

Hawaii Renewable Energy Development Venture Technology Assessment Bioenergy Crops and Technologies

1. Overview - Issues and Enabling Technology Needs

This section addresses technology issues related to bioenergy development in Hawaii within the framework of crops and conversion technologies presented in Figure 1. The plants listed on the left hand side of the figure are not all inclusive but represent a selection of the broad spectrum that are being considered as potential bioenergy species. These plants were selected based on their capacity to generate the intermediate products depicted in the figure; sugar, starch, fiber, and oil. Sugarcane (*Saccharum officinarum*) and sweet sorghum (*Sorghum vulgare*) can produce both sugar and fiber. Corn (*Zea mays*) and cassava (*Manihot esculenta*) are starch and fiber producers. Both grass and tree species are considered for their fiber production; guinea grass (*Panicum maximum*), banagrass (*Pennisetum purpureum*), *Eucalyptus sp.*, and *Leucaena (Leucaena leucocephala)*. Oil bearing species include the widest variety, including *Jatropha (Jatropha curcas)*, kukui (*Aleurites moluccana*), microalgae (eg. *Chlorella sp.*) and diatoms, soybean (*Glycine max*), peanut (*Arachis hypogaea*), sunflower (*Helianthus annuus*), and oil palm (*Elaeis guineensis*).

As shown in Figure 1, the intermediate products are transformed into bioenergy products using conversion technologies. Starch is hydrolyzed into sugars which can then be fermented to produce ethanol or butanol. The hydrolysis step is not required for sugar bearing crops. Fiber can also be used to produce ethanol or butanol by hydrolyzing its cellulose and hemicellulose portions to simple sugars that can be fermented. Fiber can also be converted into a number of bioenergy products including electricity, heat, synthetic diesel, charcoal, etc. The primary conversion technologies required to realize these transformations include gasification, pyrolysis, and combustion. Finally oils from oil seed, tree nuts, or algae can be directly combusted to produce heat and power or converted to biodiesel for use as a transportation fuel or in stationary power applications.

Figure 1 illustrates that multiple pathways exist between plant/crop options on the left of the diagram and bioenergy products on the right. A number of technology components may be required for any given pathway. Agricultural producers in Hawaii have grown a variety of crops and the basic cultural practices of land preparation, seed production, planting, fertilization, and weed control are well understood and are not viewed as primary technology challenges. Crop harvesting and the transportation of the material from field to conversion facility are two remaining unit operations. Many of the crops proposed for bioenergy development have not previously been grown commercially in the State and cost effective harvesting techniques will be important. For sugar cane, harvesting accounts for ~30% of total production costs, thus harvesting costs play a large role in determining economic viability. Due to Hawaii's agricultural worker wage rate (>\$10 per hour) and anticipated prices for bioenergy products, hand harvesting techniques are not considered to be viable and mechanized harvesting techniques will be required.

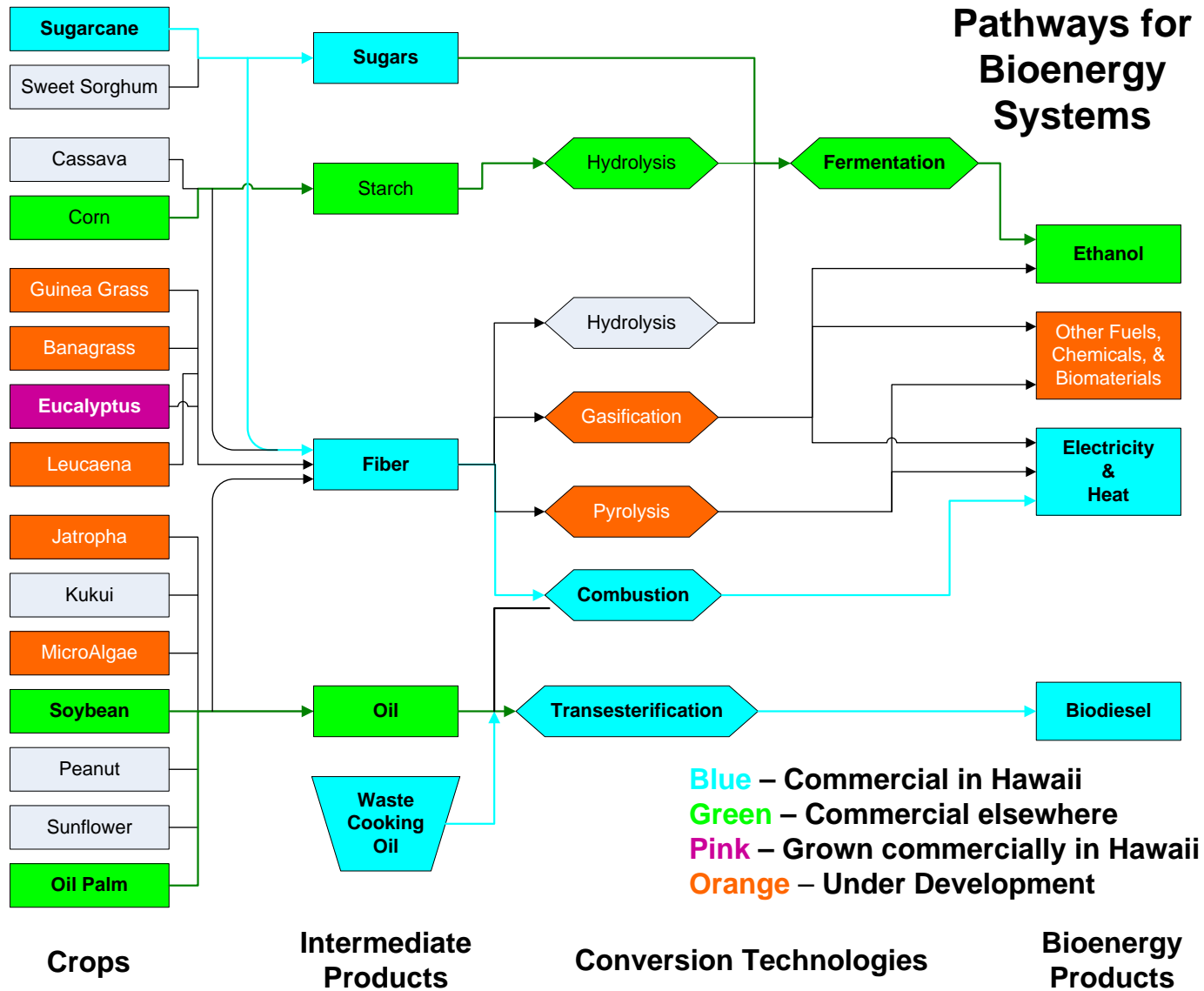


Figure 1. Pathways for bioenergy systems.

2. Crop Production Technology

2.1 Sugarcane

Sugarcane (*Saccharum officinarum*) originated in the southern Pacific region, most likely New Guinea. It grows well in the tropics where temperatures are warm, with moderately high rainfall, and heavy soils. Sugarcane has been grown commercially in Hawaii for more than 170 years and the technology for producing and processing sugarcane is well established in the state.

Soil preparation for sugarcane in Hawaii typically consists of leveling, as necessary; cross-ripping and dragging; multiple passes with large disc harrows; followed by rip-dragging the entire field. Sugarcane seed pieces, vegetative cuttings of young sugarcane stalks, are planted in furrows at a density of roughly 7 tonnes per hectare (3 tons per acre), using mechanical planters. Fertilizer (N, P, and K) could be applied at the time of planting or shortly thereafter.

Fertilizer requirements for sugarcane are high, ~200 kg per hectare (~200 lb per acre) of N, ~200 kg per hectare (~200 lb per acre) of K, and significant levels (~50-300 kg per hectare [~50-250 lb per acre]) of P probably would be needed annually. These can be applied initially with the planter as solid fertilizers or soon after planting via the irrigation tubing. Thereafter, soluble formulations containing N and K would be applied monthly through the drip irrigation tubing.

Weeds usually can be kept under control with an effective weed control program. Weed control measures for the plant crop might include a preemergence herbicide, interrow herbicide applications at approximately one month, and then spot applications, as needed. Canopy closure should occur within eight weeks of planting (slightly longer during the winter), after which in-field weed control would not be needed. Considerably less weed control would be required for ratoon (unseeded regrowth following harvesting) crops owing to heavy ground cover from harvesting operations and rapid canopy closure following harvesting.

For optimal growth, sugarcane needs ~180 cm (70 inches) of irrigation (via rainfall or applied mechanically) per year. If rainfall amounts are not adequate, it is assumed that sugarcane would be irrigated, using drip irrigation.

Sugarcane grown commercially in Hawaii normally is ripened (through a combination of water withdrawal and the application of a chemical ripener) toward the end of its growth cycle, to maximize sucrose content. The field normally is burned immediately before harvesting to reduce the amount of extraneous fibrous material (called "sugarcane trash") that needs to be handled in the processing facility (the sugar mill).

Throughout most of the cane-growing world, the plant crop (i.e., the seeded crop) for sugarcane is harvested at 14 to 18 months of age, then, annually, in

ratoon crops. By contrast, sugarcane grown commercially in Hawaii is harvested, nominally, at 24 months intervals. Though Australian-style billet harvesters have been used commercially in this state (mostly for cutting seed cane), in Hawaii, sugarcane typically is harvested using push rakes (V-cutters and other mechanical harvesters also have been used in the past). The reaped cane is consolidated into large windrows in the field, and loaded into truck-trailers using hydraulic cranes. The sugarcane truck-trailers typically carry loads of 20-50 tonnes (20-50 tons) of cane to the sugar mill. There has been considerable debate over whether sugarcane grown for energy (ethanol or other biofuels) purposes might better be harvested on a one-year rotation, unburned, using billet harvesters. Their use in Hawaii probably would require selection of new sugar cane varieties that are better suited to the shorter rotation. Energy cane, i.e., sugarcane varieties that have been selected for fiber rather than sugar production, is also a bioenergy crop option.

Most sugarcane producers have owned and maintained large networks of private agricultural roads including a broad, paved, cane-haul system that interconnect all fields with the sugar mill. This road network provides adequate infrastructure to transport harvested sugarcane from the field to any processing facility.

Technology Gaps

Because sugarcane has been produced commercially in Hawaii for nearly two centuries, there are no major technology gaps in the production, harvesting, and delivery of sugarcane, though refinements potentially could increase yields and reduce costs incrementally. Whether sugarcane produced in Hawaii should be grown under a one- or two-year cycle and whether sugarcane grown for energy purposes should or should not be burned prior to harvesting, continue to be debated. Decisions on such questions would impact agronomic, harvesting and transporting practices as well as the breeding and selection of commercial sugarcane varieties.

2.2 Banagrass

Bana or Elephant grass (*Pennisetum purpureum* Schumach) is of tropical African origin but has been introduced to all tropical areas of the world and has become naturalized throughout Southeast Asia. It typically grows as a perennial in tropical areas of South America and Asia. Banagrass is not being produced commercially in Hawaii at this time, though cultivars of banagrass have been grown in the islands for use as windbreak and on trial bases as energy and forage crops. Banagrass grows on a wide range of soil types, best in deep, well-drained friable loams with a pH of 4.5-8.2. Banagrass grows best in temperatures between 25 and 40°C (75 and 100°F), and little growth below about 15°C (60°F), and in elevations ranging from sea level to 2000 meters (6500 feet) (Cook *et al.*, 2005).

Though not fully optimized for commercial production, cultivation and harvesting strategies have been developed for banagrass grown as an energy crop and ongoing research is being conducted on this species at the University

of Hawaii at Manoa. Owing to similarities between banagrass and sugarcane, production strategies often mimic those for sugarcane, with a few exceptions, as noted below.

Soil preparation would be very similar to that used in sugarcane. The planting density of banagrass seed would be considerably lower than for sugarcane, around 2 to 3 tonnes per hectare (1 to 1.5 tons per acre). Fertilizer application would be comparable to sugarcane both in rate (kg of N, P, and K applied per hectare-year) and method of application. The method and rate of application of irrigation water also would be similar to sugarcane. Banagrass is listed as an invasive species in the Pacific Islands and in Florida; though it can be controlled by regular cutting or by applying herbicide.

It is anticipated that banagrass would be harvested, nominally, at eight months of age, though trials being performed by the University of Hawaii at Manoa are investigating much shorter rotation cycles. The harvesting schedule would have to be adjusted to avoid flowering (terminal growth of banagrass and sugarcane ceases once flowering occurs), which takes place during the winter and early spring in stands exceeding four months of age. Two types of systems for harvesting and transporting banagrass have been tested in Hawaii: (1) sugarcane billet harvesting systems and (2) forage harvesting systems. The billet harvesting system had been tried on a fairly large scale, approaching 400 hectares (1000 acres), at the former Waialua Sugar Company on Oahu, more than a decade ago. Both billet sugarcane harvesters and forage harvesters are commercial but their application to Hawaii conditions would require additional evaluation to determine the best set of technology options to serve both crop production (adaptability to terrain, field efficiency, harvesting throughput, etc.) and conversion facility (feedstock particle size, moisture content, etc.) requirements. It is anticipated that banagrass would be ratooned multiple times before being replanted.

Technology Gaps

Most of the practices presently being used for growing and harvesting banagrass have been extrapolated from sugarcane production and have not been optimized for banagrass. Major technology gaps for banagrass include breeding and selecting superior cultivars, establishing crop management practices specifically tailored to banagrass, and developing better harvesting and transporting systems.

2.3 Eucalyptus

(This section on Eucalyptus was taken largely from Friday (2006))

Eucalyptus trees, originally from Australia, were brought to Hawaii as a prospect for commercial timber production after the 1960's. Various species have been introduced into the state and can be found on at least six of the major inhabited islands. Eucalypts generally prefer temperate to tropical regions with sufficient rainfall that is distributed throughout much the year. There are possibly 600 species of *Eucalyptus* worldwide; more than 90 (not including ornamental species) have been planted in Hawaii. The most commonly planted species in

Hawaii are *E. botryoides*, *E. camaldulensis*, *E. citriodora*, *E. deglupta*, *E. globulus*, *E. grandis*, *E. microcorys*, *E. paniculata*, *E. pilularis*, *E. resinifera*, *E. robusta*, *E. saligna*, and *E. sideroxylon*.

The most productive species grow best in areas of moderate to high rainfall (>110 cm [>45 inches]). Other species grow well on lands having as little as 50 cm (20 inches) rainfall. Eucalyptus typically is not irrigated; species are usually selected to match rainfall at the particular location. Eucalypts tolerate acid soils. Some species are adapted to warm temperate regions and in Hawaii grow at elevations up to 2000 meters (7000 feet). Above this, moisture becomes severely limiting. The most productive sites in Hawaii are below 1000 meters (3000 feet) elevation.

If trees are planted on abandoned canelands, heavy rollers would be used to cut and crush cane and other vegetation. If the area is covered with very heavy vegetation or brush, a tractor equipped with a bulldozer blade could be used. The blade is held above the ground to knock down heavy brush so that a harrow or roller can crush the material. On some lands, a tractor equipped with wide-gauge shoes would be used to pull a heavy-duty, off-set cutaway harrow. After clearing, herbicide spray could be applied if the vegetation returns before planting. Tree seedlings are planted about two weeks after herbicide spraying.

Young trees do not compete well with weeds, especially in fertile soils. The critical period of development is two to three months after planting, when regrowth of a previous crop or weeds compete with the tree seedlings. Weeds should be kept under control with one application of herbicide prior to planting and two or three applications following planting. Post-planting weed control is performed with manual backpack sprayers or using tractor-mounted sprayers. At the early stage, trees are sensitive to herbicide so care should be taken to avoid contact between the herbicide and the young plants.

Tests have show that *Eucalyptus* responds well to fertilization, particularly to nitrogen. *Eucalyptus* grown on oxisols has shown phosphorus deficiency. Intercropping *Eucalyptus* with the nitrogen-fixing legume *Falcataria moluccana* (common name albizia) greatly improved growth and production of the *Eucalyptus* over chemically fertilized trees on the Hamakua coast.

Optimal harvesting age varies with species and environments, but normally is around seven or eight years. The harvesting operation for trees would be fully mechanized using commercially available equipment. A feller buncher unit, capable of cutting 0.35 m (1 foot) diameter stems, could be used to harvest standing trees. In this system, stems are sheared at the base using hydraulic shears located at the base of the feller buncher. Clean shearing would be required to minimize stump damage for good coppice regrowth. Most production scenarios, however, favor replanting over coppicing. Following tree felling, skidder/forwarders would collect the felled trees and transport them as logs, to hauling units or to centralized in-field locations where the trees would

be chipped. In-field chipping units would chip the whole trees and discharge the chips into wood chip vans.

Technology Gaps

As noted above, a large number of Eucalyptus species have been planted in Hawaii; while there is opportunity for yield improvement through better selection of species for particular environments, the increases probably will not be dramatic. The most significant technology gap associated with Eucalyptus involves selecting appropriate harvesting and transporting systems that are well suited to Hawaii's challenging terrain and other conditions.

2.4 Leucaena

(Much of this section on *Leucaena* was taken from Brewbaker (1980))

Leucaena leucocephala is a nitrogen-fixing tree or shrub, originating in Mexico and Central America. It was introduced to Hawaii as fodder. "Giant" *Leucaena* is a tree form that shares many of the traits of the more common forms of *L. leucocephala*, but does not seed and has larger stems. *Leucaena* is a drought tolerant species and is usually found in lower elevations in locations having lower rainfall. *Leucaena* grows well in neutral or slightly acid soils, and does poorly in very acid soils. With proper management, the giant *Leucaena* tree grows at a rapid pace from transplanting to mature height, growing roughly one meter (3 feet) per month during the first five months, and >15 meters (50 feet) height and 10 cm (4 inches) diameter in six years. The University of Hawaii at Manoa continues to perform research on this crop.

Nitrogen, Potassium and, possibly, Phosphorus, would be required at planting, but only K and possibly, P, would be required after planting, as *Leucaena* is nitrogen fixing. The response of *Leucaena* to P is not very well known.

Giant *Leucaena* can be established directly from sown seeds or from transplanted seedlings grown to age, 3 to 4 months. Most likely, as an energy crop, this plant species would be grown from transplants. It is anticipated that ~10,000 trees per hectare (~4000 trees per acre) would be optimal for an energy plantation.

When cut down, the tree can produce a cluster of branches to 10 meters (30 feet) in length within one year; however, if planted in a dense stand and harvested regularly, it can be maintained for decades as a low shrub.

Brewbaker (1980) considered five alternative harvesting and transporting systems for giant *Leucaena*. The swathe-felling mobile chipper was proposed as the best methods for harvesting *L. leucocephala* in Hawaii because it is capable of felling trees and chipping them directly in the field with minimal manpower. Other mechanized harvesters like feller bunchers, grapple skidders and roadside chippers require more skilled operators and are better suited to larger trees planted at lower densities.

Technology Gaps

Technology gaps in *Leucaena* production are similar to Eucalyptus; however, because *Leucaena* has not been produced in large quantities in Hawaii, in addition to selecting appropriate harvesting and transporting systems, additional research would be needed to optimize crop management practices.

2.5 Jatropha

(Much of this section on *Jatropha* was taken from Duarte and Paull (2006))

Jatropha curcas L. (Euphorbiaceae) most likely originated in the Mexican - Central American region. It is known in English as Barbados nut, castor oil, Chinese castor oil, curcas, fig nut, physic nut, pig nut, purging nut, and wild oil nut. It has been spread world-wide as a medicinal plant into tropical regions. The plant readily establishes itself and is regarded as an invasive weed in a number of countries. This perennial monoecious species is a shrub or small tree (6 m [20 feet]) with spreading branches.

Jatropha nuts are high in protein and fat; however, they contain an albumin poison, toxalbumen cursin, and a toxin, curcasin, which makes eating them potentially fatal. There has been much interest in non-toxic varieties of *Jatropha* that, potentially, could provide byproducts, such as animal feed, which could make the economics of *Jatropha* production and conversion into biofuels more attractive. The literature reports the availability of such edible (non-toxic) varieties of *J. curcas* (e.g., see Makkar, 2009).

The succulent species can be found in locations ranging from dry tropic to moist subtropical to wet tropical forests. It grows best in temperatures ranging from 20 to 28°C (70 to 80°F), and can be found from sea level to 1500 m (5000 feet) elevation. Its adaptability to drier tropical climates and poorer soils makes this oil bearing species an attractive energy crop for application to marginal agricultural lands in Hawaii. Crop research is presently being conducted on this crop by the University of Hawaii at Manoa and by the Hawaii Agriculture Research Center.

The tree can be propagated from cuttings and seeds. The cuttings root readily. Seeds germinate in about 10 days. The best time to start in the field is at the beginning of the rainy season. The young plant is sensitive to weed competition during establishment, although, normally, tillage is not needed (only the area around the plants needs to be cleaned). Planting densities of 2 x 2 m (6 x 6 feet), 2.5 x 2.5 m (8 x 8 feet), and 3 x 3 m (10 x 10 feet) have been recommended. The plant should be hedged and pruned to maintain its shape and has a productive life of 40 to 50 years. As a hedge, the planting distances should range from 15 to 25 cm (6 to 10 inches).

The *Jatropha* plant produces a fruit measuring about 3 cm (1.25 inches) in diameter that contains an oil bearing kernel. In developing countries, the fruit is harvested by hand, but mechanical harvesting would be required in any commercial operation in Hawaii. At present, *Jatropha's* flowering is not

synchronized and this results in fruit at various stages of maturity being present on the plant at any given time. Methods to address asynchronous flowering could include plant breeding, cultural practices, or selective harvesting. The latter would require development of harvesting equipment that removes only ripe fruit and does not disturb immature fruit and flowers. Given that the oil bearing kernel is only a small fraction of the mature fruit weight, the harvesting equipment might also remove the kernel and return the fruit pulp to the field surface as mulch. Use of the fruit pulp as a byproduct could justify whole fruit harvesting. Modified mechanical harvesting equipment for blueberries and olives have been proposed for *Jatropha* harvesting, however, to date, no performance test data have been published.

Technology Gaps

Jatropha presently is in the R&D stage of development in Hawaii. Superior varieties need to be identified and sound management practices have yet to be developed for that crop. The availability of non-toxic varieties of *Jatropha* could improve the economics of biofuel production by providing a seed meal that is rich in protein, which could be used to generate an animal feed byproduct. Mechanical harvesting systems need to be developed.

2.6 Oil Palm

The African oil palm, *Elaeis guineensis*, is an economically important crop for many developing countries in the humid tropics. It is the highest yielding and highly profitable oil crop and is relatively easy to grown by large plantations and small farmers alike (Soh *et al.*, 2008). The oil palm originated in West Africa but has since been planted successfully in tropical regions within 20 degrees of the equator. Malaysia and Indonesia, combined, produce roughly 80% of the world's output of palm oil, however, that species is an important export oil crop for a number of countries (Rieger, 2009).

Oil palm grows best in hot, wet tropical lowlands, that receive at least 180 cm (70 inches) of rain or mechanical irrigation per year, evenly distributed throughout the year. Temperatures below 24°C (75°F) depress growth. Though some varieties of oil palm are being evaluated in Hawaii by the University of Hawaii at Hilo and others, presently no varieties of oil palm have been reported as being superior in Hawaii's subtropical environments.

Oil palm is propagated by seed. Commercial seeds, produced typically by companies that specialize in palm breeding, are mixtures of hybrids derived from parents that are non-true inbreds. Consequently, considerable genetic variability exists among commercial palms.

Typical commercial plant density is ~140 trees per hectare (~60 trees per acre), in triangular grids, ~10 meters (~30 feet) apart (Rieger, 2009). During the first three years, little or no fruit is obtained and plantations are often intercropped with other crops.

Oil palm flowers are produced in dense clusters and are primarily insect pollinated. Oil palm trees grow to 20-25 meters (60-80 feet) tall, though rarely approach 10 meters (30 feet) in commercial production owing to harvesting limitations, bearing fruits in bunches. The fruit takes five to six months to mature from pollination to maturity. Fruit bunches can weigh 10 to 40 kilograms (20 to 90 pounds). Each fruit contains a single seed (the palm kernel) surrounded by a soft oily pulp. Oil is extracted from both the pulp of the fruit and the kernel.

There are no commercial, mechanical harvesters for oil palm. Oil palm fruit bunches are hand harvested in countries where oil palm is grown commercially. Trees must be visited every 10-15 days, as bunches ripen throughout the year. Harvesting has been semi-mechanized with power cutters and cherry-picker type lifts, but not fully mechanized.

Palm fronds and kernel meal are processed for use as livestock feed.

Technology Gaps

There are major technology gaps with oil palm. No commercial varieties of oil palm are known to be well suited for Hawaii's subtropical environment. Irrigation water requirements for oil palm are very high, which could pose a significant strain on Hawaii's water resources. Mechanical systems that are capable of harvesting oil palm fruit bunches need to be developed.

3. References

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