Alternative Jet Fuel Development

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March 20, 2018

Overview

- International Civilian Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)
- U.S. Federal Alternative Jet Fuels Research and Development Strategy
- Federal Aviation Administration's Aviation Sustainability Center (ASCENT)
- University of Hawaii activities under ASCENT

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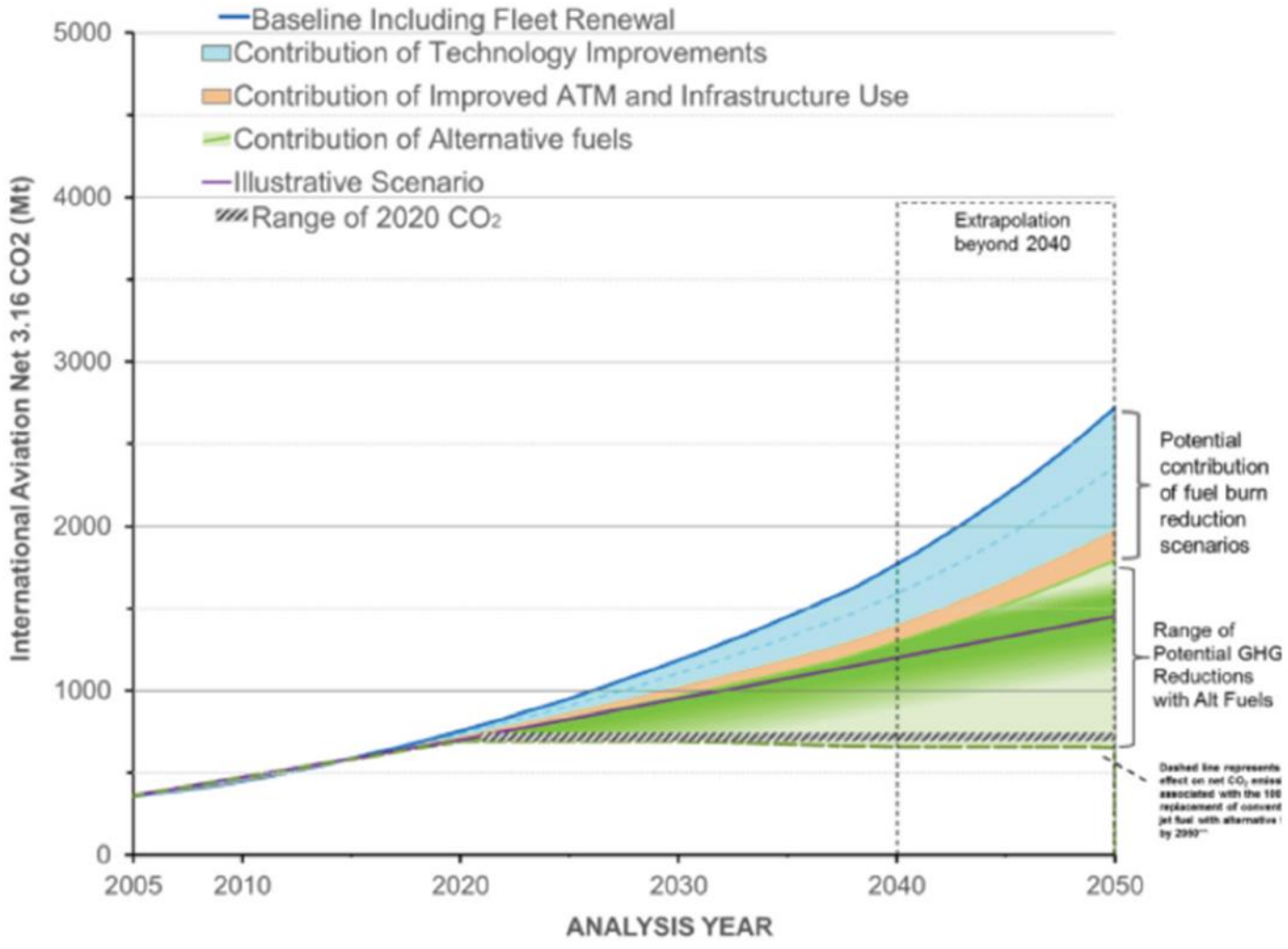
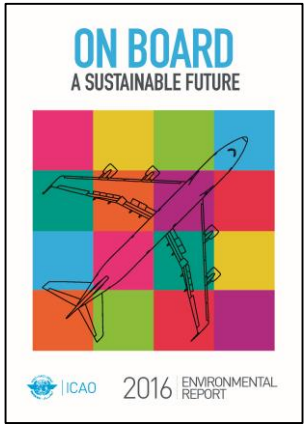
International Civilian Aviation Organization

- UN specialized agency to manage the administration and governance of the Convention on International Civil Aviation (1944)
- Reach consensus on international civil aviation Standards and Recommended Practices (SARPs)
- Ensure that local civil aviation operations and regulations conform to global norms
- Currently 100,000 flights per day around the globe

Aircraft CO_2 Emissions from International Aviation, 2005 to 2050





ICAO

On Board a Sustainable Future -- 2016 Environmental Report, International Civilian Aviation Organization, https://www.icao.int/environmental-protection/Pages/env2016.aspx

Airports supplied with AJF

- Los Angeles International (LAX)
- Stockholm Arlanda Airport (ARN)
- Oslo Gardermoen (OSL)
- Bergen Flesland (BRO)
- ICAO Alternative Jet Fueled Planes

Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

- Global market based management scheme developed by the International Civilian Aviation Organization (ICAO) to address any annual increase in total CO_2 emissions from international civil aviation above 2020 levels
- Voluntary participation from 2021 through 2026 (pilot and first phases)
- Mandatory participation by member States beginning in 2027
- Exemptions for SIDS, LDCs, and LLDCs
- Exemptions for States with a share of international aviation below 0.5 percent in 2018 and lower 10% ranking among States (based on revenue tonne kilometer (RTK), weight of sold capacity of passengers and cargo multiplied by distance flown)

https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx

2016 International Scheduled RTK[1]

State	International Scheduled RTK (million) (2016)	Ranking by State	Share by State (%)	Cumulative Share (%)	SIDS[3]	LDC[4]	LLDC[5]
CHINA[2]	76,649.0	1	12.69%	12.69%			
UNITED STATES	62,335.1	2	10.32%	23.00%			
UNITED ARAB EMIRATES	55,157.4	3	9.13%	32.13%			
UNITED KINGDOM	33,583.3	4	5.56%	37.69%			
GERMANY	31,833.6	5	5.27%	42.96%			
REPUBLIC OF KOREA	22,756.3	6	3.77%	46.72%			
QATAR	21,672.0	7	3.59%	50.31%			
SINGAPORE	19,217.6	8	3.18%	53.49%	Y		
FRANCE	18,128.4	9	3.00%	56.49%			
TURKEY	17,180.7	10	2.84%	59.33%			
JAPAN	16,990.0	11	2.81%	62.15%			
NETHERLANDS	15,793.8	12	2.61%	64.76%			
CANADA	14,756.9	13	2.44%	67.20%			
IRELAND	14,428.2	14	2.39%	69.59%			
RUSSIAN FEDERATION	12,201.6	15	2.02%	71.61%			
SPAIN	9,864.0	16	1.63%	73.24%			
THAILAND	9,697.3	17	1.60%	74.85%			
AUSTRALIA	9,684.3	18	1.60%	76.45%			
MALAYSIA	8,280.3	19	1.37%	77.82%			
INDIA	7,566.4	20	1.25%	79.07%			
LUXEMBOURG	7,097.4	21	1.17%	80.25%			
SWITZERLAND	6,700.5	22	1.11%	81.36%			
NORWAY	5,719.8	23	0.95%	82.30%			
SAUDI ARABIA	4,895.2	24	0.81%	83.11%			
ITALY	4,769.5	25	0.79%	83.90%			
PHILIPPINES	4,721.7	26	0.78%	84.68%			
ETHIOPIA	4,202.7	27	0.70%	85.38%		Y	Y
BRAZIL	4,101.2	28	0.68%	86.06%			
MEXICO	3,992.6	29	0.66%	86.72%			
BEL							
NEV							
FINLAND	3,274.7	32	0.54%	88.31%			
CHILE	3,274.7	33	0.54%	89.06%			
INDONESIA	3,110.1	34	0.51%	89.57%			

https://www.icao.int/sustainability/Pages/RTK_ranking.aspx

APEC STATES RTK RANKING

2016 International Scheduled RTK[1]

State
CHINA[2]
UNITED S
UNITED A
UNITED K
GERMANY
REPUBLIC OF KOREA
QATAR
SINGAPORE
FRANCE
TURKEY
JAPAN
NETHERLANDS
CANADA
IRELAND
RUSSIAN FEDERATION
SPAIN
THAILAND
AUSTRALIA
MALAYSIA
INDIA
LUXEMBOURG
SWITZERLAND
NORWAY
SAUDI ARABIA
ITALY
PHILIPPINES
ETHIOPIA
BRAZIL
MEXICO
BELGIUM
NEW ZEALAND
FINLAND
CHILE
INDONESIA

Rank	Country	Share by State (%)
1	China	12.7
2	U.S.	10.3
6	R of Korea	3.8
8	Singapore*	3.2
11	Japan	2.8
13	Canada	2.4
15	Russia	2.0
17	Thailand	1.6
18	Australia	1.6
19	Malaysia	1.4
26	Philippines	0.8
29	Mexico	0.7
31	New Zealand	0.6
33	Chile	0.5
34	Indonesia	0.5

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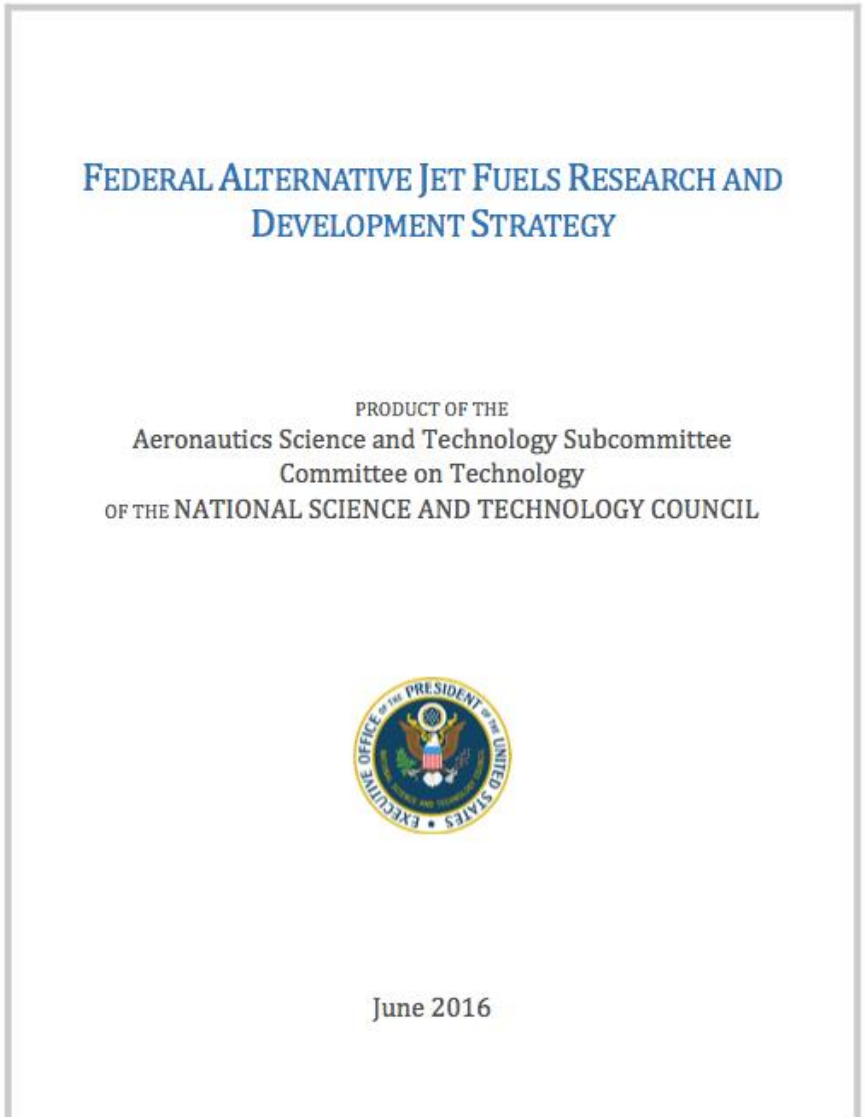
Coordinated U.S. Approach to Alternative Jet Fuel


FEDERAL ALTERNATIVE JET FUELS RESEARCH AND DEVELOPMENT STRATEGY

PRODUCT OF THE
Aeronautics Science and Technology Subcommittee
Committee on Technology
OF THE NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

June 2016

- Enhance energy security
- Expand domestic energy sources
- Facilitate a diverse, secure, and reliable fuel supply
- Contribute to price and supply stability
- Reduce emissions that affect air quality and global climate
- Generate economic and rural development
- Promote social welfare

http://www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

Feedstock Development, Production and Logistics

- Increase crop yields and water and nutrient use efficiency
- Improve disease and pest resistance
- Improve feedstock conversion characteristics
- Develop sustainable and resilient feedstock production systems
- Improve harvesting, collection, storage, densification, pretreatment and transport of physical biomass to the conversion facility
- Improve collection, storage, densification, pretreatment and transport of MSW to the converstion facility

Federal alternative jet fuels research and development strategy, 2016. Alternative Jet Fuel Interagency Working Group, National Science and Technology Council www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

Fuel Conversion and Scale-Up

- Enable discovery, development, enhancement and scale-up of conversion processes with improved yield and efficiency and reduced energy requirements leading to cost-competitive AJF production
- Develop conversion technologies that can produce AJF from multiple feedstocks and in a distributed manner

Federal alternative jet fuels research and development strategy, 2016. Alternative Jet Fuel Interagency Working Group, National Science and Technology Council www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

Fuel Testing and Evaluation

- Facilitate civil and military approval of additional AJF pathways by advancing certification and qualification processes
- Improve scientific understanding of how AJF composition impacts gas turbine combustion emissions and operability

Federal alternative jet fuels research and development strategy, 2016. Alternative Jet Fuel Interagency Working Group, National Science and Technology Council www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

Integrated Challenges

- Advance understanding of and improve environmental sustainability of AJF production and use
- Develop and validate comprehensive systems model to support AJF deployment
- Promote communication and scientific and technical R&D best practices for the national enterprise

Federal alternative jet fuels research and development strategy, 2016. Alternative Jet Fuel Interagency Working Group, National Science and Technology Council www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

Non-Technical Challenges

- Petroleum price volatility
- Limitations in production infrastructure
- Regulatory, legislative, and policy barriers
- Access to financing
- Investment risk and uncertainty
- Workforce development

Federal alternative jet fuels research and development strategy, 2016. Alternative Jet Fuel Interagency Working Group, National Science and Technology Council www.caafi.org/files/Federal_Alternative_Jet_Fuels_Research_and_Development_Strategy.pdf

US Agency Specific Contributions

Feedstock Development & Production

Feedstock Logistics

Fuel Conversion

Fuel Conversion Scale-Up

Fuel Testing & Evaluation

Integrated Challenges

DOC	X				X
DoD			X	X	
DOE	X	X	X		X
DOT				X	X
EPA					X
NASA				X	
NSF	X	X	X		
USDA	X	X	X		X

US Agency Specific Contributions

	 Feedstock Development & Production	 Feedstock Logistics	 Fuel Conversion	 Fuel Conversion Scale-Up	 Fuel Testing & Evaluation	 Integrated Challenges
DOC	X					X
DoD				X	X	
DOE	X	X		X		X
DOT					X	X
EPA						X
NASA					X	
NSF	X	X		X		
USDA	X	X		X		X

The Federal Aviation Administration is a modal organization within the Department of Transportation

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Federal Aviation Administration
Office of Environment and Energy

- Vision: Environmental protection that allows sustained aviation growth.
- Environmental and energy goals
  - Noise: Reduce the number of people exposed to significant noise around U.S. airports
  - Air Quality: Reduce significant air quality impacts attributable to aviation
  - Climate: Achieve carbon neutral growth by 2020 relative to a 2005 baseline
  - Energy: Improve National Airspace System energy efficiency by at least two percent per year, and **develop and deploy alternative jet fuels for commercial aviation**

Five Pillar Approach

- Alternative Fuels: Sustainable Alternative Aviation Fuels
  - Reduce environmental impacts, enhance energy security, and provide economic benefits
  - Collaborate with stakeholders through the Commercial Aviation Alternative Fuels Initiative (CAAFI)
  - Test alternative jet fuels to ensure they are safe for use through ASCENT and CLEEN (Continuous Lower Energy, Emissions and Noise program)
  - Analyze their potential for reducing the environmental impacts of aviation
- Science and Tools: improved scientific knowledge and integrated modeling
- Technology: new aircraft technologies
- Operations: air traffic management modernization and operational improvement
- Policy: policies, environmental standards, and market based measures

ASCENT Focus Areas

Alternative Jet Fuels

Feedstock Development, Processing and Conversion

Regional Supply and Refining Infrastructure

Environmental Benefits Analysis

Aircraft Component Deterioration and Wear

Fuel Performance Testing

ASCENT Team

Lead Universities:

Washington State University (WSU)

Massachusetts Institute of Technology (MIT)

Core Universities:

Boston University (BU)

Georgia Institute of Technology (Ga Tech)

Missouri University of Science and Technology (MS&T)

Oregon State University (OSU)

Pennsylvania State University (PSU)

Purdue University (PU)

Stanford University (SU)

University of Dayton (UD)

University of Hawaii (UH)

University of Illinois at Urbana-Champaign (UIUC)

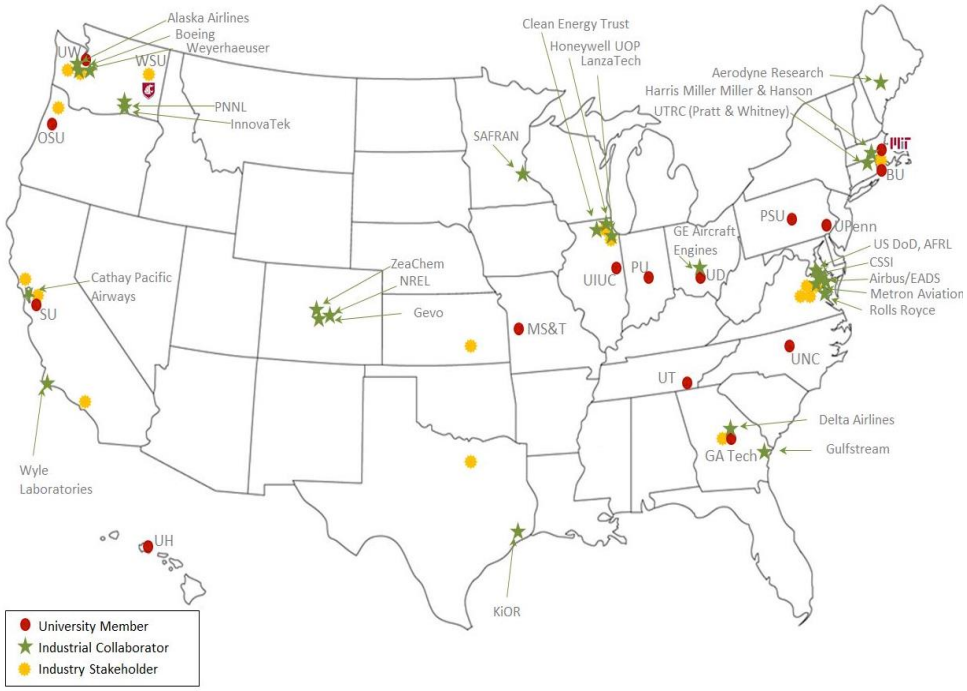
University of North Carolina at Chapel Hill (UNC)

University of Pennsylvania (UPenn)

University of Tennessee (UT)

University of Washington (UW)

Denotes Alternative Jet Fuel Participants



Advisory Committee - 58 organizations:

5 airports
4 airlines
7 NGO/advocacy
9 aviation manufacturers
11 feedstock/fuel manufacturers
22 R&D, service to aviation sector

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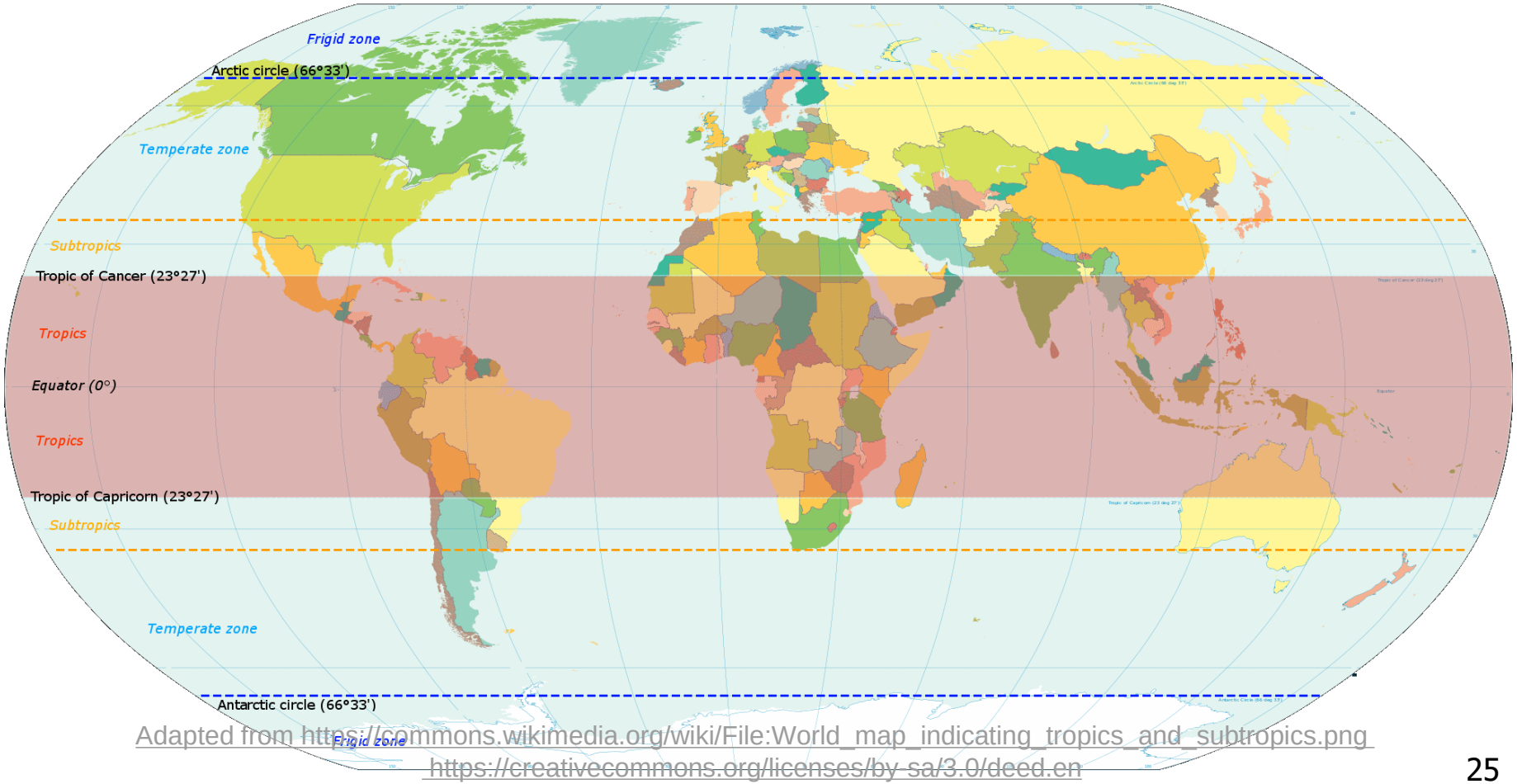
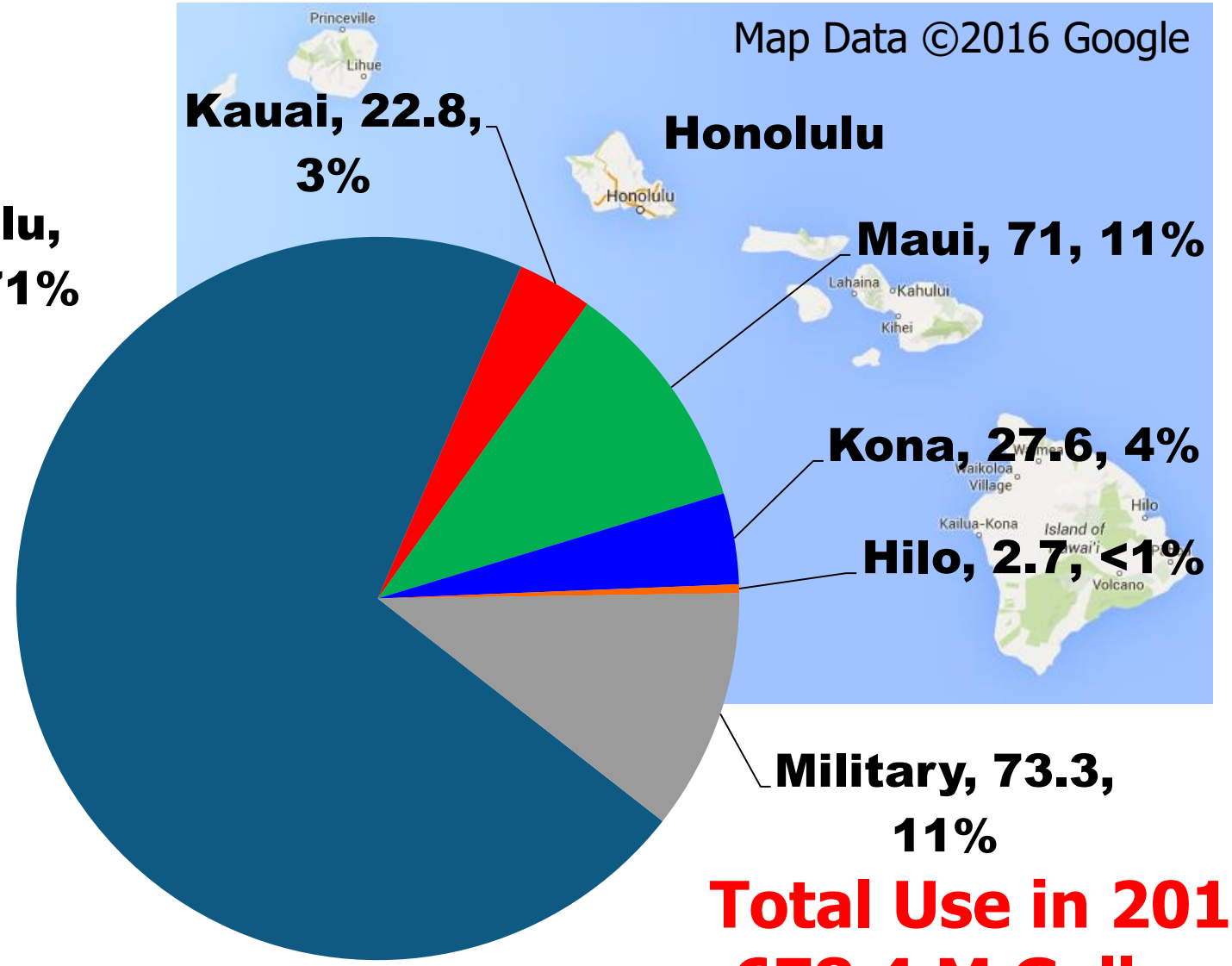
Alternative Jet Fuel Supply Chain, Tropical Region Analysis -- Motivation

- The tropics account for 36% of the world's land mass
- Tropics are home to unique biomass materials, production practices/systems, and temporal availabilities



Jet Fuel Use in Hawaii, 2015 Commercial Airports and Military (million gallons)

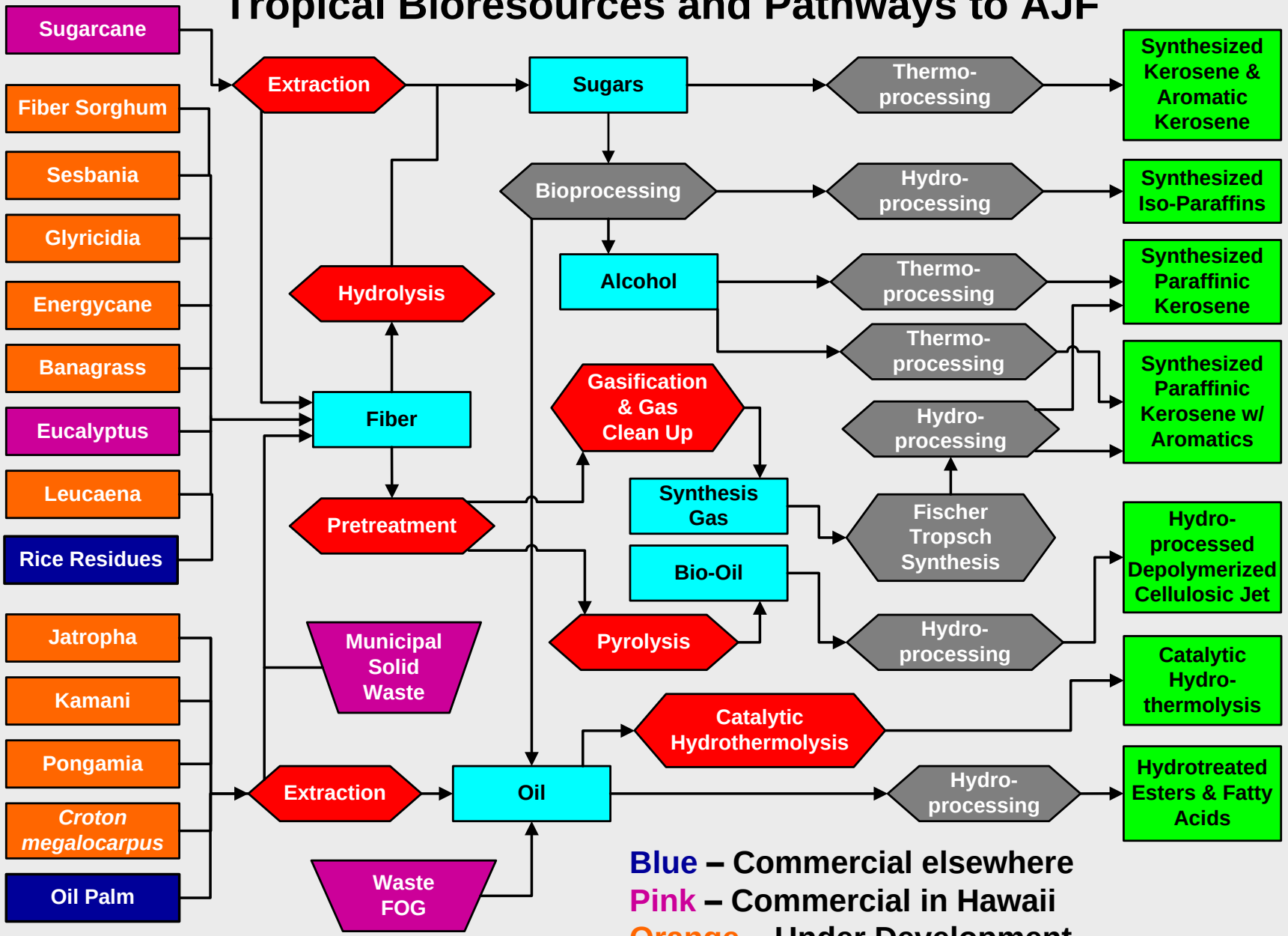


Total Use in 2015
678.4 M Gallons

University of Hawaii Objectives

- Conduct literature review of tropical biomass feedstocks and data relevant to their behavior in conversion systems for AJF production
- Engage stakeholders to identify and prioritize general AJF supply chain barriers (e.g. access to capital, land availability, etc.)
- Develop geographic information system (GIS) based technical production estimates of AJF in Hawaii
- Develop fundamental property data on biomass resources
- Develop and evaluate regional supply chain scenarios for AFJ production in Hawaii

Tropical Bioresources and Pathways to AJF



Barriers to AJF Production

- Stakeholder meeting – barriers to AJF production
  - Facilitated stakeholder meeting with representatives from agricultural landowners, biofuel companies, utilities, military, state government, refiners, fuel distributors, etc.
- Barriers identified and prioritized
  - Economic constraints (e.g. high costs of entry for production factors)
  - Issues associated with access to capital (high initial risk and uncertain ROI)
  - Insufficient government support (financial & policy incentives)
  - Cost, availability, and competition for water *
  - AJF production technologies are emerging, need commercially demonstrated technologies
  - Insufficient or inaccessibility of infrastructure (harbors, roads, fuel distribution, irrigation) to support production chain *

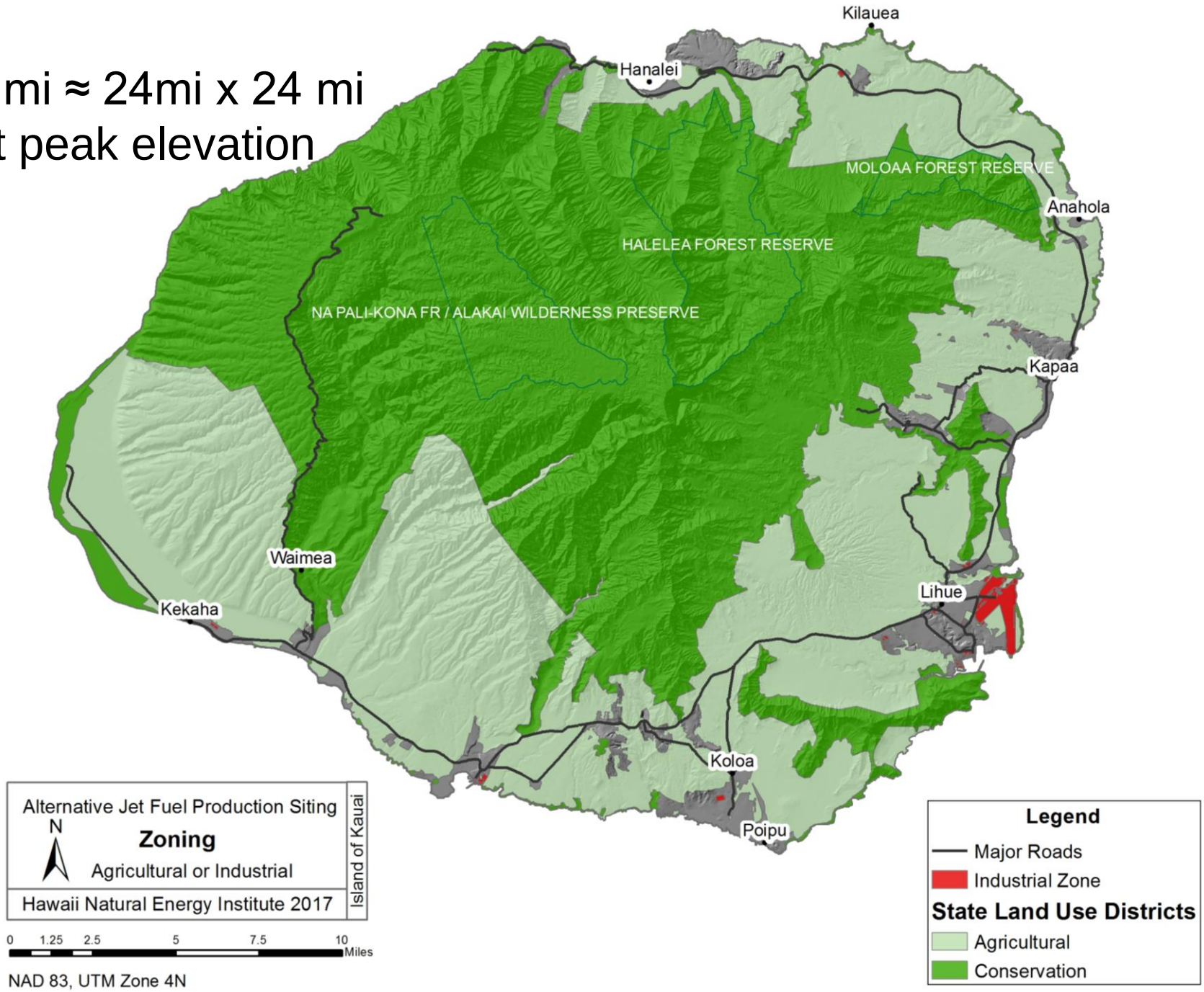
Approach – Estimates of AJF production potential in Hawaii

- GIS based approach
  - Land Capability Classification system developed by USDA/NRCS in 1972 focused on soil type and climatic classification
    - Strengths – extensive soil data, GIS ready
    - Limitations – developed with mindset of agriculture at the time and indexed to sugarcane and pineapple production
  - Water availability – rainfall and irrigation
  - Slope
  - Land use zoning
  - Contiguous area
  - Distance from industrial zoning
- Crop information from literature review
  - Soil
  - Water
  - Climate
  - Mechanization limitations (slope, soil moisture, etc.)
  - Contiguous cultivation area (scale requirements)
  - Invasiveness

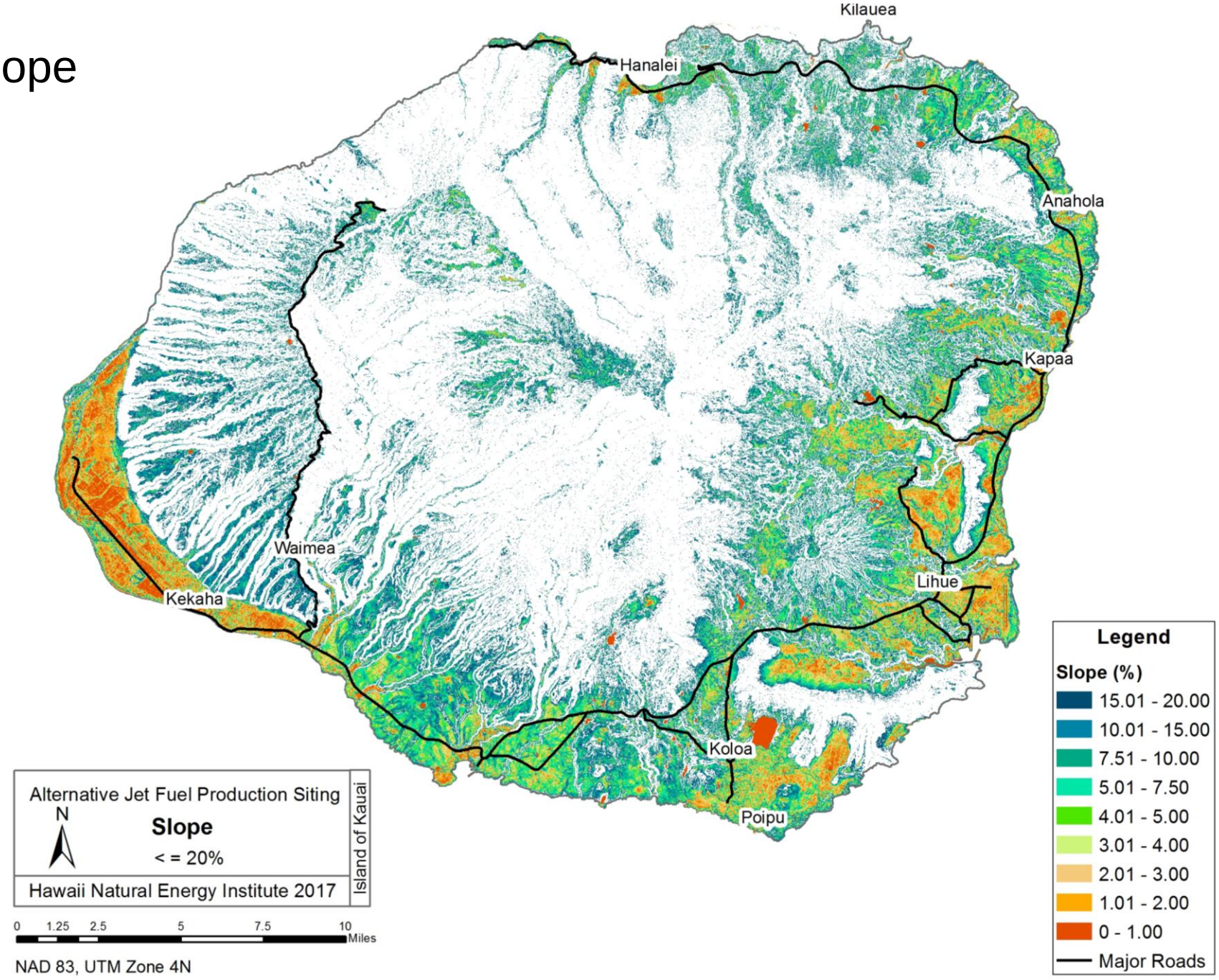
Kauai

552 sq mi ≈ 24mi x 24 mi

5,243 ft peak elevation

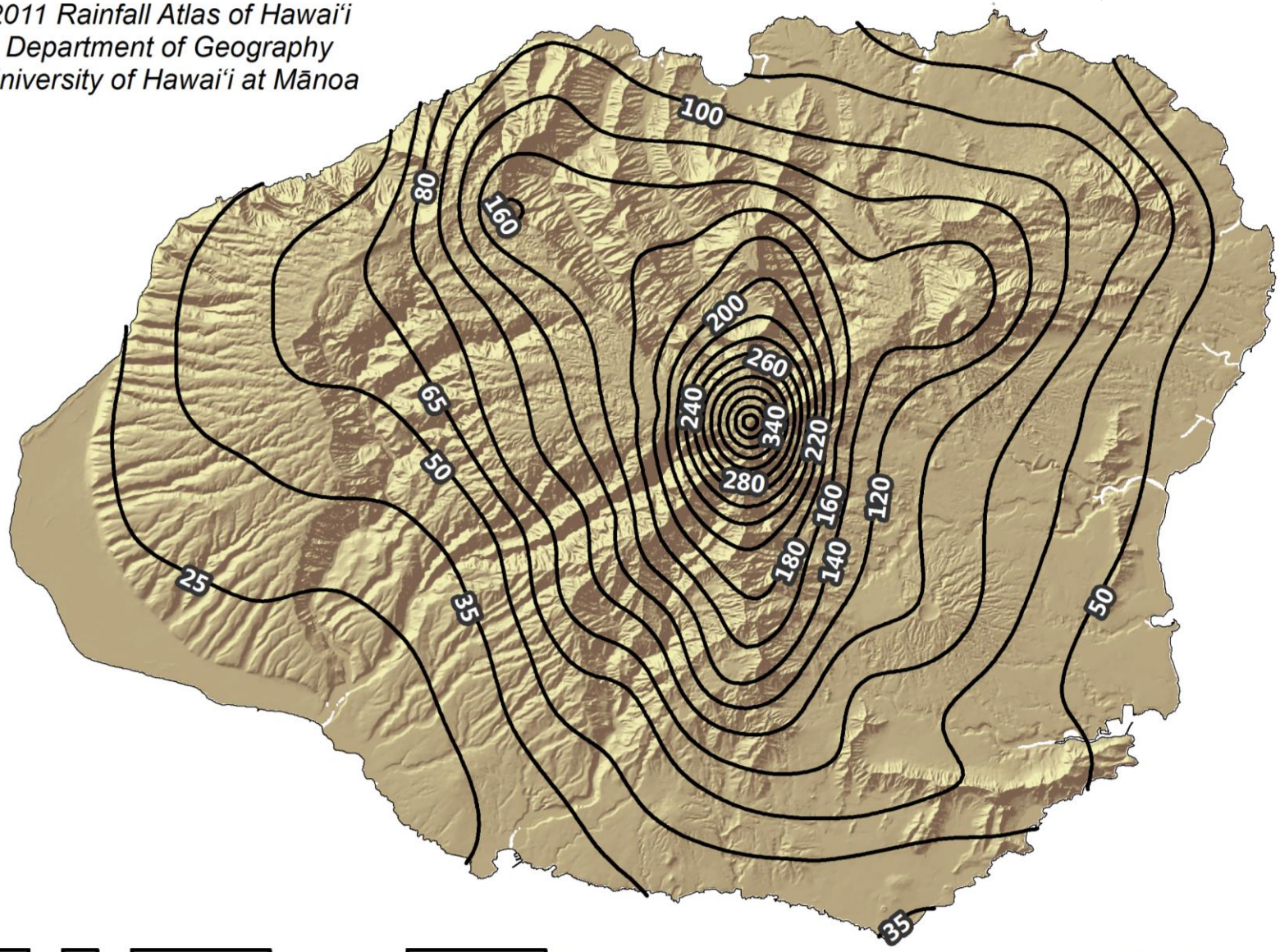


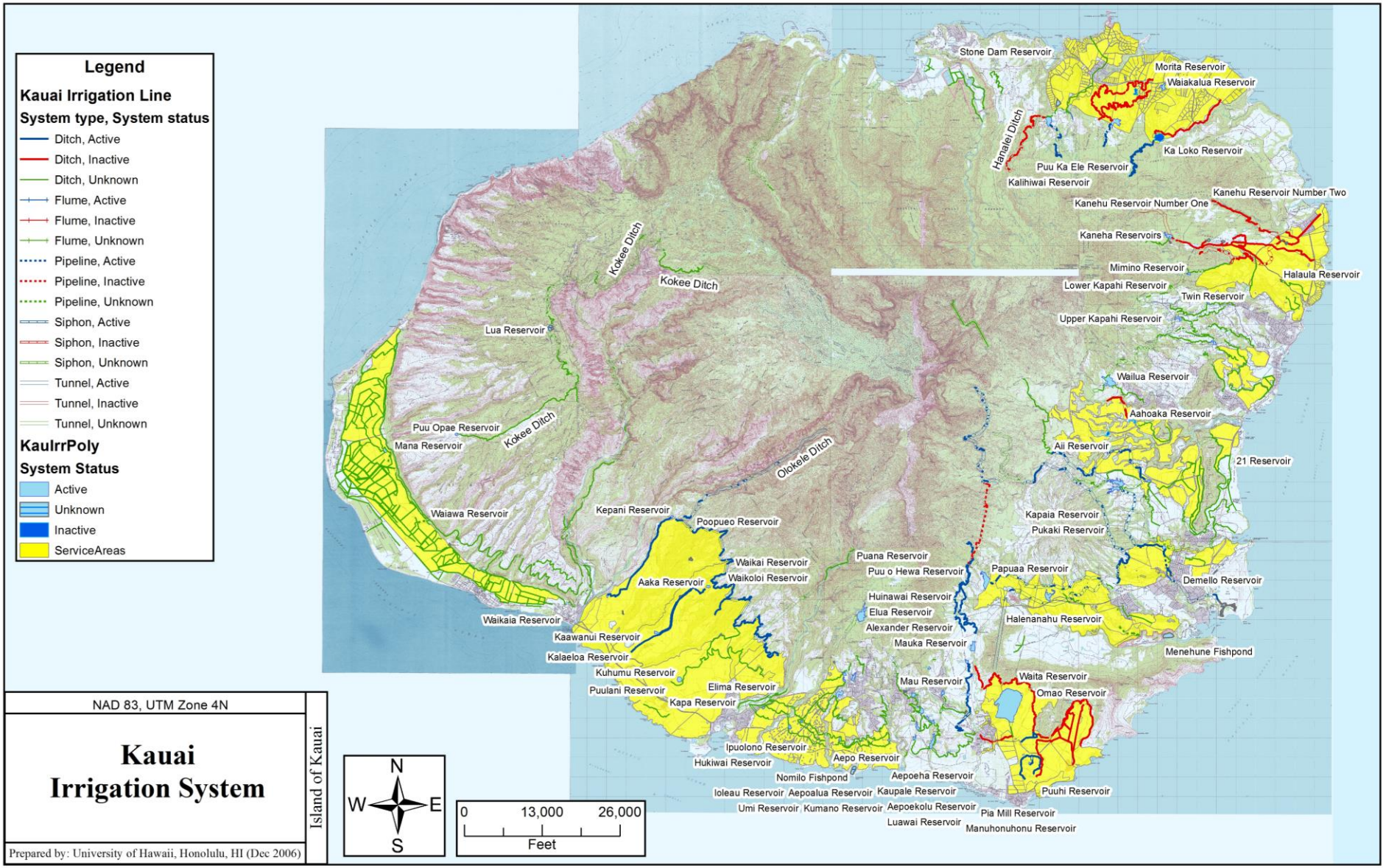
Slope


Kilauea
Hanalei
Anahola
Kapaa
Waimea
Kekaha
Lihue
Koloa
Poipu
Alternative Jet Fuel Production Siting
N
Slope
< = 20%
Hawaii Natural Energy Institute 2017
Island of Kauai
0 1.25 2.5 5 7.5 10
Miles
NAD 83, UTM Zone 4N
Legend
Slope (%)
15.01 - 20.00
10.01 - 15.00
7.51 - 10.00
5.01 - 7.50
4.01 - 5.00
3.01 - 4.00
2.01 - 3.00
1.01 - 2.00
0 - 1.00
Major Roads

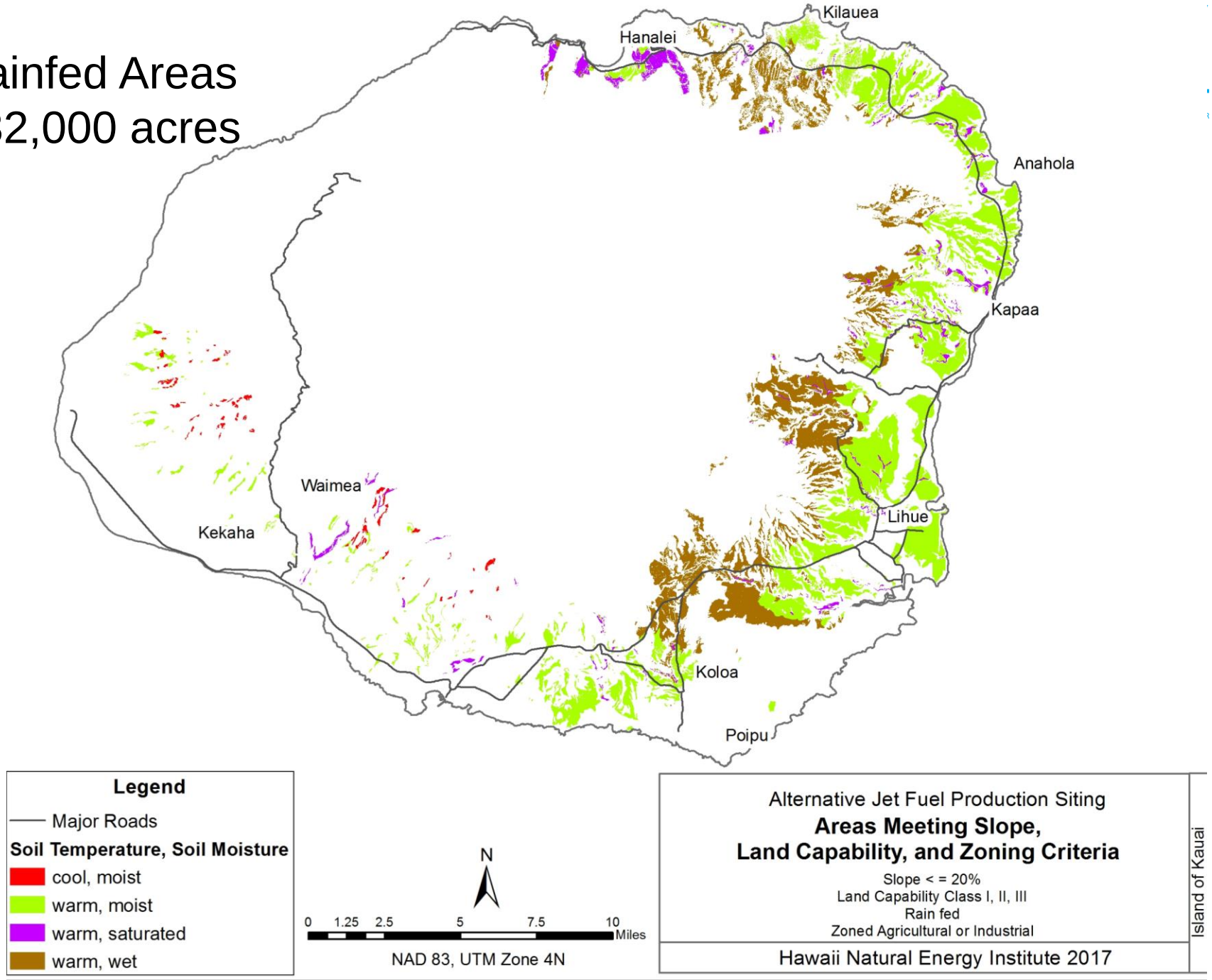
Mean Annual Rainfall
Island of Kaua‘i

2011 Rainfall Atlas of Hawai‘i
Department of Geography
University of Hawai‘i at Mānoa

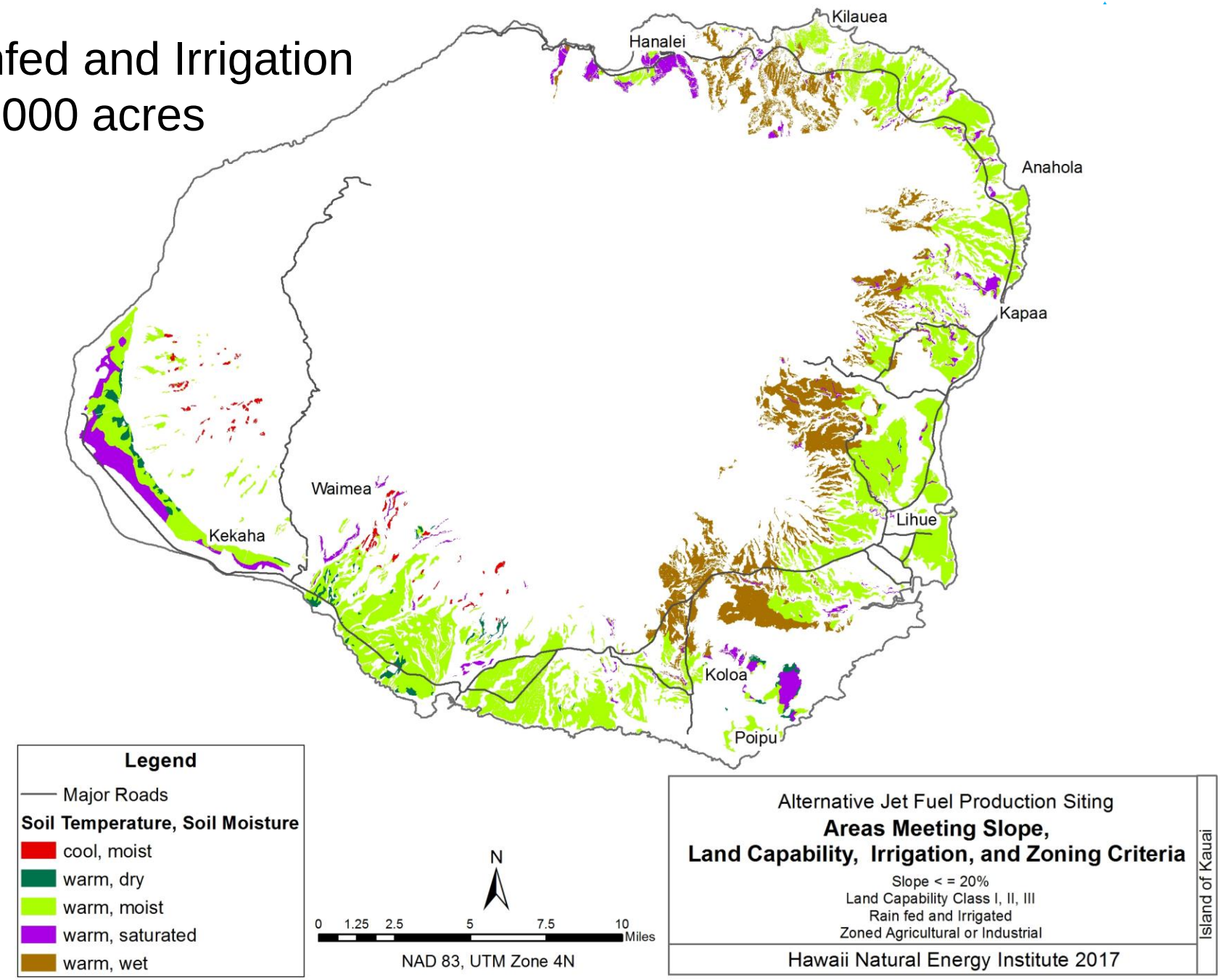



Legend
Kauai Irrigation Line
System type, System status
Ditch, Active
Ditch, Inactive
Ditch, Unknown
Flume, Active
Flume, Inactive
Flume, Unknown
Pipeline, Active
Pipeline, Inactive
Pipeline, Unknown
Siphon, Active
Siphon, Inactive
Siphon, Unknown
Tunnel, Active
Tunnel, Inactive
Tunnel, Unknown
KauIrrPoly
System Status
Active
Unknown
Inactive
ServiceAreas
Stone Dam Reservoir
Morita Reservoir
Waiakalua Reservoir
Hanalei Ditch
Ka Loko Reservoir
Puu Ka Ele Reservoir
Kalihiwai Reservoir
Kanehu Reservoir Number Two
Kanehu Reservoir Number One
Kaneha Reservoirs
Mimino Reservoir
Halaula Reservoir
Lower Kapahi Reservoir
Twin Reservoir
Upper Kapahi Reservoir
Kokee Ditch
Kokee Ditch
Lua Reservoir
Wailua Reservoir
Aahoaka Reservoir
Puu Opae Reservoir
Mana Reservoir
Kokee Ditch
Aii Reservoir
21 Reservoir
Olokele Ditch
Waiawa Reservoir
Kepani Reservoir
Poopueo Reservoir
Kapaia Reservoir
Pukaki Reservoir
Puana Reservoir
Waikai Reservoir
Waikoloi Reservoir
Puu o Hewa Reservoir
Papuaa Reservoir
Demello Reservoir
Aaka Reservoir
Huinawai Reservoir
Elua Reservoir
Waikaia Reservoir
Alexander Reservoir
Halenanahu Reservoir
Kaawanui Reservoir
Mauka Reservoir
Menehune Fishpond
Kalaeloa Reservoir
Kuhumu Reservoir
Waita Reservoir
Mau Reservoir
Puulani Reservoir
Elima Reservoir
Omao Reservoir
Kapa Reservoir
Ipuolono Reservoir
Aepo Reservoir
Hukiwai Reservoir
Nomilo Fishpond
Aepoeha Reservoir
Puuhi Reservoir
Ioleau Reservoir
Aepoalua Reservoir
Kaupale Reservoir
Umi Reservoir
Kumano Reservoir
Aepoekolu Reservoir
Pia Mill Reservoir
Luawai Reservoir
Manuhonuhonu Reservoir
NAD 83, UTM Zone 4N
Kauai
Irrigation System
Island of Kauai
Prepared by: University of Hawaii, Honolulu, HI (Dec 2006)
N
W
E
S
0
13,000
26,000
Feet

Rainfed Areas
~32,000 acres



Rainfed and Irrigation
~52,000 acres



Develop fundamental property data for tropical biomass resources

- Identified from stakeholder meetings and CAAFI/programmatic interest
- Pongamia (*Millettia pinnata*) – initial focus

  - Oil seed tree with current productivity estimated ~5 Mg/ha/year
  - Production potential in Hawaii and Florida
  - *Terviva* – start up company focused on providing pongamia germplasm for agricultural producers
  - 100 ha planted on Oahu and 100 ha scheduled for Maui
  - Property data to focus on characterization of pongamia oil, oil seed press cake, seed pod material
  - Revisit invasiveness based on plants already established in Hawaii
  - Longer term goal -- energy input/output analysis of pongamia production system

Value Chain for AJF Production

Feedstock Production	Feedstock Logistics	Conversion	Distribution	End Use

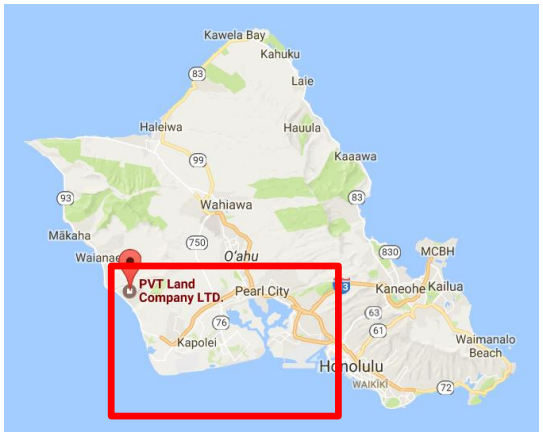




Agriculture ---- Industry ---- Investors ---- Government ---- Community

PVT Feedstock Processing Facility

Possible Locations of Value Chain Participants



ASCENT
AVIATION SUSTAINABILITY CENTER

PVT Land Company

~10 miles between PVT and CIP

Map data ©2017 Google

PVT Land Company LTD.
Akupu
Reynolds Recycling Nanakuli Village...
Pearl City
Waimalu
Keaīwa Heiau State Recreation Area
Farrington Hwy
Pearlridge Center
Aiea
Don's Truck Rental
Halawa
Pearl Harbor
Joint Base Pearl Harbor-Hickam
Makakilo
adise Cove Luau
Honokai Hale
Ewa Villages
Wet'n'Wild Hawaii
Kapolei Public Library
Veolia Water North America
HICKAM FIELD
Honolulu International Airport
Kaua St
Ewa Beach
N Rd
Kalaeloa Airport
Māmala Ba

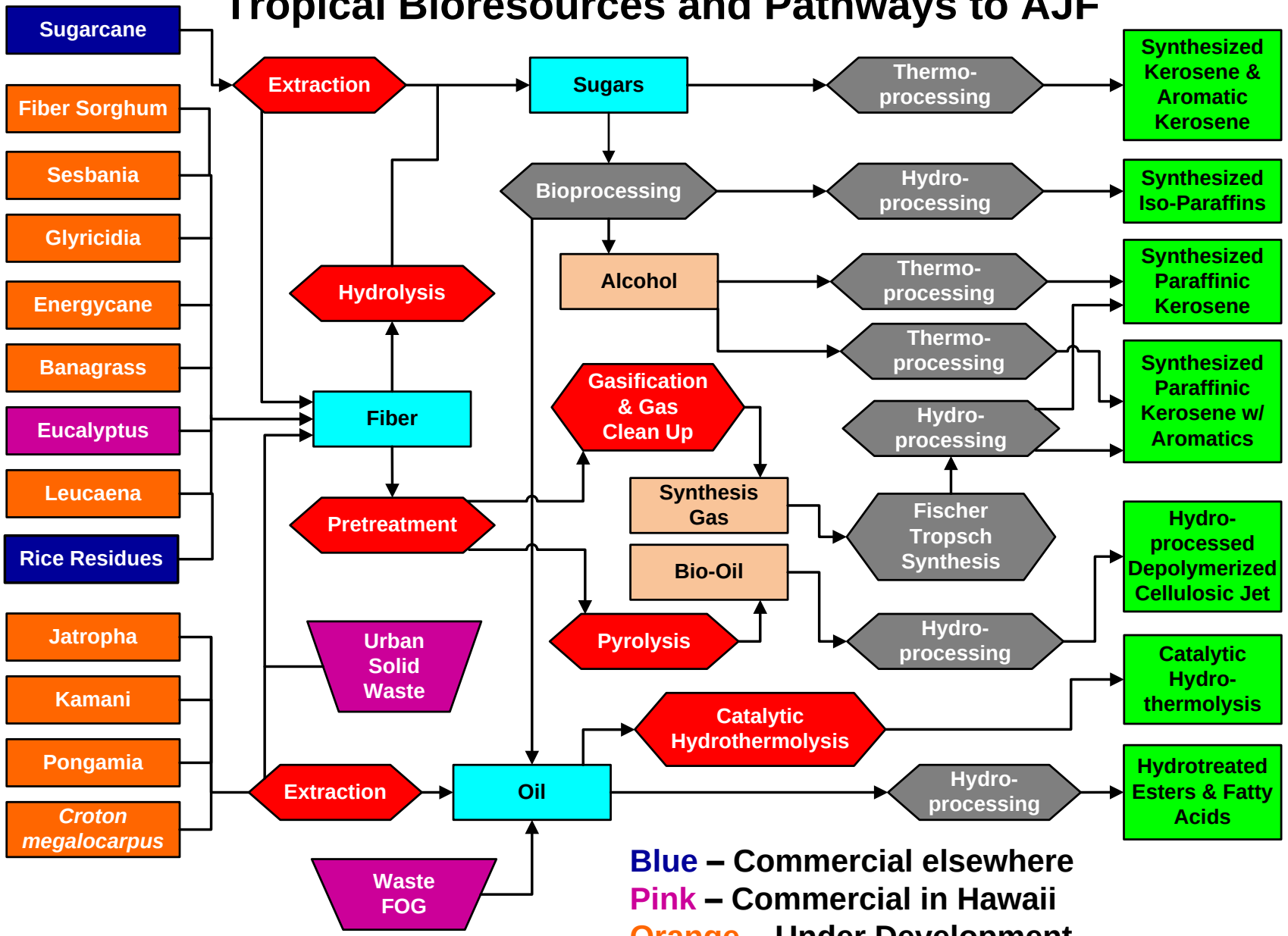
Island Energy Refinery

Campbell Industrial Park

Par Hawaii Refinery

Daniel K. Inouye Airport

Tropical Bioresources and Pathways to AJF



PVT Feedstock Characterization

- **Characterization of feedstock properties needed to inform conversion process design**
  - **Ultimate analysis for major elements: C, H, O, N, S**
  - **Proximate analysis: volatile matter, fixed carbon and ash**
  - **Major ash species: K, Cl, Na, P, Mg, Si, Fe, Ti, Al, and Ca**
  - **Minor ash species: Mn, Fe, Cu, Zn, Rb, and Sr**
  - **Moisture content**
  - **Energy content or heating value**
- **Characterization of feedstock properties needed for logistics particle size of materials, bulk densities, etc.**
- **Time series data to assess variability in supply**

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Questions?