra cathartica</i> (golden trumpet vine)
	<i>Alstonia scholaris</i> (Indian devil tree)
	<i>Calotropis procera</i> (giant milkweed)
	<i>Calotropis gigantia</i> (giant rubber bush)
	<i>Caralluma attenuate</i> (kundeti kommu)
	<i>Carissa carandus</i> L.(caranda)
	<i>Cascabela thevatia</i> L.(yellow oleander)
	<i>Cerbera manghas</i> L.(sea mango)
	<i>Catharanthus pusillus</i> (tiny periwinkle)
	<i>Cryptostegia grandiflora</i> (rubber vine)
	<i>Ichnocarpus frutescens</i> (black creeper)
	<i>Nerium indicum</i> (sweet scented oleander)
	<i>Nerium oleander</i>
	<i>Plumeria acutifolia</i> (temple tree)
	<i>Pergularia daemia</i> (sagovani)
	<i>Plumeria alba</i> (dwarf plumeria)
	<i>Tabermontana divaricata</i> (chameli)
	<i>Tylophora asthmatica</i> (Indian ipecacuanha)
	<i>Valleris solanacea</i> (dudhi ki bel)
<i>Vinca rosea</i> (periwinkle)	
<i>Wrightia tinctoria</i> (sweet indrajao)	
Asclepideaceae	<i>Asclepias currassvica</i> (Mexican butterfly weed)
	<i>Asclepias linaria</i> (pineneedle milkweed)
	<i>Cryptolepis dubia</i> (wax leaved climber)
	<i>Hemidesmus indicus</i> (kshirini)
	<i>Sarcostemma acidum</i> (soma)
Asteraceae	<i>Aster umbellatus</i> (flat-topped aster)
	<i>Baccharis bigelovii</i> (bigelow's false willow)
	<i>Arnoglossum reniforme</i> (great Indian plantain)

	<i>Pityopsis graminifolia</i> (Narrowleaf silkgrass)
	<i>Lapsana communis</i> (nipplewort)
	<i>Liatris aspera</i> (tall blazing star)
	<i>Liatris punctata</i> (Dotted blazing star)
	<i>Lactuca serriola</i> (prickly lettuce)
	<i>Solidago erecta</i> (showy goldenrod)
	<i>Packera fendleri</i> (ragwort)
	<i>Packera multilobatus</i> (basin butterweed)
	<i>Solidago riddellii</i> (riddell's goldenrod)
	<i>Verbesina alternifolia</i> (wingstem)
Convolvulaceae	<i>Argyrea nervosa</i> (elephant creeper)
	<i>Convolvulus arvensis</i> (bind weed and wild morning glory)
	<i>Ipomea purpurea</i> (morning glory)
	<i>Ipomea aquatic</i> (water spinach)
	<i>Ipomea carnea</i> (pink morning glory)
	<i>Ipomea batata</i> (sweet potato)
	<i>Ipomea leptophylla</i> (bush morning glory)
Euphorbiaceae	<i>Baliospermum solanifolium</i> (wild castor)
	<i>Croton bonplandianus</i> (ban tulusi)
	<i>Euphorbia antisyphilitica</i> (wax plant)
	<i>Euphorbia acanthothamnos</i> (greek spiny spurge)
	<i>Euphorbia dendroides</i> (tree spurge)
	<i>Euphorbia dentate</i> (toothed spurge and green poinsettia)
	<i>Euphorbia esula</i> (leafy spurge)
	<i>Euphorbia heterophylla</i> (wild spurge)
	<i>Euphorbia hirta</i> (snake weed)euphorbia lacteal (dragoon bones)
	<i>Euphorbia lathyris</i> (paper spurge)
	<i>Euphorbia milii</i> (crown of thorns)
	<i>Euphorbia mauritanica</i> (golden spurge)
	<i>Euphorbia neriifolia</i> (hedge euphorbia)
	<i>Euphorbia pulcherrima</i> (poinsettia)
	<i>Euphorbia rigida</i> (Gopher spurge)
	<i>Euphorbia royleana</i> (royl's spurge)
	<i>Euphorbia tirucalli</i> (Indian tree spurge)
	<i>Euphorbia vajravelui</i>
	<i>Excoecaria cochinchinensis</i> (Chinese croton)
	<i>Jatropha curcas</i> (purging nut)
	<i>Jatropha glandulifera</i>
	<i>Jatropha gossypifolia</i> (fignut)
	<i>Jatropha multifida</i> (coral bush)
	<i>Euphorbia tithymaloides</i> (devil's backbone)
	<i>Euphorbia cotinifolia</i> (copper plant)
	<i>Ricinus communis</i> (arind)
Sapotaceae	<i>Argania sideroxylon</i> (Moroccan ironwood)
	<i>Diploknema butyracea</i> (Indian buttert tree)
	<i>Madhuca longifolia</i> (south-Indian mahua)
	<i>Madhuca zapala</i>
	<i>Mimusops elengi</i> (Spanish cherry, bullet wood)

	<i>Tieghemella heckelii</i> (Bako-nuts)
Sapindaceae	<i>Dodonaea viscosa</i> (hop bushes)
	<i>Koelreuteria paniculata</i> (pride of india, varnish tree or china tree)
	<i>Sapindus saponaria</i> (Chinese soapberry, soapnut)
	<i>Sapindus trifoliatus</i> (south Indian soapnut)
	<i>Schleichera trijuga</i> (kusum, lac tree)

X. CONCLUSION

An advantage of utilization of such plants is by replacing the recent use of the conventional food crops for fuel production and providing the biodiesel industry with a more reliable "green" supply. This will be absolutely essential for the constant profitable feasibility of biofuel production while alleviating the trade and industry and ethical stress that this trade exerts on the food markets. Another important aspect in the use of such plants is the small amount of green-house gases emission. In current years, bioenergy has drawn more attention as a sustainable energy source that may offer a viable substitute to declining fossil fuel sources. If a non-native species has been recommended for introduction then a Weed Risk Assessment should be conducted to determine potential invasiveness in the future. Apart from saving costs of raw-materials (nutrients and fresh water use), these measures will help to reduce GHG emissions, waste amount, and the feed cost by using of nitrogen fertilizers. Also, will raise the availability of microalgae biomass for different applications (e.g. food, agriculture, medicine, and biofuels, among others) and will contribute to the sustainability and market competitiveness of the microalgae industry.

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