OBJECTIVE AND SIGNIFICANCE: Commercial aviation in Hawai‘i currently uses nearly 700 million gallons of jet fuel per year, all of it is derived from petroleum. The University of Hawai‘i (UH) is a member of the Federal Aviation Administration’s (FAA) Aviation Sustainability Center (ASCENT) team of U.S. universities conducting research on production of sustainable aviation fuels (SAF). UH’s specific objective is to conduct research that supports development of supply chains for alternative, renewable, sustainable, jet fuel production in Hawai‘i. Results may inform similar efforts in other tropical regions.

BACKGROUND: This project was initiated in October 2015 and is now continuing into its 6th year. Activities undertaken in support of SAF supply chain analysis include:

- Conducting literature review of tropical biomass feedstocks and data relevant to their behavior in conversion systems for SAF production;
- Engaging stakeholders to identify and prioritize general SAF supply chain barriers (e.g. access to capital, land availability, etc.);
- Developing geographic information system (GIS) based technical production estimates of SAF in Hawai‘i;
- Developing fundamental property data on biomass resources; and
- Developing and evaluating regional supply chain scenarios for SAF production in Hawai‘i.

PROJECT STATUS/RESULTS: Literature reviews of both biomass feedstocks and their behavior in SAF conversion processes have been completed and published. Based on stakeholder input, barriers to SAF value chain development in Hawai‘i have been identified and reported. Technical estimates of land resources that can support agricultural and forestry-based production of SAF feedstocks have been completed using GIS analysis techniques. Samples from Honolulu’s urban waste streams and candidate agricultural and forestry feedstocks have been collected and subjected to physicochemical property analyses to inform technology selection and design of SAF production facilities.

Fuel Properties of Construction and Demolition Waste Streams

A sampling and analysis campaign was undertaken to characterize fuel properties of construction and demolition waste (CDW) streams on O‘ahu. Complete results were summarized and published in “Construction and Demolition Waste-Derived Feedstock: Fuel Characterization of a Potential Resource for Sustainable Aviation Fuels Production” in Frontiers in Energy Research. As shown in Figure 3, although the combustible fraction of the samples have elevated ash levels compared to clean biomass materials, their heating values were comparable, indicating the presence of higher energy density materials. As with most refuse derived fuels, the amount of ash in the fuel and its composition is of particular importance, since ash impacts energy facility operations, maintenance, and emissions. Tests of clean wood fuel from the invasive species (Leucaena spp., common name koa haole) and CDW material were conducted at a commercial gasification technology provider facility to evaluate product composition and yields and identify contaminants (Figure 4). Summaries of test results are under review.
Future work with ASCENT partners includes:
- Analysis of feedstock-conversion pathway efficiency, product slate (including co-products), maturation;
- Scoping of techno-economic analysis (TEA) issues;
- Screening level greenhouse gas (GHG) life cycle assessment (LCA);
- Identification of supply chain participants/partners;
- Continued stakeholder engagement;
- Acquiring transportation network and other regional data;
- Evaluating infrastructure availability; and
- Evaluating feedstock availability.

**Exploration of Biomass Feedstocks for Hawai‘i**

Figure 5 shows the breakdown of land use of the nearly 2 million acres of agricultural lands in Hawai‘i. With the shuttering of much of the cane sugar and the pineapple industries, this total has dropped further. Bringing agricultural lands back into production can support diversification of the economy and support rural development. Biomass feedstocks for sustainable aviation fuel production are options that can contribute to this revitalization. This work was summarized and published in “Review of Biomass Resources and Conversion Technologies for Alternative Jet Fuel Production in Hawai‘i and Tropical Regions” in *Energy and Fuels.*
The Eco Crop model was used to complete an assessment of plant production requirements to agroecological attributes of agricultural lands in the State. Land use constraints included agricultural zoning, land capability classes (an indicator of soil quality), slope, service by irrigation systems, and current agricultural activities. The analysis focused on sites capable of rain-fed production to avoid using irrigated lands that could support food production. Oil seed crops, woody crops, and herbaceous crops were all considered; an example is shown for a eucalyptus species (Figure 6). The Eco Crop model provides an estimate of each energy crops’ productivity across the agricultural landscape. Aggregated yield of biobased feedstock and conversion efficiency from feedstock to final energy product were used as the basis for technical potential estimates. A report detailing these results is being drafted.

Figure 6. EcoCrop assessment of Saligna, Eucalyptus.
Evaluation of Pongamia

Of the sustainable aviation fuels currently approved by ASTM and the FAA, those based on the use of oils derived from plants and animals have the highest SAF yield and the lowest production costs.

**Invasiveness Assessment**

Pongamia (*Millettia pinnata*) (Figure 7) is a tree, native to the tropics, that bears an oil seed and has plantings established on O‘ahu. Under this project, an observational field assessment of trees in seven locations on O‘ahu was conducted by Professor Curtis Daehler (UH Dept. of Botany) to look for direct evidence of pongamia escaping from plantings and becoming an invasive weed. Although some pongamia seedlings were found in the vicinity of some pongamia plantings, particularly in wetter, partly shaded environments, almost all observed seedlings were restricted to areas directly beneath the canopy of mother trees. This finding suggests a lack of effective seed dispersal away from pongamia plantings. Based on its current behavior in the field, pongamia is not invasive or established outside of cultivation on O‘ahu. Because of its limited seed dispersal and low rates of seedling establishment beyond the canopy, risk of pongamia becoming invasive can be mitigated through monitoring and targeted control of any rare escapes in the vicinity of plantings. Seeds and seed pods are water dispersed, so future risks of pongamia escape and unwanted spread would be minimized by avoiding planting at sites near flowing water, near areas exposed to tides, or on or near steep slopes. Vegetative spread by root suckers was not observed around plantings on O‘ahu, but based on reports from elsewhere, monitoring for vegetative spread around plantations is recommended; unwanted vegetative spread might become a concern in the future that could be addressed with localized mechanical or chemical control. A detailed technical report “*Observational Field Assessment of Invasiveness of Pongamia (Millettia pinnata), A Candidate Biofuel Crop in Hawai‘i*” summarized this work.

**Fuel properties**

Pongamia is a potential resource for renewable fuels in general and sustainable aviation fuel in particular. This physicochemical properties of reproductive material (seeds and pods) from pongamia trees grown in different environments at five locations on O‘ahu were characterized (Figure 8). Proximate and ultimate analyses, heating value, and elemental composition of the seeds, pods, and de-oiled seed cake were determined. The oil content of the seeds and the properties of the oil were determined using American Society for Testing and Materials (ASTM) and American Oil Chemist’s Society (AOCS) methods. The seed oil content ranged from 19 to 33 % wt. across the trees and locations. Oleic (C18:1) was the fatty acid present in greatest abundance (47 to 60 % wt) and unsaturated fatty acids accounted for 77 to 83 % wt of the oil. Pongamia oil was found to have similar characteristics as other plant seed oils (canola and jatropha) and would be expected to be well suited for hydro-processed production of sustainable aviation fuel. These results were published in “*Fuel Properties of Pongamia (Millettia pinnata) Seeds and Pods Grown in Hawai‘i*” in ACS Omega.
**Caproduct Development**

Additional studies were devoted to developing coproducts from pongamia pods. Leaching and torrefaction experiments were performed to remove inorganic constituents and reduce the oxygen content of the pods (Figure 9). A 2³ factorial design of the leaching treatment determined the impacts of process operating parameters (i.e. rinse water temperature, rinse duration, and particle size) on the composition and physicochemical properties of the pods and the water. The higher heating value of the pods was found to increase from 16 to 18-19 MJ/kg after leaching, while the ash content was reduced from 6.5% to as low as 2.8% wt, with significant removal of sulfur (S), chlorine (Cl), and potassium (K). The chemical oxygen demand, non-purgeable organic carbon, and total nitrogen of the post-experiment leachates were all found to increase with the rinse water temperature and rinse duration but decrease with the increase of particle size. Leached pods were further processed via torrefaction and the targeted mass and energy yields, ~70% and 85%, respectively, were reached at a process temperature of 270°C. The S, Cl, and K contents of the leached, torrefied pods were found to be lower than that of the raw pods. The reuse of leachate on successive batches of fresh pods showed that ash removal efficiency was reduced after three cycles, although some removal was possible through 15 cycles.

Pongamia pod leaching processes and pod torrefaction processes were summarized and published in “Water leaching for improving fuel properties of pongamia Pod: Informing process design” and “Upgraded pongamia pod via torrefaction for the production of bioenergy” in *Fuel* respectively.

**Other Feedstocks**

Other potential feedstocks for Hawai‘i, kukui (*Aleurites moluccanus*) and kamani (*Calophyllum inophyllum*) nut oils, were also explored. Preliminary studies found the oil content of the kukui nuts is ~60% wt, which is ~20-30% wt higher than that of pongamia seeds and kamani nuts. The unsaturated fatty acids, however, accounted for ~90% wt of the kukui nut oil, slightly higher than that of kamani nut (~75% wt) and pongamia seed oil. Kukui and kamani nut oil are different from the pongamia seed oil, in that the primary fatty acid is linoleic acid (C18:2).

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