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Review Article

Biomass Feedstocks for Liquid Biofuels Production in Hawaii & Tropical Islands: A Review

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Abstract. Many tropical islands, including Aruba, Seychelles, Mauritius, and Pacific Island countries, are entirely dependent on importing fossil fuels to meet their energy demands. Due to global warming, improving energy use efficiency and developing regionally available renewable energy resources are necessary to reduce carbon emissions. This review analyzed and identified biomass feedstocks to produce liquid biofuels targeting tropical islands, particularly focusing on Hawaii as a case study. Transportation and energy generation sectors consume 25.5% and 11.6%, respectively, of Hawaii's imported fossil fuels. Various nonedible feedstocks with information on their availability, production, and average yields of oils, fiber, sugars, and lipid content for liquid biofuels production are identified to add value to the total energy mix. The available biomass conversion technologies and production costs are summarized. In addition, a section on potentially using sewage sludge to produce biodiesel is also included. Based on a comparative analysis of kamani, croton, pongamia, jatropha, energycane, Leucaena hybrid, gliricidia, and eucalyptus feedstock resources, this study proposes that Hawaii and other similar tropical regions can potentially benefit from growing and producing economical liquid biofuels locally, especially for the transportation and electricity generation sectors.

Keywords: biomass, feedstocks, nonedible, biofuels, liquid fuels, biomass conversion, tropical islands, sewage sludge.

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1. Introduction

The growing concerns over the depletion of fossil fuels and rising greenhouse gas emissions have stimulated searches for new biomass sources for energy production (Rajak *et al*., 2020), such as biofuel raw materials. The global reserves of energy-based fossil fuels in 2018 were 1,139 million tonnes of coal, 1,707 billion barrels of crude oil, and 187 trillion m3 of natural gas, which are projected to be exhausted in the years: 2169, 2066, and 2268 respectively (Jamilatun *et al*., 2019; Energy Outlook, 2018). These numbers are subject to change based upon technology development, but it is expected that these natural resources will become more expensive in the future. On the other hand, biofuels are being examined for transportation fuels to minimize greenhouse gas emissions and mitigate climate change concerns (Jeswani *et al*., 2020). Biofuels are considered alternative or renewable fuels in liquid and gaseous forms obtained from organic feedstocks (Koh & Ghazoul, 2008). Intensive work is being carried out to convert vehicles to biofuels in developed countries, even in countries with oil reserves (Chuvashev & Chuprakov, 2020; Anfilatov & Chuvashev, 2020) due to environmental concerns (Likhanov & Lopatin, 2020), and research is under process in developing countries for biofuels production and their usage (Angulo-Mosquera *et al*., 2021).

The global biofuel market is expanding worldwide. The market is projected to grow from US$ 307.01 billion in 2021, with an 8.3 % compound annual growth rate until 2030 (Precedence Research, 2021). In particular, the bioethanol market is expected to be US$ 64.8 billion by 2025 with a 14 % compound annual growth rate (Research & Markets, 2020) and the biodiesel market worth is projected to be US$ 51.48 billion by 2026 with a 5.9 % compound annual growth rate (Market Data Forecast, 2020). The U.S. is the largest global biofuels producer, with 38 % of total production (Statista, 2021a). It has been reported that the U.S. with 1.71 billion gallons of biodiesel and Brazil with 1.55 billion gallons are the largest producers globally (Statista, 2021b).

On the other hand, the need for biofuels in islands and similar tropical areas is exacerbated due to their remoteness, small size, and relatively high prices (Cloin & Vaitilingom, 2008). Many tropical areas, including Hawaii and small islands around Africa, in the Pacific and Indian oceans, and the Caribbean, are utterly dependent on imported fossil fuels (Repeating islands, 2012) to meet their energy needs. The average energy intensity and emission intensity in islands have increased by 23.4% and 12.4%, respectively, between 2000- 2015 (Ioannidis *et al*.,

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2019). The dependence on fossil fuels contributes to climate change and threatens these islands' existence (Parra *et al*., 2020).

Hawaii is an isolated island chain that depends almost entirely on petroleum sources to meet its energy and electricity generation needs; for example, its use of petroleum is approximately 60 times higher than in the continental United States (<1% oil) (U.S. Energy Information Administration, 2020). In 2018, Hawaii imported 34.9 million barrels of crude oil and 43.92 million refined petroleum barrels (Department of Business, Economic, Development and Tourism (DBEDT), 2019). It has been reported that 9.16 million barrels' fuel was used for electricity generation and 20.16 million barrels for transportation in 2018 (DBEDT, 2019; HEFF, 2019). This indicates that transportation and energy generation are primary consuming sectors for oil. Due to the reliance on imported petroleum in Hawaii, energy prices are more than double on average than those in the continental U.S. In fact, Hawaii has the most expensive energy prices of any U.S. states (U.S. Energy Information Administration, 2020).

Considering these challenges related to high prices, imported fossil fuels, and environmental concerns, Hawaii has started to move towards the greater use of renewable energy. Hawaii has designed an energy policy with a forceful goal to achieve 70% clean energy by 2030 with 40% generation of the targeted energy is derived using regional renewable resources (Hawaii Clean Energy Initiative, 2011), and by 2045, the goal is 100% clean energy (Hawaii Clean Energy Initiative). Renewable energy, including biofuels, is contributing 22.7% to the total energy mix of Hawaii, where other renewables such as solar (11.2%), wind (4.9%), geothermal (2.9%), biomass (2.8%), and hydro (0.9%) are also contributing (HEFF, 2019).

Biodiesel started to be imported in 2010 for electricity production in Hawaii, resulting in higher prices than fossil fuel-based electricity (HEFF, 2019). Afterward, Hawaii has started to produce biofuels by using its available resources. Now, Hawaii is producing 5.5 million gallons per year of biodiesel by using vegetable oil, waste cooking oil, palm oil, and jatropha. However, it is also expensive because of the feedstock cost. Waste cooking oil or used cooking oil offers an alternative route to generate biofuels, but further research is required to make it economical (Khajornsak *et al*., 2020). Therefore, there is a need to research potential nonedible biomass feedstocks to produce economical biofuels in Hawaii and other islands. Current research is focusing on developing liquid biofuels from different lignocellulosic biomass feedstocks rather than from food crops.

Therefore, in light of these targets, the objectives of this review are 1) to review the biofuels production in Hawaii and other tropical islands, 2) identify promising and potential nonedible feedstocks for the biofuel production which can be used in transportation and electricity generation sectors directly or with minor modification and 3) estimate which biomass, if planted in Hawaii on 1% of the available agricultural land, can produce the most biodiesel over 30 years. The overall graphical concept of this review paper is given below in Fig. 1 and is based upon recent literature.

2. Potential Biomass Feedstocks

Many and different kinds of possible feedstocks are available, but this study focused on only those appropriate for Hawaii and similar tropical islands. The list of all available potential nonedible feedstocks for biofuel production with their growing periods, required optimum rainfall and temperature is given in Table 1. These feedstocks can be grown in different geographical areas, including Hawaii (Morgan *et al*., 2019). Sewage sludge and food waste are also potential biomass resources that can be used as feedstocks for biofuel production because of their high organic content (see sections 2.6 and 2.7), generated in large quantities in urban areas and available for free.

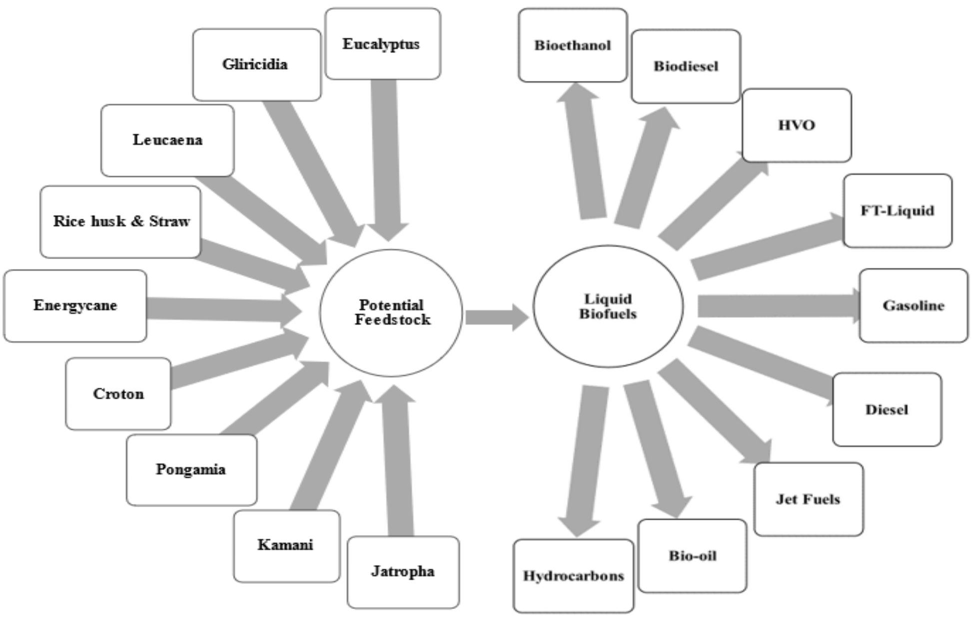

Fig. 1 Graphical representation of biomass feedstocks to biofuel production for islands.

Table 1
Potential non-edible biomass feedstocks for liquid biofuels production.

Feedstock name	Growing period (days)	Rainfall required (mm)	Temperature range (°C)	Typical yields (tonnes/ha/yr)	Yields in Hawaii (tonnes/ha/yr)	Feedstock type	References
Jatropha	220 - 239	1000 - 1500	20 - 28	6.614	1.5 - 2	Oil seed	Morgan *et al*. 2019; Hawaii Natural Energy Institute, 2019; Jongh, 2010
Kamani	300 - 329	1016 - 5080	17.7 – 32.7	17.637	----	Oil seed	Putri & Gheewala 2015
Pongamia	150 – 179	800 - 1600	11 - 26	992-9920	2	Oil seed	Bobade *et al*. 2012, Hawaii Natural Energy Institute, 2019; Aliyu *et al*., 2010
Croton	180 – 209	500 - 2500	16 - 38	1.76 – 6.70	---	Oil seed	Orwa *et al*., 2009, Hawaii Natural Energy Institute, 2019
Sugarcane	350 - 500	800 - 1500	15 - 45	160.93	66.13	fiber	Kinoshita & Zhou, 1999; Walter *et al*., 2011; Ebrahim *et al*., 1998; Riajia 2020
Energycane	210 – 239			44.95	19.7	fiber	Sandhu & gilbert 2014, Hawaii Natural Energy Institute, 2019
Rice husks and straw	180 – 209	~1000	20 - 40	9.1	----	fiber	Food and Agriculture Organization, 2009 & 2012; Civilsdaily, 2017
Leucaena hybrid	282	1000 - 2500	25 - 30	16.5	3.7 – 14.3	fiber	Brewbaker, 2008; Hawaii Natural Energy Institute, 2019
Gliricidia	210 – 239	900 - 1500		16.5 - 33	----	fiber	Kimaro, 2009
Eucalyptus	200 – 300	600 - 1400	8 - 23	17	8	fiber, oil	Binkley *et al*., 2003; Hawaii Natural Energy Institute, 2019

2.2. Jatropha

Jatropha is a promising biomass feedstock for biodiesel production because it is nonedible and a multipurpose plant that can be cultivated on poor soil (Openshaw, 2000; Biswas *et al*., 2013; Jingura *et al*., 2015). Central America and Mexico are the origins of the jatropha plant, but now it grows in many equatorial and subtropical regions worldwide (Jongh, 2010; Henning, 2009). There are three seeds per fruit, and it takes three to four months after blossoming to mature (Kumar & Sharma, 2008). The seeds' yields depend on the seeds` quality (genetic, variety, etc.), soil fertility, and breeding methods. Jatropha produces seeds that are a promising oil production source (Hagen, 2012) and it grows for approximately 40 years. (Jayed *et al*., 2009). The average optimum yield, oil contents, and jatropha seed compositions are shown in Table 2 and Fig. 2 (Raja *et al*., 2011). 22.6 kg hydrocarbon-based jet fuel was reported in Brazil from 46.7 kg of partially refined jatropha oil (Bailis & Baka, 2010). The jatropha seed oil has been recognized as an appropriate feedstock for biodiesel production (Jongschaap *et al*., 2007; Sunil *et al*., 2008) because a biodiesel yield of 90% is reported through alkaline catalyzed transesterification (Folaranmi, 2013). The characteristics of Jatropha seed oil are similar to those of diesel, and it is cultivated on diverse wasteland with little agricultural farming (irrigation or fertilization) and contains 40 % to 60 % oil (Tikko *et al*., 2013).

2.3. Kamani

The kamani plant's scientific name is "*Calophyllum inophyllum L.*," and it is mainly cultivated in warm climates, even though it occasionally arises inland at higher altitudes. The kamani trees grow in tropical areas, counting Pacific islands and Hawaii (Friday *et al*., 2006). It is a very famous plant, and its leaves, flowers, bark, seeds, and fruits are utilizing as a medication for skin diseases, wounds, ulcers, etc. (Craker *et al*., 2009; Shanmugapriya, 2016). Kamani seeds usually are produced twice a year, and a tree can produce about 100 kg of fruit containing 18 kg of oil in a year (Dweck & Meadows, 2002). Average yields and oil contents of kamani kernels are summarized in Table 2. The composition of kamani oil is presented in Fig. 3 (Salveybee, 2016). Kamani oil can be used as a potential source of bioenergy (Morgan *et al*., 2019), and this oil can produce biodiesel through transesterification. The energy output of kamani biodiesel (via transesterification) is higher than the input. Input energy here means the consumption of energy (7,493 MJ/ton) for producing biodiesel, and output energy mean how much energy biodiesel and by-products can produce (94,182 MJ/ton). The energy balance difference between output and input with coproducts is 86,811 MJ/ton biodiesel, and without coproducts is 33,897 MJ/ton biodiesel, which indicates that the process is energy efficient (Putri & Gheewala, 2015).

Table 2
Summary of biomass feedstocks, yields and seed oil contents.

Feedstocks	Biomass yield (dry) (tonnes/ha/yr)	Seed oil content (wt. %)	First yield starts in (yr)	Expected lifetime to produce biomass (yr)	Lifetime of plant (yr)	References
Jatropha	7.16	30 - 40	2	30	40	Gour, 2006; Francis *et al*., 2005; Kumar Tiwari *et al*., 2007; Federation of Oils, Seeds & Fats Associations, 2014; Jayed et al., 2009).
Kamani	17.637	40 -45	5 - 7	25	---	Azam *et al*., 2005; Friday & Okano, 2006; Putri & Gheewala, 2015
Pongamia	9	30 - 42	3 - 5	25	100	Ofimagazine, 2015; Inventancia 2017
Croton	5.1 – 20.94	30 -45	3	---	---	Orwa *et al*., 2009; Kibazohi & Sangwan, 2011). Plants for a Future, 2021

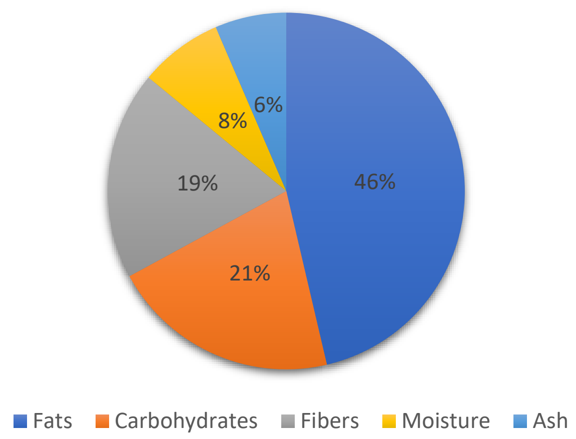

Fig. 2 Composition of the Jatropha seed.

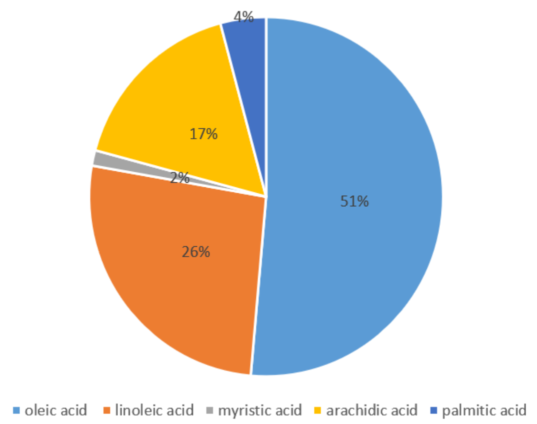

Fig. 3 Fatty acids composition of kamani oil.

2.3. Pongamia

Pongamia is generally known as a pongame oil tree, and its scientific name is "Millettia Pinnata." It has been reported that pongamia is used as a medicine, animal fodder and an oil source in tropical areas and many countries of Asia, including China, Japan, India, Malaysia, Nepal, Myanmar, and Thailand (Scott *et al*., 2008). Pongamia is native to and naturally occurs in northern and other parts of Australia and has been newly entrenched in moist tropical areas, including the U.S. There are three potential coproducts of pongamia such as seed oil (valuable source for biodiesel), pods (fit for combustion), and seed cake (valuable as organic fertilizer) (Scott *et al*., 2008; Sreedevi, 2009). The summary of average yields and oil contents is given in Table 2, and Fig. 4 shows the composition of pongamia (Bobade & Khyade, 2012; Baste *et al*., 2013; Ortiz-Martinez *et al*., 2016.). These promising compositions of fatty acids and oil-rich seeds make it a possible source of renewable energy (Biswas *et al*., 2013; Scott *et al*., 2008; Bobade & Khyade, 2012; Ortiz-Martinez *et al*., 2016; Peteet, 2006). It has been reported that 129.13 million gallons of pongamia crude oil can produce 150.55 million gallons of biodiesel through transesterification (Parsad & Singh, 2020)

2.4. Croton

Croton belongs to the "*Euphorbiaceae"* family of plant species. Croton is considered an endemic tree in Sub-Saharan Africa, which has lately been proposed as a promising source of liquid biofuels due to its high oil yield (Aliyu *et al*., 2010). The croton can be used for firewood, charcoal, fence posts, and wind and soil protection (Kindt *et al*., 2007). Other parts of the tree, including leaves, seeds, and roots, are used for medicinal purposes (Matu & Staden, 2003; Kituyi *et al*., 2001; Orwa *et al*., 2009). The average croton seeds yields and oil contents can be seen in Table 2 and the composition of croton oil is summarized in Fig. 5 (Plants for a Future, 2021). Croton megalocarpus has been recognized as a potential commercial resource for biodiesel production (Morgan *et al*., 2019; Aliyu *et al*., 2010; Misra *et al*., 2010). Because it has been reported that the pure croton megalocarpus oil (CMO) can power diesel engines just as well as petroleum-derived engine grade diesel fuel, producing a maximum of 6.5 kWe power and roughly 13 kW thermal output with a high electricity generation efficiency of 26.3% – 26.6% with a total 76 % of prime energy efficiency (Duwei *et al*., 2013).

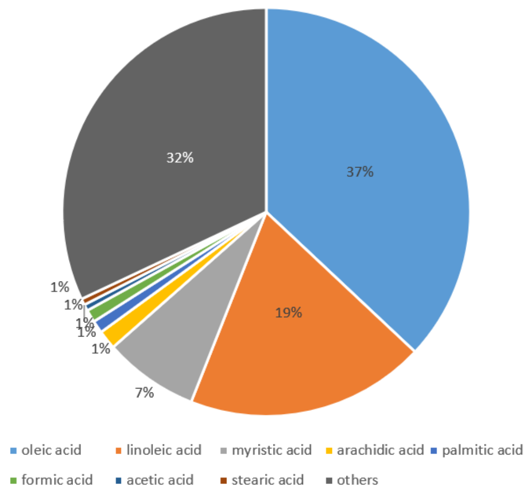

Fig. 4 Fatty acids composition of pongamia oil.

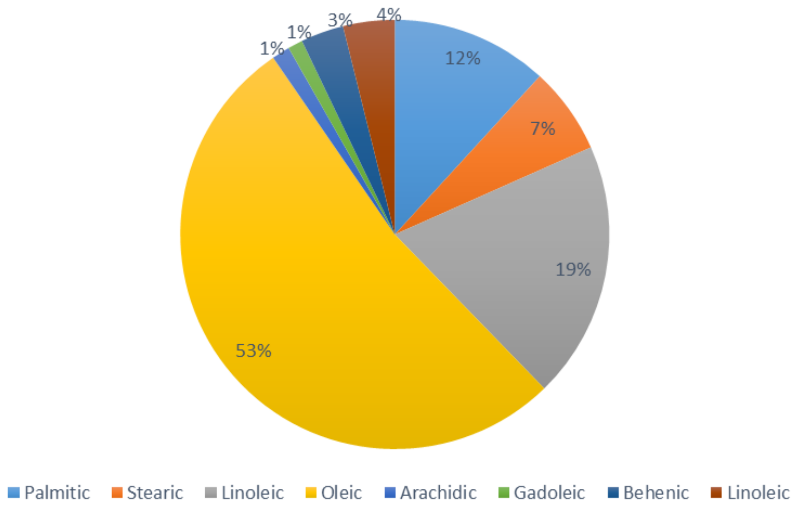

Fig. 5 Fatty acid composition of croton oil.

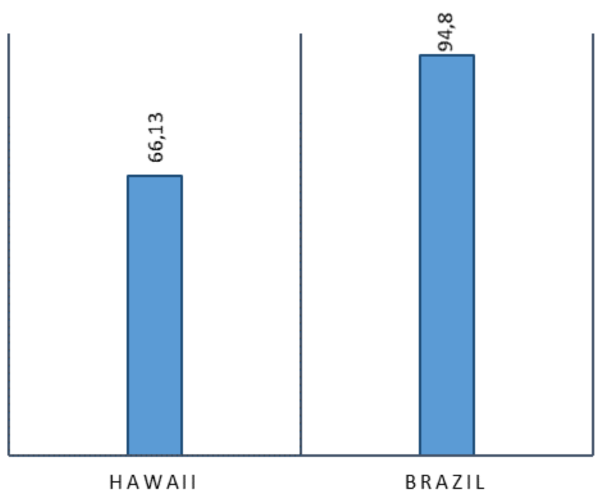

Fig. 6 Average sugarcane biomass yields (tonnes/ha/yr) in Hawaii and Brazil.

2.5. *Fiber as a feedstock*

Lignocellulosic biomass is becoming a popular feedstock for biofuel production. Different types of trees and grass species have been assessed in Hawaii to find potential resources to produce alternative jet fuels (Morgan *et al*., 2019). Potential plant fiber feedstocks are discussed here for the production of biofuels in Hawaii.

2.5.1. *Sugarcane*

Sugarcane is a widespread crop cultivated globally and is considered a major crop. It occurs in almost all countries, but the African species has a high sugar content (sucrose content above 20%) in its sap (Karp & Shield, 2008; Rainbolt & Gilbert, 2008; Carr & Knos, 2011). It was grown in Hawaii starting in the 1800s to produce sugar, molasses, and bagasse as byproducts. Sugar and molasses can be converted into ethanol through fermentation (Morgan *et al*., 2019). Sugarcane is the most attractive feedstock in Hawaii for biofuels' production due to its swift growth, high yields, and drought tolerance (Kinoshita & Zhou, 1999; Battie & Laclau, 2009). The average yield of sugarcane biomass on a dry basis in Hawaii and Brazil are summarized in Fig. 6 with 60% fiber and 40% sugar (Kinoshita & Zhou, 1999; Walter *et al*., 2011). Bagasse is produced as a residue from the crushing of sugarcane to extract its sap and is a resource for cellulosic ethanol production (Sandhu & Gilbert, 2014). Also, bagasse is exploited as a fuel source for combustion in the paper pulp manufacturing industry (Covey *et al*., 2006). Except for ash, bagasse is composed of energy-rich compounds (see Fig. 7), that can be used for liquid biofuel production (Morgan & Turn, 2017).

2.5.2. *Energycane*

Energycane is considered an excellent biomass source with high fiber content and a low concentration of sucrose. The differences between energycane and sugarcane are related to sugar extraction and steam required for processing (Leal, 2007). It has been stated that energycane can generate more energy due to its four times higher biomass production than sugarcane (Matsuoka *et al*., 2015; Sica, 2021). The energycane juice is mainly composed of water, sugar, and minerals content, which provides more sugar per hectare than the traditional sugarcane due to its high yields (Carvalho *et al*., 2014; de Souza, 2014). Energycane consists of approximately 54% juice on a wet basis, containing 10% of the total sugars (sucrose) (Kim & Day, 2010). Fig. 8 shows the average yield of energycane's biomass in Florida and Hawaii (Morgan *et al*., 2019; Sandhu & Gilbert, 2014). The energycane (Fig. 9) biomass can generate cellulosic ethanol (Morgan *et al*., 2019; Morgan & Turn, 2017). The juice and bagasse from energycane clones were successfully fermented to produce an overall 3.92 tonnes/ha ethanol yield (Thammasittirong *et al*., 2017).

2.5.3. *Rice husks and straw*

Rice was first planted in Southeast Asia, India, China, and its cultivation has spread to more than 100 countries (Normile, 1997). Rice is harvested annually and grown from temperate to tropical climates (Vaughan & Morishima, 2003). The world's highest rice yields reported are 20.94 tonnes/ha/yr in China, 11.9 tonnes/ha/yr in Australia, and 9.14 tonnes/ha/yr in the U.S. (Food and Agriculture Organization, 2009 & 2012). There are two residues: husks and straw, generated in rice cultivation and widely used for energy or heat production through combustion. Rice husk is a byproduct extracted from rice milling, and it accounts for 20 to 22% by weight of the harvested rice. It consists of the organic component (80%), and the remainder is ash (silica) (Zafar, 2005). The entire world's bioethanol production from rice husk is estimated as 131.4 to 152.8 million barrels per year (Abbas & Ansumali, 2010). It is a potential source of bioenergy, which is produced in large quantities in southeast Asia. There are low or nearly zero land-use risks if rice husks are used as bioenergy or feedstock for biofuels (Food and Agriculture Organization, 2009). Ash in rice husks comprises approximately 90% silicon dioxide (Morgan & Turn, 2017). Rice straw is among the most common agricultural residues globally, with an energy content of about 14 MJ/kg with a 10% moisture content. Globally, roughly 800 to 1,000 million tonnes of rice straw are produced in a year, with about 600 to 800 million tonnes per year produced in Asia. It continues to increase rapidly due to the short turnaround time required for intensified rice cropping (Rice Straw Management, 2019). Rice straw can be used to produce liquid biofuels based upon the conversion of its cellulose and hemicellulose content, as summarized in Fig. 10 (Morgan & Turn, 2017). It has been reported that rice straw could be used to produce 54.14 billion gallons of bioethanol per year worldwide (Belal, 2013). High costs in collecting and transportation of rice straw residual for further processing (Morgan *et al*., 2019) as well as high carbon to nitrogen ratio, which leads to the low biodegradability and high ash content containing sulfur, chlorine and potassium (Morgan & Turn, 2017) are the leading reasons of the limited rice straw usage in energy-producing applications. The ash content of straw may also require pretreatment (Wu *et al*., 2020), making it a less attractive fuel feedstock when compared to other sources.

2.5.4. *Leucaena hybrid*

Leucaena hybrid is a prevalent plant that can be used to produce multi-products such as fuelwood, mulch, timber, and livestock fodder (Youkhana & Idol, 2016). Leucaena leucocephala is mainly found in Mexico and Central America but is now also grown in tropical and subtropical areas (Hakimi *et al*., 2017). It is a fast-growing leguminous tree that produces nonedible seed oil (Ilham *et al*., 2015). The seed kernel contains 20% oil utilized as a feedstock to produce biofuels, especially biodiesel through transesterification (Meena *et al*., 2013). It was investigated to evaluate its potential for biodiesel and concluded that it could be used as a feedstock for biodiesel production through alkali catalyzed transesterification (Hakimi *et al*., 2017). It was grown in one of Hawaii's agricultural universities, which proved that it could proliferate within five years and produce high biomass yields (Brewbaker, 2013). High herbage yields have been recorded as 16.53 tonnes/ha/yr in Hawaii, Australia, and southeast Asia (Youkhana & Idol, 2016). It can also be used as a renewable energy biomass resource for power generation, whereas also providing leafy material as a supplemental feedstock for livestock (Tudsri *et al*., 2019).

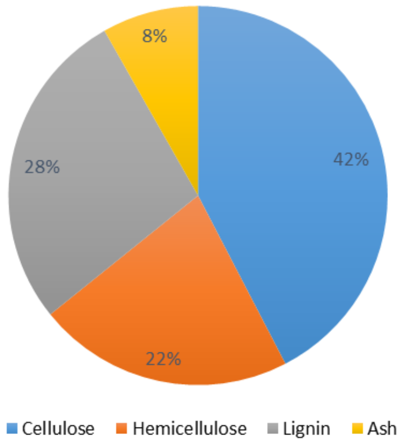

Fig. 7 Composition of bagasse.

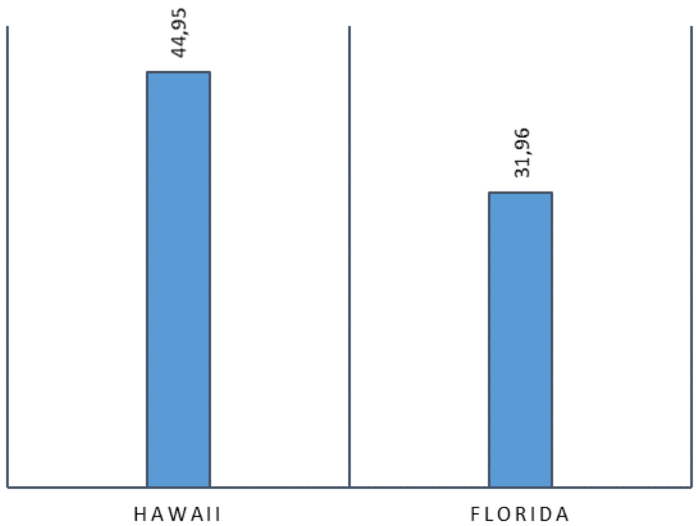

Fig. 8 Average yields (tonnes/ha/yr) of energycane biomass in Hawaii and Florida.

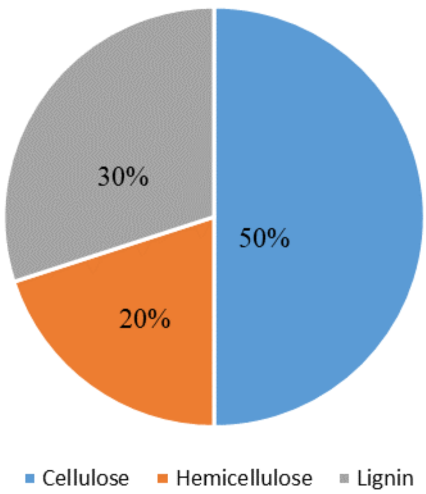

Fig. 9 Composition of energycane biomass.

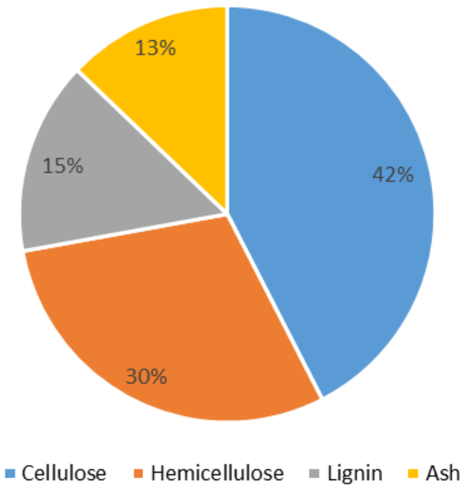

Fig. 10 Composition of rice straw.

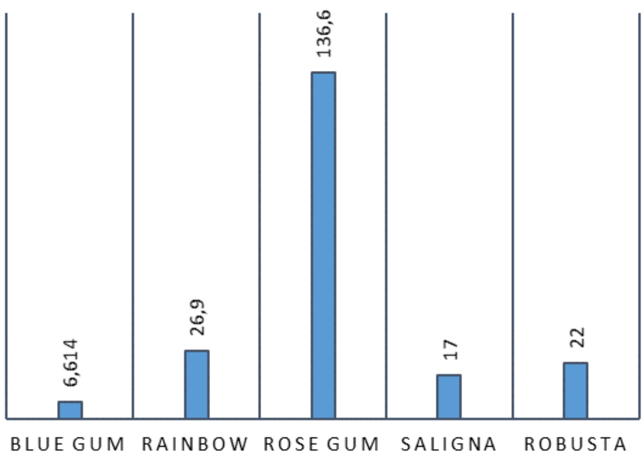

Fig. 11 Different types of Eucalyptus trees and their average yields (tonnes/ha/yr) for bioenergy usage.

2.5.5. Gliricidia

It is a native plant found in dry tropical woodlands in Mexico and Central America (Simons & Stewart, 1994) but is also found in tropical and subtropical areas worldwide (Knothe *et al*., 2015). Cuttings and seeds can be used to grow it for lumber to be used in building structures, poles, biofuels (Knothe *et al*., 2015; Baloch *et al*., 2015; Kumar & Simon, 2016), and the leaves can be used for animal fodder (Atapattu *et al*., 2017). It is called "gamal" in Indonesia and is used for different purposes, including firewood, medicine, and feedstock for cattle (Amrita *et al*., 2016). Recent research has synthesized the methyl esters from Gliricidia sepium seed oil and determined their important fuel properties. The seed fatty acids profile is reported as 49 % of linoleic acid, 16.5 % of palmitic acid, 14.5 % of stearic acid, and small quantities of long-chain fatty acids (Knothe *et al*., 2015). It has the ability for nitrogen fixation and can improve the fertility and moisture content in soil because its fallen leaves disintegrate promptly, releasing nitrogen (N) and potassium (K) (Baloch *et al*., 2015). Gliricidia has extraordinary nutritional worth based upon its protein content and has been used for medical treatments (Kumar & Simon, 2016). When planted as either fuelwood or fodder, gliricidia can yield 16.53 to 33 tonnes/ha/yr biomass when intensively cultivated.

2.5.6. Eucalyptus

Eucalyptus is a typical hardwood tree with more than 700 different species that grow in the world's hottest regions (Gledhill, 2008). It has excellent potential to provide woody feedstock at a low cost due to its rapid growth rate (Harper *et al*., 2010; Sochacki *et al*., 2013). Commercial-scale plantations are located in various places, from Hawaii to South Africa, and researchers are showing great interest in using it as a feedstock for energy purposes (Field *et al*., 2007; Campbell *et al*., 2008). Some eucalyptus species with high biomass yields are reported in Hawaii for fiber production. The average yields of some eucalyptus species in Hawaii and similar regions are summarized in Fig. 11 (Sochacki *et al.*, 2013; Palma & Carandang, 2014; Stape *et al.*, 2008; Hinchee *et al.*, 2009). These species of eucalyptus can be used for paper, fiber, furniture, fuelwood, charcoal, and as a biofuel feedstock (Farmer, 2013; Ugalde & Perez, 2001; Hunde *et al.*, 2003; Simmons *et al.*, 2008; Hoogeveen *et al.*, 2009). The eucalyptus seed contains approximately 60% oil content, primarily due to its cineole content. A eucalyptus biodiesel yield of 86% has been reported via transesterification (Verma *et al.*, 2016).

2.6. Food waste as a renewable energy source

Food waste is generated globally and mainly comprises vegetables, fruits, meat, fish, bones, poultry, eggshells, cereals, tea leaves, coffee grounds, pet foods, and other residues (Karmee, 2016; Food Waste Policy, 2014). According to the (IFCO, 2020) and (Food and Agriculture Organization of the United Nations, 2015) reports, 1.3 billion tonnes of wasted food are generated per year worldwide, worth more than $1 (U.S.) trillion. It has been reported that the land use for waste food is approximately 28 % of the total world`s agricultural area, which accounts for 1.4 billion hectares (Chainey, 2015). It has been reported in the (Food and Agriculture Organization of the United Nations, 2015) report that food waste contains 45% fruits and vegetables, 35% fish and seafood, 30% cereals, 20% dairy products, and 20% meat and poultry.

In the U.S., approximately 40% of food produced is wasted annually (NRDC, 2012). According to the (U.S. Environmental Protection Agency, 2016), 38.4×10^6 tonnes of food was wasted in U.S. in 2014, which was 14.9% of total municipal solid waste (industrial, constructive and hazardous waste are excluded). 76.5% out of 38.4×10^6 tonnes went to landfills, 18.48% was utilized to generate energy, and 4.94% was composted. Mathew Loke and Pingsun Leung estimated that Hawaii discards 161.5 kg of food per person in a year. They also estimated that Hawaii wasted 2.614×10^5 tonnes of food in 2010, 26% of the total available food supply worth more than US$1 billion (Smallwood, 2016). Hawaii depends on imported foods to fulfil its food requirements and it has been reported that a significant amount of food waste is generated (Matthew & James, 2019). So, there is a need to reduce, reuse, and recycle food waste for a sustainable environment and potential for biofuel production.

Reducing and recycling food waste is growing worldwide, including in Hawaii (Food and Agriculture Organization of the United Nations, 2015). Reducing waste improves food utilization, food security, saves consumers money, reduces water/land use, saves energy, saves labor, reduces global warming and methane gas emissions (Matthew & James, 2019). The U.S. Environmental Protection Agency has designed a hierarchy (Fig. 12) for food recovery in Honolulu, with the priorities listed below.

Source reduction: Food recovery's first priority is source reduction, in which the goal is to prevent food waste in the first place or minimize the amount of surplus food produced. Many tools help with source reduction (U.S. Environmental Protection Agency, 2021) food recovery, national restaurant association conserve program, lean path).

Feed hungry people (donation): Aloha Harvest Food Rescue, Food Pantries, Rock and Wrap it Up, Sustainable America, Refed Innovator Database, and Food Banks are the organizations that accept food as a donation in Honolulu. Non-perishables are accepted by the majority of the NPOs, while a minority of them accept perishable foods.

- *Feed animals (divert food scraps):* Large pig farms may accept food scraps. According to the U.S. Federal Swine Health Protection Act, food scraps must be boiled before feeding to pigs, if it contains meat or animal products. As a result, single-stream fruits and vegetables and grain wastes are of primary interest for use as pig feed to many local pig farmers. Animal feed made from brewer`s spent grain can be used for any livestock. The majority of breweries donate their grain to local farms that use a single food waste source to donate their excess/byproducts to local farms.
- *Industrial use (waste oils to biofuels)*: Fats, oils, and grease (FOG) can be used as feedstocks for biofuel production in several industrial applications. FOG and food scrapings can also produce energy through anaerobic digestion, and digestate (leftover residue) can then be enriched for soil modification.
- *Composting:* Food scraps are turned into nutrient-rich soil supplements by composting, which can be achieved on-site in limited quantities or on commercial scales.
- *Landfill:* When food is disposed of in a landfill, it is somewhat similar to disposing of the food waste in a plastic bag. The nutrients in the food waste do not return to the surrounding soil. Bacteria decompose the wasted food to produce methane gas which is released into the atmosphere.

The establishment of the H-Power facility (waste to energy) in 1990 was a game-changer to produce electricity in Honolulu and sold to the electricity company (Matthew & James 2019). 98.3% of food waste equivalent to 118,175 tonnes were received at the H-Power facility after its expansion (Beck, 2006). Other and neighboring Hawaiian Islands have no waste to energy facility, and most of their food waste is landfilled (Matthew & James, 2019).

Food wastes are a potential energy source that has basically no feedstock cost and can be used for liquid biofuels production to meet transportation needs because it contains lipids, amino acids, carbohydrates, and other carbon-containing substances (Karmee, 2016; Karmee & Lin 2014 (a,b); Pham, 2015). The approximate amount of carbohydrates (65%), lipids (25%), and proteins (10%) in bakery wastes has been reported (Karmee, 2016). Lipids can be converted into biodiesel by transesterification, and carbohydrates converted into sugars, where the sugars are fermented in bioethanol, acetone, or biobutanol (Karmee, 2016; Karmee & Lin, 2014 (a,b); Pham, 2015; Ozturk, 2020). Lipids extracted from fat-containing food waste can be converted into biodiesel with yields of approximately 96%. On the other hand, 94% bioethanol yields can be obtained by fermentation of high sugar content food wastes. In addition, bio-oil and biochar can also be obtained from food waste through the pyrolysis process (Karmee, 2016).

Table 3
Biofuel technologies and product economic comparison.

Technologies	Feedstocks	Feedstock cost (US$/gal or other unit)	Operational and production cost (US$/gal)	Capital cost (US$/gal)	Product	References
Fermentation	Sugarcane	0.81		2.10	Ethanol	Black & Veatch, 2010; U.S. Department of Agriculture , 2021
	Molasses	0.91		2.40		
	Corn	-----	1.05	---		
Hydrolysis	Cellulose	0.31	0.35	4 - 8	Ethanol	Black & Veatch, 2010; McAloon *et al.*, 2000; Monti *et al.*, 2007
Thermochemical	Biomass	0.31	0.7 - 1.0	4 - 8	Ethanol	Black & Veatch, 2010; Boerrigter and Rauch, 2005; Brown, 2019
Transesterification	Different sources	0.45 – 0.55	0.2 – 0.40	0.80 – 1.20	Biodiesel	Radich, 2004; Black & Veatch, 2010; Fu *et al.*, 2016
Methane reformation	Landfill gas	2 – 5 /million BTU	0.62/ million BTU	----	Methane, hydrogen	Black & Veatch, 2010
Hydro-treated esters and fatty acids (HEFA)	Jatropha	0.5 per kg	---	0.96 – 1.44 (20% higher than biodiesel)	HVO, Biodiesel	Morgan *et al.*, 2019; Wang & Tao, 2016
	Palm	0.79 per kg	---			
	Camelina	1.75 per kg	---			
	Algae	3.55 per kg	9.2			
	Soybean	1.14 per kg	4.1			
	Rapeseed	1.72 per kg	---			
	Waste cooking oil	0.12 – 0.47	---			
Fischer-Tropsch gasification	Generic biomass	41/tonnes	----	----	Methanol	Williams *et al.*, 1995; Tijmensen, 2002; Larson *et al.*, 2009; Brown, 2019
	Poplar	33/tonnes			FT liquid	
	Switchgrass	46/tonnes			Gasoline, diesel	
Fast pyrolysis	Biomass	94 – 188 /Mg		5.6 – 14.4 (million)	Bio-oil	Uslu et al., 2008
Hydrothermal liquefaction	Biomass	----	-----	-----	Gasoline, diesel, etc.	----
Direct sugars to hydrocarbons (DSHC)	Sugars	---	4.6/gallon	---	Pentadecane Jet fuels	Morgan *et al.*, 2019; Wang & Tao, 2016

Fig. 12 Food recovery hierarchy in Honolulu (U.S. Environmental Protection Agency, 2021).

2.7. Sewage sludge

Municipal sewage sludge is the residue generated by wastewater treatment plants. The global annual sewage sludge generation on a dry basis is approximately 20×10^6 tonnes and gradually increasing due to population growth, urbanization, and industrialization (Spinosa, 2015). It consists of various organic and inorganic aqueous materials derived from residents, industries, institutions, and storm (monsoon) water drainage, requiring chemical, physical and biological treatments (U.S. Environmental Protection Agency, 1993; Usman *et al.*, 2012). It has the potential for low-cost biodiesel production through the transesterification process of the extracted lipids (Arazo *et al.*, 2017). A 96.51% biodiesel yield has been reported through acid-catalyzed transesterification of the lipids (Jazie, 2019). Sludge as a feedstock would aid in bioremediation and the production of low-cost biofuels in an environmentally friendly manner. The organic concentration varies from location to location. In the U.S., the sewage sludge has 36.8 wt. % of fatty acids and steroids which are excellent sources for biodiesel production (Jarde *et al.*, 2005; Kargbo, 2010). Hawaii produces approximately forty thousand tonnes of dry sewage sludge in a year. Some sewage sludge is currently incinerated for power steam generators that generate electricity in Honolulu (Kozacek, 2017).

3. Biomass Conversion Technologies and Economics

Several techniques, processes, or methods can produce biofuels from different biomass resources that can be used anywhere globally. Some of the latest and emerging technologies are playing essential roles for various liquid biofuels production, such as Fischer-Tropsch gasification, hydrothermal-liquefaction (HTL), fast-pyrolysis, direct sugars to hydrocarbons (DSCH), alcohol to jet (ATJ) fuel, and hydro-treated esters and fatty acids (HEFA). The purpose of direct sugar conversion to hydrocarbons (DSCH) and alcohol-to-jet fuel (ALT) processes are to produce sugars from cellulosic or hemicellulosic materials through hydrolysis and alcohols by other than fermentation methods (Morgan *et al.*, 2019; Klein *et al.*, 2018). Based on their available biomass resources, Hawaii and similar islands can use these technologies for efficient and economical biofuels production.

The production of biofuels in large quantities at a commercial scale is usually expected to benefit from the "economy of scale" that will enable liquid fuel production at a reasonable cost (Black & Veatch, 2010). This concern is essential in Hawaii, where topography restraints resource accessibility and biomass raw material transport. These constraints, including feedstock, transportation, and conversion, impact cost estimations for biofuels production in Hawaii (DBEDT, 2019). The summary of all available technologies, feedstocks, operational, production and capital cost for biofuels production is given above in Table 3.

For bio-ethanol production, feedstock cost depends on its availability, quantity and its location. It will be more cost-effective if the ethanol production plant is situated near the biomass processing facilities. Transportation costs are dependent on the type and quality of biomass. For example, costs will be high if a biomass feedstock has low density or high moisture content. The economics of biodiesel is improving due to the rising and volatile oil prices and geopolitical concerns. There is finite information for the operating and capital costs of the

HEFA or HRJ process provided in the literature. The supply and shipping of biomass for gasification are challenges as compared to fossil fuels. However, the FT-gasification synthesis of biomass is feasible, and many of the researchers have reported on its feedstock cost, capital investment, and product value. The cost estimation of the pyrolysis process depends on the type of reactor using in the process. The production of biofuels (gasoline to diesel) is technically possible and feasible through hydrothermal liquefaction. Still, the production costs are higher than gasification and fast pyrolysis of biomass or petroleum-based fuels. Limited information has reported on the production cost of liquid fuels or hydrocarbons from sugars through DSHC.

The renewable energy sources in the world`s energy mix are needed as low carbon alternative energy sources due to climate change, address environmental concerns, and decrease dependence on imported fossil fuels (International Energy Agency, 2017). Biomass can be used for several different energy purposes, such as burned for heat production or electricity generation and converted into biofuels for transportation. It can also be utilized as a renewable heat source. There are biomass resources available in various islands that can meet their bioenergy demands, but availability depends upon local conditions and agricultural practices (Svetlana *et al.*, 2018).

Hawaii is a suitable place for the production of biomass, as discussed in this study. It has favorable environmental conditions for growing and harvesting feedstocks for biofuel production and utilization in the energy and transportation sectors to achieve Hawaii`s renewable energy targets. These feedstocks can be developed across different geographic areas in Hawaii and other tropical places. Particularly in the tropics of Cancer and Capricorn in the northern and southern hemispheres, approximately 23.5° latitudes away from the equator, there is abundant sunlight year-round depending on seasonal weather conditions.

The amount of land suitable for energy crop production is vital to estimate energy crop production potential. It has been reported that Hawaii has suitable land for energy crop cultivation because of having both irrigated (300,000 acres) and rainfed (800,000 acres) land. The fundamental reason for examining the possibility and potential of biomass generation in Hawaii is that the fixed available area for agriculture uses will not increase. Identification of new and potential biomass production will lead to additional increases in biofuels yields.

3.1. Geography of Hawaii

Hawaii is an archipelago of eight islands that lies southwest of the continental United States, southeast of Japan, and northeast of Australia in the Pacific Ocean. Hawaii's islands are approximately 2,000 miles southwest of the continental United States. The tropical weather, unique topography, natural environment, and multicultural community of Hawaii are well-known. The island of Hawaii, also known as the Big Island, is the largest by area, while Oahu, where Honolulu is located in the most populous.

Hawaii's climate is mild due to its location in the tropics, with average daytime of 29.4 ˚C in summer and 25.6 ˚C in winter, respectively (Go Hawaii, 2021). Islands have rainy and dry seasons, and the regional climate varies depending on one's location concerning the mountain ranges. Hawaii is exceptionally biodiverse with native plants and animals due to its remoteness and tropical climate, and it has the most endangered species in the U.S. (Amanda, 2021).

3.2. Land use for agriculture in Hawaii

According to the Department of Urban Regional Planning, Hawaii has 7,521 farms on 1,121,329 acres. There are 1,930,224 acres of land used for agriculture by the State Land Use Commission, of which 430,000 acres belong to the state. The U.S. Department of Agriculture (U.S. Department of Agriculture, 2021) has classified that approximately 42 % of Hawaii`s agricultural land or 806,705 acres are not being used. The majority of Hawaii's farmland is for grazing, with the remaining be used for agriculture, woods, and farmsteads or roadways. Only 4 % of the total agricultural land or 44,336 acres are planted for long-term crops, and 125,391 acres are not being used due to limited built structures. Hawaii has a total of 950,602 acres of land for agriculture production (The Kohala Center, 2009; Jung, 2021).

3.3. Benefits of biofuels in Hawaii

If Hawaii can partially switch from imported fossil fuels to locally produced economical biofuels, it can effectively use its existing power plants and transportation infrastructure. Biofuels are more environmentally friendly than most fossil fuels, helping decrease carbon footprint by lowering greenhouse gas emissions. Local biofuel production can help Hawaii to boost its energy security, economic prosperity, and environmental quality. According to the U.S. Department of Energy's (U.S. Department of Energy, 2015) Office of Energy Efficiency & Renewable Energy, benefits of biofuels production and uses in the economy, energy, environment and feedstocks in Hawaii are given below;

- **Economic:** Hawaii spends about $4 billion on petroleum-based transportation fuels each year. A local biofuel production industry could meet about 10% of the projected demands of liquid fuel by 2030, generate 2000 jobs and between $0.5 to $1 billion in annual revenue.
- **Energy:** The U.S. military in Hawaii, which has a significant presence, hopes to utilize biofuels in the future. By 2050, the U.S. Pacific Command plans to replace 25% of the 140 to 150 million gallons of petroleum fuels used yearly for aviation and marine use with biofuels.
- **Environment:** Today, petroleum fuels meet approximately 90% of Hawaii's energy requirements. Locally generated biofuels minimize vulnerability to oil price fluctuations while also lowering the costs and risks of shipping 1.8 billion gallons of petroleum per year.
- **Feedstocks:** Multi-crop approaches and better usage of idle land offer alternative biomass solutions for Hawaii.

Table 4
Summary of average values for biofuel estimation with 90% extraction/conversion efficiency.

Feedstocks	Biomass yields (dry) (tonnes/ha/yr)	Oil contents (avg. wt %)	First yield starts in (avg. yr)	Estimated production (yr)
Jatropha	7.2	35.0	2.0	30
Kamani	17.7	42.5	6.0	25
Pongamia	9.0	36.0	4.0	25
Croton	13.0	37.5	3.0	25

3.4. Estimation of biofuel production from various feedstocks

This study has estimated the average biofuel production from oleaginous feedstocks focusing on Hawaii. The average values were taken from Table 2 assuming constant average biomass yields (tonnes/ha/yr), seed oil content, the time required to produce the first crop of seeds, and how long the plants or trees can produce seeds are reported. In order to calculate the total production amounts, an average 90 % extraction and conversion efficiency was chosen for this estimation. Only 1% of the available agricultural land (~ 8067.5 acres or 3266.24 ha) was considered from the available land (806,705 acres) in Hawaii for potential growing the feedstock in plantations. In addition, the time needed to produce the first crop of seeds was used to estimate this production-based values reported in the literature. The summary of all these parameters for estimating potential biofuel production in Hawaii is given in Table 4.

These feedstocks can be used for biodiesel production through the transesterification process in the presence of a catalyst (acid/base) and its reaction is given below in equation 1.

$$\text{Oil} + \text{Alcohol} + \text{Catalyst} \rightarrow \text{Biodiesel} + \text{Glycerol} \quad (1)$$

Fig. 13 shows the estimated cumulative biodiesel production for a period of 30 years based for a parcel of agricultural land utilizing the parameters in Table 4 in the case jatropha, kamani, pongamia and croton plants were planted on four parcels of land in the first year. At the end of year five, jatropha and croton are the leading feedstocks for biodiesel production because of their short time for the first yield i.e., after two and three years from planting. Afterward, biodiesel production from all feedstocks increases proportionally with time, but kamani and croton show a significant difference over the long term compared to others because of their higher biomass yield and oil contents. Kamani, pongamia, and croton show no change in biodiesel production from year twenty-five to thirty years because of having a twenty-five-year life period for seed oil production. The byproduct of the transesterification reaction is glycerol which can be co-digested as sewage sludge, disposed of, or used for soap production. This quantity of biodiesel production is directly related to land acreage that is planted and feedstock yields etc. In order to produce substantial amounts of biofuels from these plants and their seed nuts, at least ten years is needed after the initial planting.

$$\text{Biodiesel Estimation} = B \times L \times Y \times O \times E \times C \quad (2)$$

Equation 2 was used to estimate the total biodiesel production where "B" is the biomass/seed yield (tonnes/ha/yr), "L" is the land use (hectare), "Y" is the no. of years, "O" is seed oil content (wt %), "E" is the extraction efficiency and "C" denotes the conversion efficiency. In this estimation, if 1% of the available agricultural land in Hawaii was planted, it could produce jatropha, kamani, pongamia and croton derived biodiesel with 6630.1, 19831.1, 8571.9 and 12917.4 tonnes per year, respectively. Kamani yields the highest biodiesel of 19831.1 tonnes per year production, which is approximately 1.2 % of Hawaii`s total ground transportation consumption needs, 4.1% of only military consumption and 1.6 % of the consumption for electricity generation. It has been reported that the energy output of kamani biodiesel (via transesterification) is higher than the input energy (section 2.2). The estimation shows that kamani can add significant value to achieve the 25% biofuels replacement in military consumption by 2050 (section 3.3) if greater acreage was planted. Biodiesel production can potentially be increased by lessening the density of trees (usually 400 trees per hectare) and allocate more land for growing kamani plants.

Based on the above results, kamani and croton can be planted and used as a potential feedstock for biodiesel production in Hawaii and other tropical regions for the long term because the tropical climate can meet the optimum growing conditions for these plants. The average rainfall and temperature requirement are similar for all feedstocks discussed in this study, and jatropha and pongamia have grown in Hawaii. The economic life period for kamani, pongamia and croton seeds is 25 years while jatropha is 30 years; further biodiesel production would require replanting these feedstocks after the plants stop producing seeds. The feedstocks, operation and production cost can also be estimated by considering the average values of the transesterification process reported in Table 3. Similar estimation can be performed for fiber feedstocks to produce cellulosic bioethanol in 1% of agricultural land, but this study did not estimate these values due to the limited literature reported for extraction and conversion efficiencies. These fiber-containing feedstocks also have great potential for biofuel production due to their high lignin, cellulose, and hemicellulose contents.

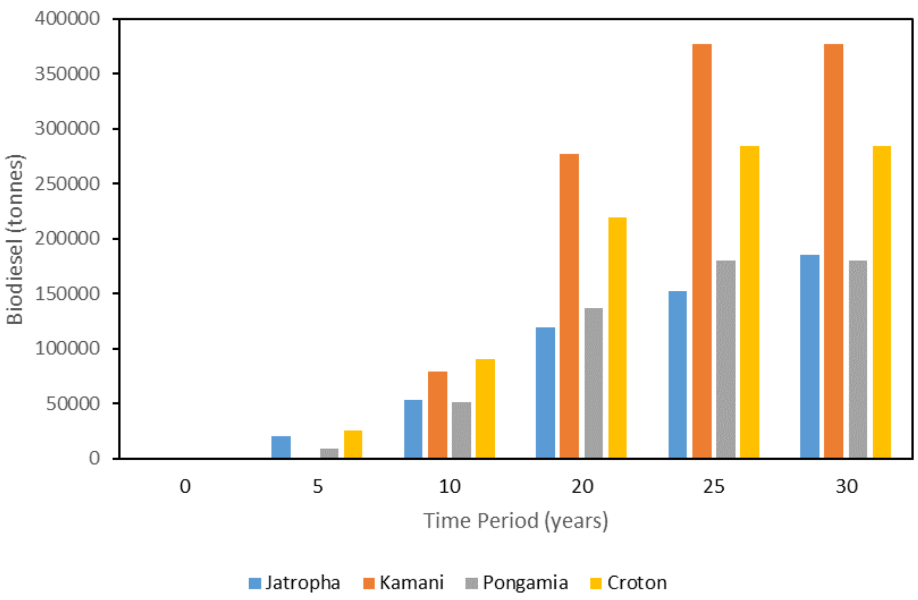

Fig. 13 Cumulative biodiesel production estimation from oligenerous feedstocks if planted on 1% of Hawaii's agriculture land.

3.5. Other Applications

Residual biomass can be found in production processes which can be used for other applications. For example, bottom and fly ashes are generated during the energy production process through biomass combustion. There are various reports on fly ash incorporation in the creation of new building materials. The manufacturing of mortars by utilizing biomass fly ash has been studied (Teixeira *et al*., 2019). Another study has described the positive results of using biomass fly ash in cement, conventional and self-compacting concrete. The biomass bottom ash has also been reported feasible to use in cement, mortar, or concrete (Manuel *et al*., 2020). A massive quantity of waste is generated from agricultural and forestry processes. Agricultural biomasses are usually discarded or burned, but these wastes/residues can be utilized as feedstocks for valuable products (Nimisha *et al*., 2019). Biomasses have the potential to produce biofuels, polymers, and construction materials. Cellulose, hemicelluloses and lignin-rich wastes can be used to produce chemicals, resins, and enzymes (Khedari *et al*., 2003). The main universal crops, including wheat, rice, barley, maize, soybean, sugarcane, sugar beet, and rapeseed, produce significant potential biomass of almost 3.3×10^{10} tonnes of residue (Nimisha *et al*., 2019).

The development of advanced and eco-friendly materials for green building applications is being encouraged (Guna *et al*., 2019). In this regard, renewable resources, including wastes, have been studied and are being used to develop long-term thermal insulating materials. (El Hage *et al*., 2019). Natural resource composites have been reported to have low density, good thermal characteristics, and fewer environmental effects (Eschenhagen *et al*., 2019). Rice and wheat husk are the key byproducts of natural resource materials, suitable for developing long-term building materials (Buratti *et al*., 2018). Wood fibers are also alternative resources commonly used due to admirable mechanical characteristics and reasonable prices (Mantia & Morreale, 2011).

Biochar is a type of charcoal produced through pyrolysis that has agricultural and environmental applications. It is a carbon-rich solid material valuable in agriculture since it improves the soil quality while preventing pesticides and other nutrients from seeping into the runoff. It is also an excellent carbon sink. Carbon sinks are reservoirs for storing carbon-containing chemicals and trapping carbon-based greenhouse gases (National Geographic Society, 2012).

4. Recommendations

Favorable seasonal weather consisting of moderate temperatures and rainfall are two essential factors required for the efficient growth of biomasses in tropical regions. It has been reported that biomass yields in Hawaii are much higher than in other places in the U.S. because of the year-round growing season and abundant rainfall, which can mitigate biofuel production`s potential drawbacks.

It is possible that agricultural economics, feedstock availability, land availability, and biomass transportation to biorefineries (location barriers) can influence the development and commercialization of biofuel production.

In order to convert biomass into biofuels various technologies and process equipment are needed such as reactors, boilers, gasifiers, etc.. Biomass factors and its characteristics, including biomass type (Sansaniwal *et al*., 2017a), moisture contents (Sansaniwal *et al*., 2017a, b; Ramos *et al*., 2018), particle size (Sikarwar *et al*., 2016; Parthasarathy & Narayanan, 2014) and ash contents (Asadullah, 2014; Sikarwar *et al*., 2016) affect the required product yield, quality, and conversion efficiency. It has been reported that the updraft and downdraft fixed bed gasifier are suitable for the biomasses with moisture contents up to 60% w/w and 25% w/w, respectively (Ramos *et al.*, 2018; Sansaniwal *et al.*, 2017b). The operating parameters, including the fluidized bed material, operating conditions (temperature and pressure), air, oxygen, steam, air to fuel and steam to biomass ratio also affect the performance of gasifiers. The most popular catalyst or commonly used bed materials include silica, limestone, dolomite, nickel and potassium and alkaline metal oxides (Devi *et al.*, 2005; Sutton *et al.*, 2001). It has been reported that the temperature range of 750°C to 850°C is used for agriculture waste gasification and 850°C to 950°C for woody biomass gasification and high-pressure gasification is recommended for the biofuels for turbines and engines (Sikarwar *et al.*, 2017; Ahmad *et al.*, 2016; Asadullah, 2014). The optimal air to fuel range is 0.2 to 0.3 for both fixed and fluidized bed gasifiers has been reported (Kumar *et al.*, 2009). For tropical biomasses such as sugarcane, energycane, eucalyptus and Leucaena have been processed in a fluidized bed reactor for fast pyrolysis at 450°C with a heating rate of 400°C/s which gave 55.1 wt. %, 55.1 wt. %, 48.1 wt.% and 40.8 wt.% bio-oil yields, respectively (Morgan *et al.*, 2016).

Although it is possible to propose which biomass should be cultivated based on the economics and technologies reported in this review, successful projects related to biofuels production should start at the community level by initially building relationships between stakeholders. In the past, problems have arisen due to not correctly engaging the community within Hawaii, e.g., in several cases such as a paper mill, which became outdated due to improper commercial zoning and controversial eradication plans for papaya crops (Kohala Center, 2009).

5. Conclusion

Until recently, energy consumption in Hawaii has not been secure and, in many cases, unsustainable, environmentally unfriendly, uneconomical, and has lacked local community support. Continued dependency on imported fossil fuels and the impending future energy crises will impact lifestyles and economic growth if the islands do not change their selection of energy sources. Hence, the hunt for renewable liquid fuels is vital for sustainable development and economic quality of life. However, to satisfy the increasing demand for transportation fuels, alternatives that can be locally produced and stored are needed. Local biofuel production and efficient energy use are deemed the most cost-effective way to meet the energy requirements. This study presented data and discussed how nonedible biomass feedstocks can be used to produce biofuels in the near and longer term, increasing the renewable energy share in Hawaii and other tropical regions to meet their future renewable energy targets. Furthermore, sewage sludge and food waste processing may also produce liquid economic fuels in highly populated urban areas.

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