RHODIUM GROUP

Technical Appendix

Transcending Oil

Hawaii's Path to a Clean Energy Economy

Prepared for Elemental Excelerator

April 2018

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About this Document

This document provides additional technical and methodological details underpinning *Transcending Oil: Hawaii's Path to a Clean Energy Economy*, an independent report by Rhodium Group in partnership with Smart Growth America, commissioned by Elemental Excelerator.

The full report is available here:

https://rhg.com/research/transcending-oil-hawaii-clean-energy-economy

APPENDIX A

Historical Assessment and Data Methods

STAKEHOLDER INTERVIEWS AND MEETINGS

To gather data and frame our historical analysis for Hawaii, Rhodium Group drew on over 200 hours of stakeholder interviews and meetings arranged with the help of Elemental Excelerator. These interviews, which included face-to-face meetings in Hawaii as well as phone interviews, gathered both qualitative as well as quantitative information from a range of on-the-ground viewpoints. These interviews were conducted over the November 2017 to March 2018 timeframe with individuals from a variety of organizations including: Oahu Economic Development Board, Distributed Energy Resources Council of Hawaii, Hawaiian Electric Company, Earthjustice, Ulupono Initiative, Hawaii Department of Transportation, Honolulu Authority for Rapid Transportation, City and County of Honolulu, Honolulu Department of Transportation Services, Blue Planet Foundation, Hawaii Public Utilities Commission Division of Consumer Advocacy, Hawaii Energy, Hawaii Gas, Hawaii Natural Energy Institute, Kauai County, Hawaii State Legislature, Kauai Island Utility Cooperative, Island Energy Services, Maui County, Hawaii County, Oahu Metropolitan Planning Organization, Hawaii State Energy Office, US Environmental Protection Agency, Par Pacific Holdings, Inc., Kevala Analytics, Servco Pacific Inc., Pacific Biodiesel, University of Hawaii, Manoa, and the Hawaii Bicycling League.

In addition to these interviews, Rhodium Group and Smart Growth America (SGA) engaged with wide variety of stakeholders during the events and meetings listed in Table A.1.

Table A.I: Public meetings for stakeholder involvement

Event	Date	Attendees
Hawaii Clean Energy Initiative Meeting	1/31/2018	25
Sustainable Transportation Forum	3/7/2018	21
Private Fleets Meeting	3/9/2018	38
Maui Energy Conference	3/15/2018	25
Drive Electric Hawaii	4/2/2018	10

DATA SOURCES

To construct a thorough picture of the historical energy landscape in Hawaii, we relied heavily on publicly-available corporate and government data sources including the following: Energy Information Administration; Hawaii Department of Business, Economic Development and Tourism; US Bureau of Economic Analysis; State of Hawaii; Hawaiian Electric Company; Hawaii Clean Energy Initiative; Hawaii Energy; Hawaii Public Utilities Commission; SGA; US Census Bureau as well as internal Rhodium Group analysis. These sources are cited individually throughout the report as data is presented.

Throughout this report, all dollar values are 2016 constant dollars.

IMPACT CALCULATIONS

Rhodium Group relied on publicly available data when available. Conventional pollutant power sector emissions were calculated using renewable energy and energy efficiency data from Hawaii Energy and other public sources. We assume that oil generation would have been used by the power sector instead of the renewable generation and energy efficiency measures that occurred.

APPENDIX B

Electric Power Sector Analysis

MODELING HAWAII'S FOUR MAJOR ELECTRIC POWER SYSTEMS

To model the electric power systems in Hawaii, we used the SWITCH capacity expansion tool.[i] SWITCH is a modular model capable of capturing the functionality of a high-renewable penetration grid including integral components, such as energy storage and demand response.[ii] Our starting point was the version of SWITCH specifically designed for modeling Oahu's electric power system by Matthias Fripp at the University of Hawaii, Manoa.[iii][iv] We customized most of the parameters in this version of the model to reflect modifications to resource availability, electricity demand, and resource costs. Likewise, we created models of the Hawaii, Maui, and Kauai electric power systems using a combination of Hawaiian Electric, Kauai Island Utility Cooperative (KIUC) and Energy Information Administration (EIA) data, plus the data sources listed below for individual resource parameters. The islands function as separate power grids with no option for interconnectivity.

TIME SERIES SAMPLING

For this analysis, seven time periods were analyzed, and the midpoint of each was used to linearly interpolate results for all years in the forecast. The time periods represent 2020-2021, 2022-2024, 2025-2029, 2030-2034, 2035-2039, 2040-2044 and 2045-2049. Within each time period, 20 sample days were created and statistically weighted according to likeliness to occur within a given period. In each sampled day, we modeled all 24 hours. We chose to model 20 days based on their statistical likelihood to occur within the typical 8,760-hour meteorological year. We chose a dozen of the days to be the mean of each month and eight of the days to represent "extreme" resource days. We split the eight days into two seasons, Winter-Spring and Summer-Autumn, to better capture wind variation. From each season combination, we constructed four days based on available hours: two days with high resource value, one likely to occur only once per decade and one likely to occur once per year; and two days with low resource value, one likely to occur only once per decade and one likely to occur once per year. We then paired capacity factors with corollary demand days, i.e., low-renewable resource days were paired with high demand days and vice-versa. Mean days were paired with mean demand days.[v]

RENEWABLE RESOURCE POTENTIAL BY ISLAND

We assessed each island's potential for renewable resources, including wind, utility-scale solar (sun), geothermal, and hydroelectric (hydro), based on available literature and stakeholder input. Sources and input estimates are provided below in Table B.1.

Table B.1: Resource Assumptions by Island

Island	Resource Category	Resource Type	Source	Value (MW)
Hawaii	Geothermal	Geothermal	GeothermEx[vi]	488
Hawaii	Hydro	Hydroelectric	ORNL[vii]	49
Hawaii	Sun	Rooftop Solar	Google / RHG[viii]	704
Hawaii	Sun	Grid-Scale Solar <5% Slope	NREL/PSIP[ix]	30,484
Hawaii	Wind	Grid-Scale Wind	NREL/PSIP	3,532
Kauai	Sun	Grid-scale solar Ground Mount (Including Military)	NREL	830[x]
Kauai	Hydro	Hydroelectric	ORNL	81
Kauai	Sun	Rooftop Solar	Google / RHG	285
Maui	Geothermal	Geothermal	GeothermEx	38
Maui	Sun	Grid-Scale Solar <5% Slope	NREL/PSIP	783
Maui	Wind	Grid-Scale Wind	NREL/PSIP	840
Maui	Hydro	Hydroelectric	ORNL	11
Maui	Sun	Rooftop Solar	Google / RHG	652
Oahu	Hydro	Hydroelectric	ORNL	1
Oahu	Sun	Grid-Scale Solar <5% Slope	NREL/PSIP	796
Oahu	Wind	Grid-Scale Wind	NREL/PSIP	183
Oahu	Wind	Offshore Wind	PSIP	800
Oahu	Sun	Rooftop Solar	Google / RHG	2,986

The utility-scale solar resource potential by island are also displayed in Figures B.1-B.3 for Oahu, Hawaii, and Maui, respectively.

Figure B.1: Oahu Utility-Scale PV Potential

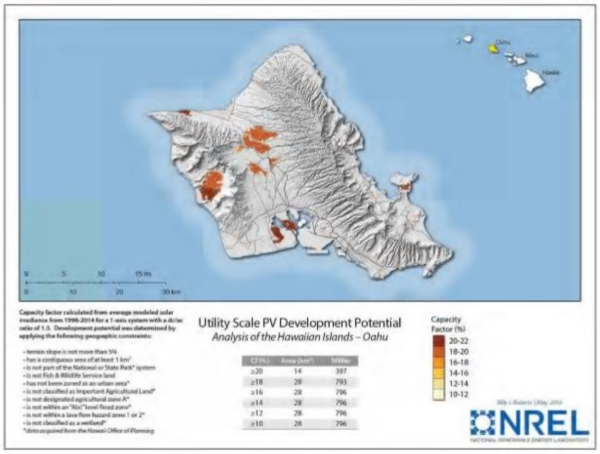
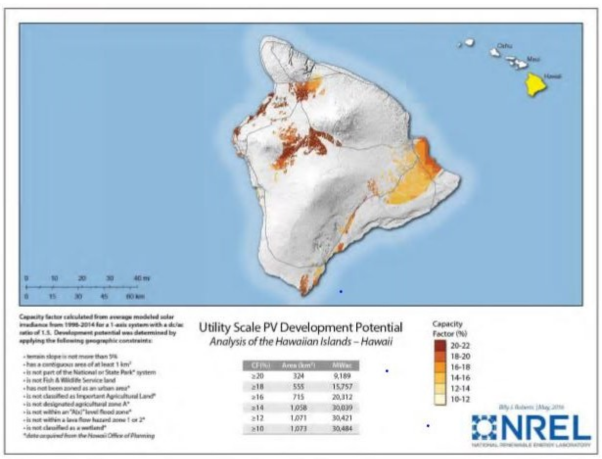
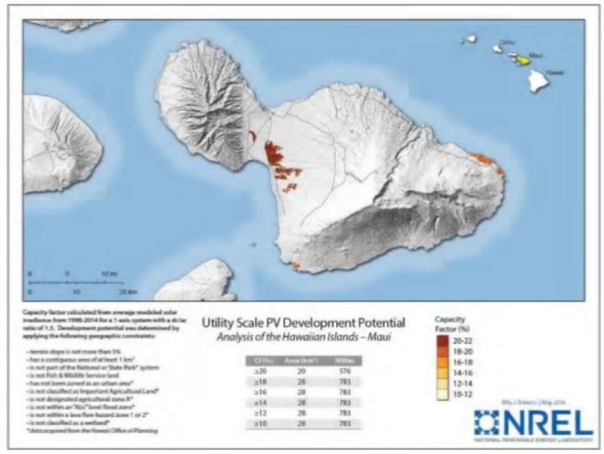


Figure B.2: Hawaii Utility-Scale PV Potential



For distributed solar, we used estimates derived from Google's Project Sunroof, where available, and supplemented missing zip codes using a regression analysis based on population, geospatial solar irradiance data, and employment density to account for both residential and commercial installations.

Figure B.3: Maui Utility-Scale PV Potential



VARIABLE GENERATION PERFORMANCE CHARACTERIZATION

To determine island- and resource-specific capacity factors, we selected sites identified by the National Renewable Energy Laboratory (NREL) in the most recent Hawaiian Electric Power Supply Improvement Plan (PSIP) as the most likely areas for renewable development. For offshore sites, we used Bureau of Ocean Energy Management reports to identify likely areas. To determine annual variability, we used NREL's System Advisor Model (SAM) for solar irradiance with wind speed from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) based Renewables.ninja database. We obtained typical meteorological years (TMY) for wind and solar for a point within each zone. For wind, where applicable, we adjusted capacity factors to match annual island data used in the most recent PSIP. We derived capacity factors for 8,760 hours per year for each site and technology (onshore wind, offshore wind, fixed rooftop solar, and single-axis tracking solar) to get island-specific variable capacity profiles.

EXISTING AND PLANNED RESOURCES

We based existing and planned generation for Oahu, Hawaii, and Maui on the 2014 Hawaiian Electric PSIP data.[xi] KIUC data was used for Kauai. When necessary, we used EIA data to fill data gaps. We based utility plant and distributed generating resource retirements on a 65-year lifetime for fossil generators and a 25-year lifetime for renewable generators. If a fossil plant is planned to retire per Hawaiian Electric estimates, we scheduled that plant to retire in our modeling, per the PSIP retirement date. This includes the AES coal plant on Oahu, scheduled to retire in 2022.

RENEWABLE ENERGY TECHNOLOGY COSTS

Assumed renewable energy technology options and overnight capital costs are shown by island in Figures B.4-B.7. We based these costs on the most recent PSIP costs for renewable generation by island in 2016. We then created a cost-decline curve based on 2017 NREL Annual Technology Baseline (ATB) scenarios.[xii] We assumed Kauai costs to be the same as Hawaii and Maui. Our High Cost curve reflects the cost decline in the ATB mid case and the Low Cost curve reflects the cost decline in the ATB low case. We also account for federal and state subsidies and tariffs in these numbers.

Figure B.4: Oahu Renewable Technology Costs

$/kW, 2016 real dollars

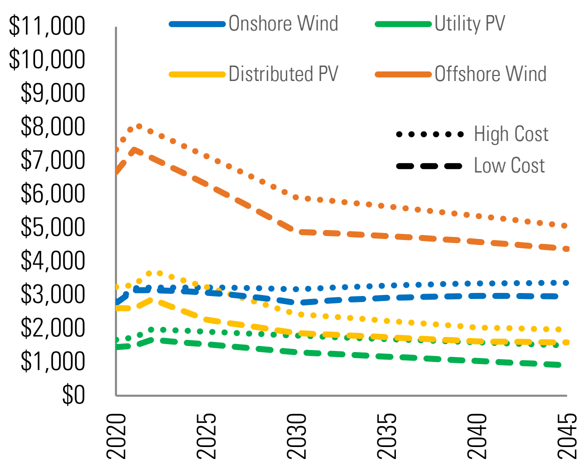


Figure B.5: Hawaii Renewable Technology Costs

$/kW, 2016 real dollars

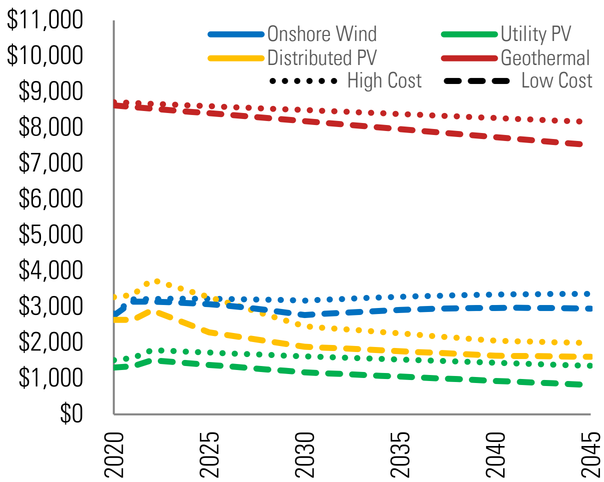


Figure B.6: Maui Renewable Technology Costs

$/kW, 2016 real dollars

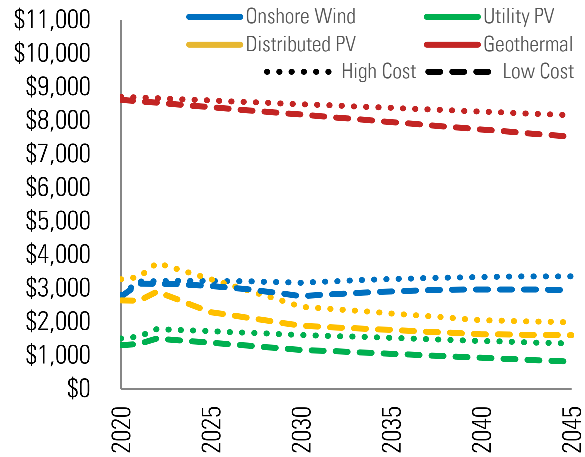
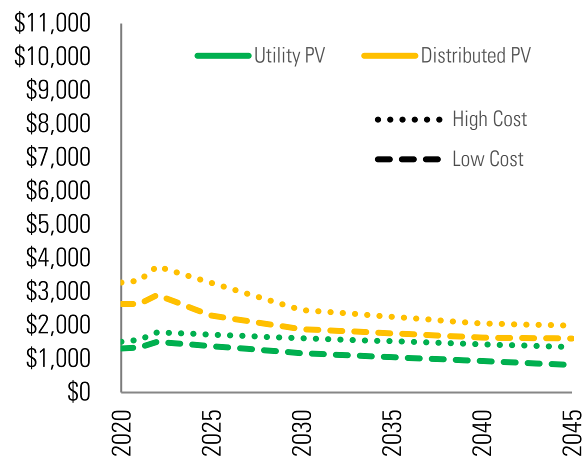


Figure B.7: Kauai Renewable Technology Costs

$/kW, 2016 real dollars



We added an additional transmission connection cost for all utility-scale plants. The cost to update the distribution system to accommodate high penetrations of distributed solar generation was modeled using values from the PSIP. We use the low end of the PSIP numbers for costs in our Low Renewables cost assumptions and the high end of their costs in our High Renewables cost assumptions.

BIODIESEL AND BIOMASS PARAMETERS

We assume existing and planned plants that burn biomass in the form of pellet-biomass or municipal solid waste to continue using biomass as their fuel source. A total of 5.5 million gallons of biodiesel per year is available for consumption in the electric power sector based on the current biodiesel refining capacity in

Hawaii. This is allocated by island based on proportional electricity demand.

FOSSIL FUEL OPTIONS

The options and costs for new fossil generation are presented in Table B.2. Liquefied natural gas was not considered for this analysis in line with the Hawaiian Electric PSIP Preferred Plan.[xiii]

Table B.2: Fossil Fuel Technology Options

Technology	Combined Cycle Gas	Simple Cycle Gas	Simple Cycle Gas	Internal Combustion	Internal Combustion
Size (MW)	152	100	20.5	9	54 (6 x 9 MW)
Fuel	Oil	Oil	Oil	Oil	Oil
Island	Oahu	Oahu	Hawaii Maui Kauai	Hawaii Maui Kauai	Oahu Hawaii Maui Kauai
Heat Rate (Btu/kWh)	8,333	9,860	9,860	10,166	10,166
Fixed O&M ($/kW year)	10	12	12	12	12
Variable O&M ($/MWh)	3	7	7	13	13
Overnight Capital Costs for all years	$1,660	$1,237	$3,586	$5,407	$2,493

We based power plant fossil fuel prices on 12-month rolling average delivered prices to utilities, by island, between 2006 and 2017 as reported by Hawaii's Department of Business Economic Development and Tourism (DBEDT).[xiv] In our Low Renewables scenario, we assume the lowest applicable fuel costs for each fuel on each island from these data. For our High Renewables scenario, we assume the highest applicable fuel cost for each fuel on each island. We assume fuel prices in each scenario remain the same throughout the projection time frame.

SHORT-TERM ENERGY STORAGE

Short-term energy storage is represented by 4-hour discharge Lithium-ion batteries. These batteries must charge and discharge within the same 24-hour sample day. We assumed that the batteries cycle once per day to achieve a maximum 15-year lifetime. For battery costs, our assumptions start with the costs assumed for 2016 in the most recent PSIP and decline as projected in the latest report on electricity storage cost by the International Renewable Energy Agency (IRENA).[xv]

LONG-TERM ENERGY STORAGE

Long-term energy storage is represented by hydrogen storage which can also be used for short-term intraday arbitrage. The hydrogen system is composed of an electrolyzer that converts water to hydrogen when excess electricity is available, a storage tank, and a fuel cell to convert stored hydrogen to electricity. The costs of hydrogen storage are preliminary because it is not a widespread technology. For this analysis, we used the cost assumptions assumed in the main SWITCH model. These costs are based on the latest Department of Energy (DOE) and NREL data for hydrogen electrolysis and storage.

CONVENTIONAL AND EV LOAD FORECASTS

Gross hourly conventional load for each island was derived from the 2014 PSIP filing material and scaled proportionally to meet demand forecasts.[xvi] Gross load includes the impact of assumed energy efficiency savings assumed by Hawaiian Electric in the most recent PSIP, but it does not include reductions and/or shifts in retail sales due to customer-sited generation, storage, or demand response. Based on guidance from KIUC, we assumed that Kauai's demand curve followed a similar path to Maui but scaled to Kauai's overall demand. Electric vehicle gross load was added to our conventional gross load projections as appropriate for each scenario. To determine when those vehicles would charge, we used load shapes derived from an Idaho National Lab study on vehicle charging behavior without time-of-use pricing incentives.[xvii]

Using SGA's VMT forecast as the driver of overall ground transport demand we use PATHWAYS, to determine the number of vehicles and energy demand by fuel for electric vehicles for each island for each EV penetration scenario. To get the shape of the vehicle electricity demand load curve we took a representative charging curve empirically derived from a non-time of use impacted charging curve (i.e., no demand shifting incentives) sourced from Idaho National Laboratory.[xviii]

LOAD SHIFTING

We based our assumptions for the amount of conventional load available on the most recent PSIP Demand Response Evaluation. Approximately 4% of conventional load is available for load shifting in the 2025-2029 period; this increases to 10% in the 2045-2049 period. Up to 50% of the electric load from electric vehicles is assumed to be available for load shifting. This is based on the amount of load shifting that occurs for electric vehicles in time-of-use pricing zones in available literature.[xix] Based on hourly electricity prices in SWITCH, load shifting resources are utilized when it's economic to do so within the constraints described above.

APPENDIX C

Ground Transportation Energy Modeling

MODELING HAWAII'S GROUND TRANSPORTATION SECTOR

To model ground transportation we used EnergyPATHWAYS (PATHWAYS), a stock-accounting model focused on all energy consuming and producing sectors. Based on technology specific energy consumption and stock retirement rates it calculates total energy consumption and energy-related emissions. Scenarios are designed exogenously allowing for specific VMT and stock specifications. Additional documentation can be found on the PATHWAYS website.[xx]

We ran PATHWAYS for the entire state of Hawaii to get sales and energy demand for the entire ground transportation fleet. Using this Hawaii calibrated output, we scaled output to each island based on VMT and vehicle stock projections constructed by SGA. PATHWAYS uses assumed energy efficiency projections for each vehicle type (heavy, medium, and light duty trucks, light-duty vehicles, and buses) and fuel-class (electric, diesel, gasoline, etc.) to calculate the end-use energy demand. For electricity, this demand is added to gross load with island-specific assumptions for line losses. We also capture fossil fuel consumption and associated GHG emissions with assumed Corporate Average Fuel Economy (CAFE) standards.

APPENDIX D

Employment Impacts

MODELING CHANGES IN EMPLOYMENT

Using outputs from our electric power sector forecasts, we estimate the employment impact from 2020 to 2030 of 1) electric power sector investments and 2) electricity price changes resulting from those investments. In this way, our approach captures the net employment effects of additional clean energy investment, including the displacement of investment and jobs in other sectors, and the jobs created when energy cost savings are redirected into the local economy.

CHANGES IN EMPLOYMENT FROM ELECTRIC POWER SECTOR INVESTMENTS

Our analysis includes the number of jobs created from investment in new renewable and fossil-fuel power generation capacity, as well as fixed and variable operations and maintenance (O&M) for new and existing capacity.[xxi] In addition, we estimate the effects of investments in increased deployment of energy storage, grid connection, and transmission costs associated with the construction or installation of new generation assets. All electric sector investments are calculated using the most recent PSIP technology costs for 2016 for each island to standardize the comparison between scenarios where renewable technology costs are different.

We estimate the impact of these investments on employment using 2016 county-level economic data and employment multipliers in IMPLAN.[xxii] IMPLAN is a static input-output (I-O) model that captures direct (jobs created onsite at the plant), indirect (jobs created in companies supplying the plant with materials or services) and induced (jobs created when employees spend their paychecks) employment impacts. Because clean energy industries do not currently exist in most I-O models, including IMPLAN, we derive jobs estimates based on an assessment of how $1 spent on the installation and operations of each energy technology is allocated across industrial sectors. For this, we use costs from the 2017 NREL ATB[xxiii] and NREL's Jobs and Economic Development Impact (JEDI) models.[xxiv,xxv] Employment effects are calculated on a full-time equivalent basis.

CHANGES IN EMPLOYMENT FROM ENERGY COST SAVINGS

The transition from imported oil to clean energy will reduce the costs required to operate Hawaii's electric systems. Some of this money will flow through to ratepayers. For each county, we model retail electricity rates using wholesale electricity rates projected in our electric power scenarios, and the historical relationship between retail and wholesale prices. From this, we obtain the difference in the growth rate of retail prices between the least-cost and current policy scenarios. For residential consumers, we use the difference in retail growth rates and the share of annual spending on electricity for the county's median household income to obtain cumulative electricity bill savings over the 2020-2030 period. We calculate commercial sector savings in a similar way, using the difference in retail growth rates and the cost-share of electricity in total output for each sub-sector. For both the residential and commercial sectors, spending induced by electric savings is modeled for each county in IMPLAN as a household income change for households at the county median income level.[xxvi] We assume that commercial energy cost savings that pass through to tourists, who account for approximately 20% of annual consumer spending, are not spent locally.[xxvii,xxviii]

WHAT OUR ANALYSIS DOES NOT INCLUDE

Our analysis does not capture some of the potential macroeconomic effects of an energy transition, including the potential for clean energy investments to put upward pressure on interest rates and wages. While accelerating clean energy investment is unlikely to impact interest rates in a meaningful way given the size of Hawaii's economy, the state's low unemployment rate makes wage inflation more likely. Without a model to capture this kind of macroeconomic feedback, the employment impacts associated with new clean power investment and energy savings should be considered independently and not be interpreted as additive.

APPENDIX E

Transportation Projection Inputs from Smart Growth America

This appendix consists of SGA's documentation of its methods for projecting VMT, EV penetration and aviation demand.

VEHICLE MILES TRAVELED

Using current VMT estimates from Hawaii DOT and other sources of data, we allocate total VMT among different counties and sources (e.g., households, transit, and freight), then develop VMT forecasts based on the following key components (described in more detail below):

1) Analysis of existing land use patterns and estimated household VMT production.

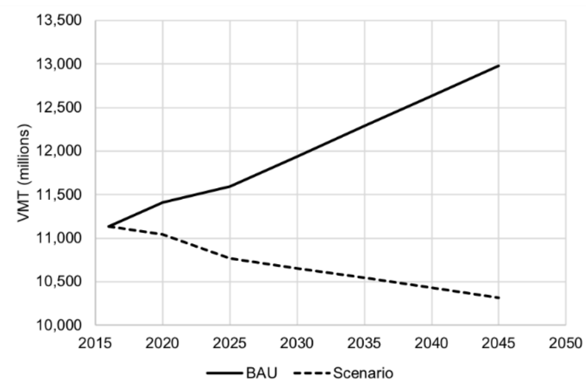
2) Adjustments to account for additional VMT from transit, commercial, and fleet vehicles.

3) Assumptions about possible changes in land use, infrastructure, and transportation policy over a 30-year period, under business as usual and policy scenario conditions.

4) Estimates of the effects of those changes on VMT production based on knowledge from existing literature.

Based on our analysis, VMT is expected to increase from 11,132 million in 2016 to 12,978 million in 2045 (a 16.6% increase) under business as usual conditions. Under our policy scenario assumptions, which include bold changes in land use, non-auto transportation options, and transportation pricing, VMT could be reduced by 7.3% below current levels by 2045, a 20.5% reduction from business as usual. These forecasts are depicted in Figure E.1.

Figure E.1. Total VMT forecasts under business as usual and policy scenario conditions



Estimates of VMT by county and vehicle type are shown in Table E.1 and Table E.2 under business as usual and policy scenario conditions, respectively.

Table E.2. VMT by county and vehicle type under business as usual conditions, millions

Historical (bold), forecasted (light)

	Cars	EV cars	ICE cars	Light trucks	EV light trucks	ICE trucks	Buses	Heavy trucks
2010	**898,452**	**244**	**898,181**	**187,733**	**27**	**187,706**	**2,103**	**861**
2015	**1,001,879**	**3,671**	**997,800**	**191,984**	**408**	**191,576**	**2,465**	**1,439**
2020	1,145,864	11,550	1,133,030	202,199	1,283	200,916	2,780	1,926
2025	1,241,764	25,369	1,213,576	206,791	2,819	203,972	2,996	2,404
2030	1,337,664	45,989	1,286,565	211,383	5,110	206,273	3,211	2,882
2035	1,433,564	74,445	1,350,847	215,975	8,272	207,704	3,427	3,359
2040	1,529,464	111,773	1,405,272	220,567	12,419	208,148	3,642	3,837
2045	1,625,364	159,009	1,448,687	225,159	17,668	207,492	3,857	4,315

Table E.3. VMT forecast by county and vehicle type under policy scenario conditions, millions

Year	County	Bus	Paratransit	Trucks	Household	Other	HART	Total
2016	Hawaii	4.601	1.970	5.592	2116.146	75.446	0.000	2203.756
2020	Hawaii	4.760	2.038	7.105	2097.112	74.768	0.000	2185.782
2025	Hawaii	4.958	2.123	8.996	2073.319	73.920	0.000	2163.315
2030	Hawaii	5.156	2.208	10.887	2049.526	73.071	0.000	2140.848
2035	Hawaii	5.355	2.293	12.778	2025.733	72.223	0.000	2118.381
2040	Hawaii	5.553	2.378	14.669	2001.940	71.375	0.000	2095.914
2045	Hawaii	5.751	2.462	16.560	1978.147	70.526	0.000	2073.447
2016	Honolulu	13.160	5.634	15.995	6052.634	215.793	0.000	6303.216
2020	Honolulu	13.614	5.829	20.322	5998.191	213.852	0.000	6251.807
2025	Honolulu	14.181	6.072	25.730	5930.138	211.426	-157.680	6029.867
2030	Honolulu	14.748	6.315	31.139	5862.085	209.000	-157.680	5965.606
2035	Honolulu	15.316	6.557	36.547	5794.032	206.573	-157.680	5901.345
2040	Honolulu	15.883	6.800	41.956	5725.979	204.147	-157.680	5837.085
2045	Honolulu	16.450	7.043	47.365	5657.925	201.721	-157.680	5772.824
2016	Kauai	1.651	0.707	2.007	759.336	27.072	0.000	790.773
2020	Kauai	1.708	0.731	2.549	752.506	26.829	0.000	784.323
2025	Kauai	1.779	0.762	3.228	743.968	26.525	0.000	776.262
2030	Kauai	1.850	0.792	3.907	735.431	26.220	0.000	768.200
2035	Kauai	1.921	0.823	4.585	726.893	25.916	0.000	760.138
2040	Kauai	1.993	0.853	5.264	718.355	25.611	0.000	752.076
2045	Kauai	2.064	0.884	5.942	709.818	25.307	0.000	744.014
2016	Maui	3.827	1.639	4.652	1760.215	62.757	0.000	1833.088
2020	Maui	3.959	1.695	5.910	1744.382	62.192	0.000	1818.138
2025	Maui	4.124	1.766	7.483	1724.591	61.486	0.000	1799.450
2030	Maui	4.289	1.836	9.056	1704.800	60.781	0.000	1780.762
2035	Maui	4.454	1.907	10.629	1685.008	60.075	0.000	1762.073
2040	Maui	4.619	1.978	12.202	1665.217	59.370	0.000	1743.385
2045	Maui	4.784	2.048	13.774	1645.426	58.664	0.000	1724.697

CURRENT VMT

The total statewide VMT estimate from Hawaii DOT is 11,132 million in 2016. SGA broke this down by vehicle type and county as follows.

By vehicle type

- Transit VMT (bus and paratransit) is based on estimates from U.S. DOT.
- Truck VMT is based on the ratio of registered trucks to registered non-bus/non-truck vehicles (passenger cars, light trucks, fleet vehicles and motorcycles), assuming each truck travels twice as many miles as other vehicles, on average.
- Household VMT is based on estimates from the Center for Neighborhood Technology (CNT) H+T Index at the Census block group level.
- The remaining unaccounted for VMT is classified as "other," comprised mainly of light- to medium-duty fleet and commercial vehicles.

By county

- Household VMT is assigned to counties based on CNT's block group level data, using de facto estimates of the number of households.
- All other VMT is assigned to counties in proportion to household VMT, except that Kalawao County is assigned no VMT from bus or paratransit vehicles.

FORECAST: BUSINESS AS USUAL

All VMT forecasts are based on assumptions about future growth patterns, transit provision, and transportation costs. To project future growth patterns, each county is divided into three area types based on estimates of household VMT from CNT:

A) Low-VMT areas (<17,500 vehicle miles per year);

B) Medium-VMT areas (17,500 to 22,500 vehicle miles per year);

C) High-VMT areas (> 22,500 vehicle miles per year).

The current distribution of households in each area type and the projected 30-year growth rates are shown in Table D.3 for each county. Due to influxes of part-time residents and visitors, the de facto number of households is higher than numbers reported in the U.S. Census. Therefore, county-specific population factors based on data from the Department of Business, Economic Development and Tourism, also shown in Table E.4, are applied to block-group level Census estimates.

Table E.4. Current household distribution by land use type and county, with population factors and 30-year growth rates

County	Total households (de facto)			Population factor	30-year growth
	A	B	C		
Hawaii	482	6,433	62,609	107%	52%
Honolulu	80,715	101,078	140,066	104%	12%
Kauai	0	372	27,381	124%	32%
Maui	0	11,854	53,442	122%	37%

a. 30-year growth rates are based on density classes (0 to 4, 4 to 12, and 12 or more households per acre) rather than VMT classes, due to the available historical data and the close relationship between density and household VMT.

Under business as usual conditions, our analysis assumes that future growth will occur in similar patterns to growth over the last 15 years (Table E.5) and that all households experience an average 4% decrease in VMT by 2045, based on the 1.4 % average decrease experienced between 2007 and 2016.

Table E.5. Future growth patterns under business as usual conditions

County	Total households (de facto)			Share of new growth		
	A	B	C	A	B	C
Hawaii	482	6,334	98,930	0%	0%	100%
Honolulu	102,494	115,923	143,419	54%	37%	8%
Kauai	0	372	36,187	0%	0%	100%
Maui	0	23,762	65,783	0%	49%	51%

This growth also contributes to density increases, which lower VMT in certain areas. To estimate density increases, our analysis assumes all new households in area type A would be infill development, resulting in a proportional density increase, and one-in-four households in area type B would infill development. These assumptions are based on the relative difficulty of greenfield development in denser area type A, compared area type B, where more undeveloped land exists.

Our business as usual forecast assumes that non-household VMT increases in proportion to household VMT, within each county. It also assumes Honolulu's high capacity rail project reduces VMT by 158 million each year beginning in 2025. This value is the difference between the no-build scenario and the fixed guideway alternative in the Honolulu Rail Transit Project Final EIS, multiplied by 365 to convert from daily to annual VMT. We use the more conservative (low-end) VMT reduction.

FORECAST: POLICY AND PROGRAMS SCENARIO

Our recommendations to reduce total VMT – and therefore energy consumption – across Hawaii is through a three-pronged approach involving:

- Limiting outward growth in high-VMT areas;
- Improving opportunities for compact mixed-use growth in low-VMT areas;
- Improving non-auto transportation options and incentives.

This aim can be achieved by pursuing the following specific programs and policies.

Transportation demand management

The term *transportation demand management* (TDM) often refers to employer-based programs that encourage employees to carpool, use transit, walk, bike, and occasionally work from home. These programs are important for reducing VMT and, with it, energy consumption and demand. TDM should be an overarching suite of policies and programs that goes beyond the traditional employer-based approach to include a larger group of stakeholders through the establishment of a transportation management association (TMA), an organization of employers, businesses and local governments. Citywide, TDM can include anything that reduces the overall length and frequency of vehicle trips—land use changes, more direct connections, transit enhancements, bicycle and pedestrian facilities, parking constraints and pricing mechanisms.

Land conservation

The last 15 years of growth in Hawaii and Kauai Counties has occurred mainly at densities below four units per acre, where each household contributes around 25,000 vehicle-miles per year. In contrast, half of the growth in Maui County and one-third of the growth in Honolulu County were at densities between four and 12 units per acre, where each household contributes around 20,000 vehicle-miles per year, and half of the growth in Honolulu County was at densities above 12 units per acre, where each household contributes only around 15,000 vehicle-miles per year.

Urban growth boundaries (like those in Oregon) and other land conservation policies can limit the amount of low-density, outward growth, minimizing the amount of new VMT added, while simultaneously concentrating growth in already-developed areas where densities will gradually increase.

To achieve the VMT reductions needed to support a clean energy future, our policy scenario assumes no new homes be added in area type C (high-VMT) and that 70% of growth in Honolulu County will be in area type A (low-VMT). These policies, alone, account for roughly 16% of our total estimated VMT reduction.

Compact, mixed use planning and zoning

Compact, mixed use development patterns put people closer to destinations and opportunities, often giving them the options of driving shorter distances, walking or biking. Compact areas also support transit use. Zoning policies (e.g., form-based codes or “SmartCodes”) can both enable and encourage denser, mixed-use development in suburban areas throughout the state. Moreover, without the appropriate zoning policies in place, concentrated inward growth may not be possible or it might take place in more segregated land use patterns that still require longer trips, usually by automobile.

To achieve the VMT reductions needed to support a clean energy future, our policy scenario assumes that all new growth will occur in pockets of compact, mixed-use development. In Hawaii and Kauai Counties, very little of this development style currently exists so it should grow around existing medium density centers (area type B). In Honolulu and Maui Counties, density and land use mixing will increase in area type B and to a limited extent in Downtown Honolulu (area type A).

Parking management

Parking reform is an essential component of compact, mixed use growth, and travel demand management. Research shows the parking is consistently oversupplied (typically by around 30-50% for residential parking). These excess parking spaces take up considerable amounts of space and drive up construction costs by $15,000 to $60,000 per space, making compact development more difficult. Research also shows that parking is one of the most important factors affecting people’s decision to drive, particularly when there are other reasonable travel options available. Parking management strategies typically fall into two related categories: 1) reforming zoning codes to eliminate excessive minimum parking requirements and 2) ensuring that users pay parking costs directly.

Local governments can eliminate or reduce parking requirements for new developments, price public parking accordingly and regulate existing parking through transportation demand management programs. They can also implement policies that encourage employers and private building owners to "unbundle" parking costs from wages, rents, and the prices they charge for goods and services.

To achieve the VMT reductions needed to support a clean energy future, our policy assumes aggressive parking management policies are implemented in Downtown Honolulu (area type A), restricting its availability and roughly doubling direct user costs in monetized terms. Moderate parking management policies should also be implemented across all of area type B. Parking policies, alone, account for roughly 29% of our total estimated VMT reduction.

Subdivision ordinance reform

Newer subdivisions often lead to disconnected streets characterized by cul-de-sacs and hierarchal, tree-like patterns. These layouts increase travel distances between homes and key destinations, which lengthens drives, makes make walking and biking unrealistic travel options and increases energy consumption. In contrast, dense, highly connected street networks typically provide more direct routes, make walking and biking safer and more convenient, and provide better access to transit. Existing street networks can sometimes be reconnected through capital investment programs (as in Charlotte, North Carolina) but a less expensive and often more politically viable option can be ensuring that new roads are highly connected through subdivision ordinances specifying maximum block lengths.

Our policy scenario assumes that, through such programs, street connectivity increases by 20% in existing area type B of Honolulu and Maui Counties and by 10% in Downtown Honolulu (area type A). These policies account for roughly four % of our total estimated VMT reduction.

Non-auto transportation improvements

People often drive even short distances because they do not have access to quality transit or sufficient walking and biking facilities. Sidewalks, protected bike lanes, and safer more frequent road crossings can make walking and biking more attractive options for people who are interested in walking or biking but concerned about safety. These people make up about 60% of the population with regard to bicycling. These kinds of improvements overlap considerably with network improvements described above. They can become part of a Complete Streets program, Safe Routes to Schools program, general road maintenance and roadway design standards or development review.

Transit enhancements can include new service, more frequent service, more efficient routes, better first- and last-mile connections to transit, more comfortable waiting areas, real-time arrival information, and fare reductions.

To achieve the VMT reductions needed to support a clean energy future, our policy scenario assumes that people's access to transit increases by 40% in area type B of Hawaii and Kauai Counties and by 10% area types A and B of Honolulu and Maui Counties (in addition to Honolulu's planned high capacity rail project). This additional transit service account for roughly two % of our total estimated VMT reduction.

Road or mileage pricing

Governments can manage vehicle travel demand through pricing mechanisms like congestion charges in urban areas, mileage-based road pricing, increased taxes on gasoline, and other road user fees. Private entities can also play some role through programs like pay as you drive insurance. Pricing mechanisms are most effective when the costs are incurred directly, as with congestion pricing or tolling, rather than being rolled into weekly, monthly or annual fees. Government could also help people understand transportation cost by unveiling those costs through real-time tracking tools – much like how people today use applications to track and compare travel time options or car dashboards that show real-time fuel use.

To achieve the VMT reductions needed to support a clean energy future, our policy scenario assumes that road or mileage pricing increases the cost of driving by 50% statewide. That increase is in addition to offsets for any potential decreases in the cost of driving due to lower gas prices, more fuel efficient vehicles, or less expensive alternative energy sources. This level of pricing accounts for nearly half of our total estimated VMT reduction.

ESTIMATING IMPACTS FROM POLICIES AND PROGRAMS

We quantify the potential impacts of each the policies and programs described above by estimating their effect on specific related impacts, based on knowledge of their relationship to VMT from research and literature. For example, we know that a 10% increase in density is associated with a 1% decrease in average household VMT. Each of the policies and programs is related to specific impacts described in Table E.6. These impacts were chosen because we can associate them with specific changes in VMT, described as elasticities below.

Table E.6. Related impacts associated with policies and programs

Policy or program	Related impacts
Land use preservation	Inward growth (+ density)
Compact, mixed use planning, and zoning	Inward growth (+ density); land use mixing
Parking reform	Parking cost
Subdivision ordinance reform	Street design/connectivity
Non-auto transportation improvements	Street design/connectivity; Access to transit
Road or mileage pricing	Road/mileage cost
Traffic impact assessments	Inward growth (+ density); Street design/connectivity; Access to transit

In developing our policy scenario, we made assumptions about: 1) where future growth would occur by area type and 2) what kinds of changes would occur within each area type. For instance, we assume that all new growth in Hawaii County will occur in area type B (compared to zero percent under the business as usual conditions). Given the limited size of area type B under current conditions, this requires approximately 20% of the current area type C to become area type B (representing densification and other changes to the built environment). That leaves approximately 55,000 existing households in area type C, and a new 50,000 households in area type B. Growth patterns for each county are shown in Table E.7.

Table E.7. Future growth patterns under policy scenario assumptions

County	Total households (de facto)			Share of new growth (%)		
	A	B	C	A	B	C
Hawaii	482	49,899	55,365	0	120	-20
Honolulu	108,699	113,072	140,066	70	30	0
Kauai	0	10,938	25,620	0	120	-20
Maui	0	38,528	51,017	0	110	-10

In Hawaii County, where area type B grows considerably, we do not assume any other changes occur within either existing area type. The same is true for Kauai County.

In Honolulu and Maui counties, however, we assume changes occur within each area type—densification, land use mixing, street design and connectivity changes, and increased parking costs due to changes in the availability of parking. As in the business as usual case, our analysis assumes all new households in area type A would be infill development, resulting in a proportional density increase, and one-in-four households in area type B would infill development.

We also assume there will be increased access to transit, particularly in Hawaii and Kauai (area type B), and increased road or mileage costs across the state. These changes are summarized in Table E.8 and Table E.9.

Table E.8. Assumed changes in related impacts (part I)

% share

County	Density			Land use mixing			Street design / connectivity		
	A	B	C	A	B	C	A	B	C
Hawaii	X	0	0	X	0	0	X	0	0
Honolulu	35	3	0	5	20	0	10	20	0
Kauai	X	0	0	X	0	0	X	0	0
Maui	X	56	0	X	20	0	X	20	0

Table E.9. Assumed changes in related impacts (part 2)

County	Parking cost			Access to transit			Road or mileage cost		
	A	B	C	A	B	C	A	B	C
Hawaii	X	25	0	X	40	0	X	50	50
Honolulu	100	25	0	10	10	0	50	50	50
Kauai	X	25	0	X	40	0	X	50	50
Maui	X	10	0	X	10	0	X	50	50

Elasticities

To estimate the effects of these changes on VMT, we rely on elasticities from literature, shown in Table E.10. As in *Moving Cooler*, we use multiplicative elasticities to avoid double-counting the effects of bundled strategies—i.e., density increases, land use mixing, street design and connectivity, and parking costs. Other strategies—transit improvements and pricing—are considered as additive effects.

Table E.10. Elasticities from literature

Policy effect	Source	Elasticity	
Density	Stevens 2017	-0.10	-0.47
Land use mixing	Stevens 2017	-0.03	
Street design/connectivity	Stevens 2017	-0.14	
Parking cost	Kuzmyak et al. 2003	-0.30	
Access to transit	Stevens 2017	-0.05	
Road/mileage cost	Hymel & Small 2015	-0.20	

For several effects, Stevens (2017) lists separate elasticities based on studies that control for self-selection. In the case of density increases, this elasticity is twice as large (-0.22). For land use mixing, however, the elasticity actually becomes positive (0.11). To be conservative and to rely on estimates based on a larger number of studies, we use elasticities as reported without controlling for self-selection.

Sources

- Hymel, K. M., & Small, K. A. (2015). The rebound effect for automobile travel: Asymmetric response to price changes and novel features of the 2000s. *Energy Economics*, *49*, 93–103.
- Kuzmyak, J. R., Weinberger, R., Pratt, R. H., & Levinson, H. S. (2003). Parking Management and Supply. In *TCRP Report 95: Traveler Response to Transportation System Changes*. Washington, DC: Transportation Research Board.
- Stevens, M. R. (2017). Does Compact Development Make People Drive Less? *Journal of the American Planning Association*, *83*(1), 7–18.

Final VMT estimate

These assumptions result in estimates of total household VMT by county. Total VMT was estimated as in the business as usual estimate, but with some variations:

- Non-household, non-transit VMT changes in proportion to household VMT;
- Bus and paratransit VMT increase by 25% due to increased service;
- Truck VMT increases at the same rate as in the business as usual case;
- Honolulu's high capacity rail project reduces VMT by 158 million each year beginning in 2025.

As a result, we calculate that total VMT in Hawaii can be reduced by 7.3% over 30 years, a 20.5% reduction from the business as usual growth trend.

Individual policies and programs

Disregarding any of the individual policies or programs above limits the overall impact of our policy recommendations. Without land use, parking, and street design impacts, for example, the reduction from BAU is only estimated to be 11.1% (an overall increase of 3.6% over 30 years). Similarly, the reduction from BAU without road or mileage pricing is only 10.5%. The sensitivity of our estimates to different impacts are shown in Table E.11.

Table E.11. Resulting VMT reductions under various conditions

Conditions	VMT	Change from current	Change from BAU	Share of total change
Current	11,132	0.0%	–	–
Business as usual (BAU)	12,978	16.6%	0.0%	–
Policy scenario	10,316	-7.3%	-20.5%	100.0%
No inward growth	10,748	-3.4%	-17.2%	83.8%
No land use mixing	10,335	-7.2%	-20.4%	99.3%
No street design/connectivity	10,415	-6.4%	-19.7%	96.3%
No parking cost	11,078	-0.5%	-14.6%	71.4%
No land use, parking, or design	11,535	3.6%	-11.1%	54.2%
No new transit	10,362	-6.9%	-20.2%	98.3%
No road/mileage cost	11,614	4.3%	-10.5%	51.2%

Some factors like land use mixing and transit have small overall impacts on their own, but should be considered important for meeting these goals, nonetheless. New transit, for example, will likely be essential for meeting increased density and parking management goals and potentially just as important for justifying road and mileage pricing, from a political standpoint.

ELECTRIC VEHICLE PENETRATION

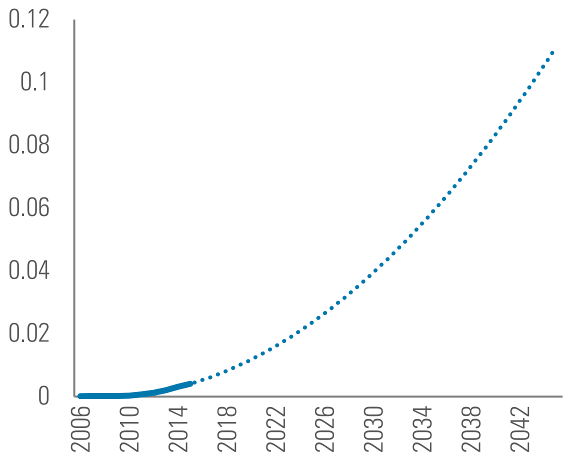
Extending recent trends, SGA expects the fleet mix to include more EVs but not enough to make up for growth, so the number of ICE vehicles will actually increase. A summary of this trend is shown in Table E.11.

This estimate is based on the following data and assumptions:

- Fleet data is based on vehicle registrations as reported by Hawaii State Department of Transportation, Safe Communities Program. For this analysis, we do not include motorcycles.

- Growth in EVs, also based on vehicle registrations, is polynomial, an assumption that best fits the last decade of experience (compared with linear and exponential functions). See Figure E.2.

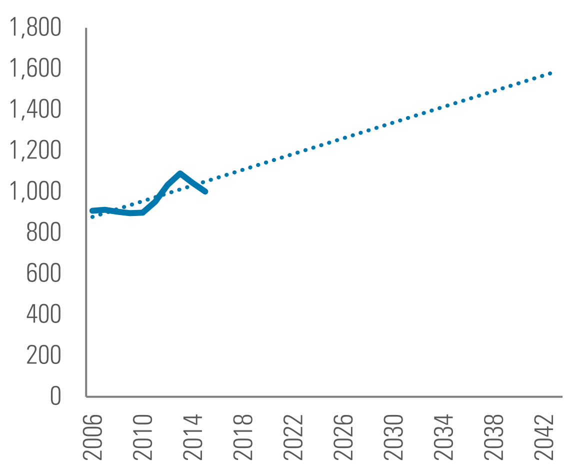
Figure E.2. Observed and projected share of Hawaii cars that are EVs.



- Given the mix of EVs in the market and in the product pipeline today, we assume EVs break down 90% as cars and 10% as light trucks.
- Growth in the fleet is represented by linear extrapolations from historic growth in sub fleets (cars, light trucks, buses, and heavy trucks) and summed. The car fleet trend is shown in Figure E.3.

Figure E.3. Historic and projected growth in Hawaii car fleet, based on a linear trend.

Thousands



- Historically the number of vehicles per capita is growing. See Figure E.12. Using this trend, we would expect to see 1.1 vehicles per capita in 2040, based on projected population growth, while our linear projections from vehicle subfleet growth yield an estimate of 1.07 vehicles per capita. While these are very similar, we choose to report the lower fleet-growth-based trend, which is consistent with our notion that we will naturally also see less VMT over time as parts of Hawaii densify.

Figure E.4. Hawaii vehicles per capita

Historic with trendline

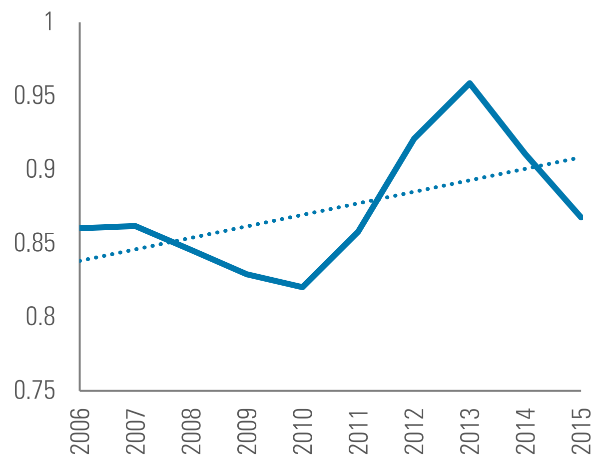


Table E.12. Trends in the Hawaii vehicle fleet.

Historical (bold), predicted (light)

	Cars	EV cars	ICE cars	Light trucks	EV light trucks	ICE trucks	Buses	Heavy trucks
2006	**907,659**	**114**	**907,532**	**189,878**	**13**	**189,865**	**2,349**	**670**
2007	**911,607**	**147**	**911,444**	**192,175**	**16**	**192,159**	**2,260**	**696**
2008	**903,518**	**161**	**903,339**	**191,459**	**18**	**191,441**	**2,213**	**799**
2009	**895,770**	**162**	**895,590**	**188,860**	**18**	**188,842**	**2,143**	**813**
2010	**898,452**	**244**	**898,181**	**187,733**	**27**	**187,706**	**2,103**	**861**
2015	**1,001,879**	**3,671**	**997,800**	**191,984**	**408**	**191,576**	**2,465**	**1,439**
2020	1,145,864	11,550	1,133,030	202,199	1,283	200,916	2,780	1,926
2025	1,241,764	25,369	1,213,576	206,791	2,819	203,972	2,996	2,404
2030	1,337,664	45,989	1,286,565	211,383	5,110	206,273	3,211	2,882
2035	1,433,564	74,445	1,350,847	215,975	8,272	207,704	3,427	3,359
2040	1,529,464	111,773	1,405,272	220,567	12,419	208,148	3,642	3,837
2045	1,625,364	159,009	1,448,687	225,159	17,668	207,492	3,857	4,315

AVIATION PETROLEUM DEMAND

Fuel consumption by airplanes departing Hawaii airports represents a large and growing portion of Hawaii's total GHG emissions. Fuel consumption data show from that planes filled up with 542 million gallons of fuel in 2014,[xxix] which, when burned, added 11.4 billion pounds of CO2 to the atmosphere.[xxx] Jet fuel accounts for more than half of the fuel consumed for transportation.[xxxi] Moreover, emissions from the aviation sector have been growing. The number of passengers arriving and departing Hawaii airports has risen steadily in recent years as the state's tourism market recovered from the great recession. Airborne freight volumes have also continued to rise.[xxxii]

While other sectors, such as electricity and surface transportation, have ready, off-the-shelf low-carbon technologies, few available technologies can reduce GHG emissions from planes. Over the past several decades, airplane manufacturers have made dramatic improvements in airframe and engine efficiency, but that means there is relatively little additional efficiency that can be weaned from the basic existing designs.[xxxiii] Radical new airframe and engine designs have been proposed, but these concepts are decades away from entering the market (see sidebar). Jet propulsion technology depends on burning carbon-based fuel. The existing airplane fleet cannot be retooled to use another power source.[xxxiv]

In addition to the technological barriers, there are regulatory constraints that limit the ways that the state of Hawaii could control GHG emissions from aviation. Federal law broadly preempts aviation regulation in order to create a uniform operating environment for airlines and other operators. The federal aviation authorization preempts all rules that would affect the operation of aircraft[xxxv] and the Clean Air Act, which generally creates a state-based regulatory regime, excludes aircraft engine emissions from state control.[xxxvi]

Proposed approach

The one area with both proven technology and opportunity for state policy intervention is reducing the carbon content of fuels by replacing fossil fuel-based jet fuel with a blend including renewable biofuels. An achievable biofuel blend would reduce the carbon intensity of fuels – and thus the GHG emissions from aircraft departing Hawaii airports – by 35%.

Biofuels for jet engines is emerging but tested technology. Test flights with biofuels began in 2008; and by 2015, 22 airlines performed over 2,500 commercial passenger flights with biofuel.[xxxvii] Despite many tests, however, commercialization has been slow. The total global production of alternative aviation fuel in 2016 was less than 4 million gallons and is growing slowly.[xxxviii] A few fuel operations now include biofuels into their fuel mix on an ongoing basis. For example, California-based AltAir is supplying United at Los Angeles International Airport (LAX) with 15 million gallons of fuel derived from waste oils; Red Rocks will produce 12 million gallons per year of fuel derived from forest products in Oregon for Southwest and FedEx; and Fulcrum Energy has signed agreements to, by 2025, supply 85 million gallons per year of fuel derived from municipal solid waste to Cathay Pacific and BP.[xxxix]

One of the most serious barriers to scaling up this new technology is that biofuels are still significantly more expensive than conventional jet fuel.[xl] Fuel cost represents one-third of airlines operating expenses, so airlines must be price sensitive in selecting fuel sources.[xli] For comparison, conventional jet fuel costs averaged $0.78 per kg in the U.S. from 2013 to 2015.[xlii] The Department of Defense procured alternative jet fuels derived from sugar and agricultural wastes from 2007 to 2012 at prices ranging from $3.09 to $8.98 per kg.[xliii] A techno-economic model of these fuel pathways suggests the costs for these fuel types could be lowered to $2.44 to $2.50 per kg.[xliv]

Biofuels have not yet scaled up to full commercial scale, but our model predicts that as the technology matures, it will soon be able to, particularly with the supportive policies by the state of Hawaii discussed below.

The design of existing aircraft and engine technology limit the amount of bio-based fuel that can be incorporated into the fuel mix.[xlv] Fuel blends including 50% bio-based fuel are certified to "drop in" to the fuel supply.[xlvi] Our model assumes the portion of bio-based fuel in the fuel mix will reach 50%.

How much fuel and where does it come from?

Planes departing Hawaii airports filled up with 542 million gallons of fuel in 2014[xlvii] and we project that amount will increase to 632 million gallons in 2045. Our GHG reduction approach calls for replacing half – 316 million barrels – of that with biofuel.

Hawaii could produce this substantial amount of biofuel locally, but reaching the level of production to supply half the aviation fuel will require an enormous amount of agricultural land to be devoted to fuel production.

Feedstocks

The total carbon content of biofuels, factoring the lifecycle emissions, depends on their source material (known as feedstock), the way this feedstock is grown, and the refining process to turn the organic feedstock into synthetic fuel. Certain feedstocks and agricultural practices can create so much additional GHG emissions, through energy-intensive growing or induced land use changes, as to negate the total GHG benefits.[xlviii] An ICCT meta-analysis of potential feedstocks and processes for bio jet fuel identified lignocellulosic and waste feedstock as the sources with the lowest overall GHG footprint.[xlix] These feedstocks will allow for biofuels that have a lifecycle carbon content of approximately 70% less than conventional jet fuel.[l]

Hawaii's waste volume – including municipal solid waste and agricultural waste – is insufficient to meet the volume of aviation fuel needed.[li]

Hawaii could meet the demand for biofuel by adding crops grown specifically for fuel production. Meeting the fuel demand will require a substantial amount of the state's available agricultural land. A Hawaii Natural Energy Institute study identifies the potential of Hawaii's agricultural land to produce products to be converted to biofuel. Sugarcane and short-rotation wood crops like eucalyptus and *leucaenaare* found to produce the greatest fuel yield.[lii] In combination – with sugarcane planted at flatter grades and wood crops grown on grades too steep for sugarcane – the two together could produce a total of 422 million gallons a year of bio jet fuel.[liii]

Producing enough fuel to supply all flights departing Hawaii with a 50% biofuel blend would thus require approximately three-quarters of the state's agricultural land devoted to fuel crops by 2050. Reaching this level of production would require dramatic changes. In 2017 Pacific Diesel planted the largest biofuel crop in the state's history, planting 115 acres of sunflowers on land previously used for sugarcane production. This crop yields only an estimated 100 gallons of oil each harvest, or 300 gallons per year.[liv]

This study does not look in detail at what other agricultural uses would be crowded out by this scale of fuel crop production, but that will be an important consideration.[lv]

Refining

In addition to the feedstock capacity, Hawaii will need sufficient refining capacity to convert this organic product into synthetic bio jet fuel. While there are not refiners in the state currently processing bio-feedstocks into jet-equivalent fuel,[lvi] the owner of the largest refinery is reportedly interested in adding biofuel refining capacity when sufficient feedstock is available.[lvii] This refinery has a capacity of 94,000 barrels a day or 34 million barrels annually.

If Hawaii enacts policies to eliminate or reduce the fleet of internal combustion engines for on-road vehicles, there will be excess capacity in systems now used for transporting, storing, and refining gasoline and diesel. Converting these systems to producing and storing bio jet fuel could ease the transition.

Start-up and growth

Our model assumes three years (until 2021) to secure a biofuel feedstock, establish the refining capabilities, and make needed adjustments or additions to airport fueling infrastructure. We then assume that, with state incentives (discussed below), the amount of biofuel in the airport fuel blend grows steadily to reach 50% by 2040.

Policies: how to do it

We identify four distinct ways Hawaii could increase the use of biofuels in aviation:

- Financing the additional cost of biofuels by procuring co-benefits and funding infrastructure;
- Requiring a biofuel fuel mix in on-airport fueling facilities;
- Adopting a low-carbon fuel standard for aviation fuel; or
- Charging differential, carbon-based landing fees to incentivize airlines to use biofuels

Finance co-benefits

Hawaii could encourage the use of biofuels by underwriting the additional cost for these fuels. Rocky Mountain Institute and SkyNRG evaluated possible ways for Sea-Tac Airport and its operator, Port of Seattle, to finance a sustainable fuel supply. [lviii] The study finds that the public entity cannot directly pay for the commodity used for a private company. However, the public authority could structure financing for co-benefits, such as increased air quality or reduced GHG emissions, and could support the development of needed infrastructure. Hawaii could procure reduced GHG emissions from aviation fuel suppliers. Rocky Mountain Institute also evaluated many possible funding sources that the Port (or, likewise, Hawaii) could use to pay for these co-benefits and new infrastructure.

Require a biofuel mix at airports

Hawaii could also use its position as the airport operator to promote biofuels. Fueling facilities at Hawaii's airports are privately owned by Hawaiian Fueling Facilities Corporation (HFFC), a consortium organized by 22 airlines, and are managed by Airport Service Group International (ASIG).[lix] In general, fuel supplies at airports are owned by airlines and managed by designated suppliers.[lx]

HDOT airports division has leased airport space to HFFC to construct fueling facilities. When renewing or renegotiating these lease agreements, HDOT could require HFFC to provide bio-aviation fuel from these on-airport facilities.

Other airports leading the way on biofuels have made similar arrangements. Norway's state-run airport operator, Avinor was the first to mix biofuel directly into the fuel supply used for all airlines, through an agreement with AirBP, Lufthansa, KLM, and SAS at Oslo airport. The program extended to Bergen airport, as well, and all planes fueling at these two airports now use this biofuel blend. Norway has set a mandatory mix of 1% biofuel by 2019, increasing to 30% by 2030.[lxi] Sweden's state airport operator Swedavia has followed; Gothenburg airport began including biofuel into its fuel blend through a partnership with AirBP and SkyNRG in October 2017.[lxii] In the U.S., Seattle's Sea-Tac is in the lead planning for and developing infrastructure to drop biofuel into the airport's main fuel supply.[lxiii] In 2017 ASIG ran a biofuel demonstration program with Singapore Airlines at San Francisco's SFO airport.[lxiv]

Institute renewable fuel standard

Hawaii could institute a low-carbon fuel standard (LCFS) for aviation fuel, mandating that fuel suppliers meet a certain carbon content in the fuel they supply.

California has adopted an LCFS for gasoline and diesel used for on-road vehicles. The standard works as a cap-and-trade program, granting credits to fuel suppliers for low-carbon fuel and requiring suppliers to hold credits equal to the total carbon content of their supply.[lxv] The California Air Resources Board (CARB), the agency that manages this standard, is now considering adding a standard for aviation fuels.[lxvi] The proposal from CARB would allow aviation fuel suppliers to collect credits for producing low-carbon aviation fuel, but not accrue deficits for producing conventional aviation fuel. Airlines have supported this proposal and argue that while aviation fuels are left out of the LCFS scheme, fuel producers are encouraged to use the still-limited bio-based feedstocks to produce road fuels rather than aviation fuels, as the road fuels earn credits, and aviation fuels do not.[lxvii]

Charge differential landing fees for clean fuels

To incentivize airlines to use biofuels Hawaii airports could charge differential takeoff/landing fees based on the use of biofuel or the carbon content of fuel used. High fees on aircraft operators using conventional fuels and low fees on operators using biofuels could offset the cost differential for using more expensive biofuels.

The FAA has explicitly allowed airports to charge differential fees, so long as the fees are applied fairly and without discrimination.[lxviii] For instance, airports are allowed to charge different fees for different times of day to manage airport congestion. Revenues raised from fees for use of the airport must be used "wholly for airport and aeronautical purposes."[lxix] To comply with international aviation agreements, rates must be "not in excess of the full cost…of providing the facilities and services efficiently and economically at the airport."[lxx] These terms have not been defined. Developing airport infrastructure for clean fuels would count as a facility expense.

Hawaii airports already charge landing fees at different rates for interisland and overseas flights. As of 2017, typical airport charges are approximately $15.04 per passenger for international flights, $11.87 per passenger for domestic overseas flights, and $7.57 per passenger for interisland flights.

Endnotes

[i] http://switch-model.org/

[ii] http://www2.hawaii.edu/~mfripp/papers/Switch_2_Preprint.pdf

[iii] http://uhero.hawaii.edu/assets/WP_2016-1.pdf

[iv] https://github.com/switch-hawaii/

[v] https://www.renewables.ninja/

[vi]http://www.geothermalcommunities.eu/assets/elearning/9.14.AssessmentOfEnergyReservesAndCostsOfGeothermalResourcesInHawaii.pdf

[vii] Kao, S. C., McManamay, R. A., Stewart, K. M., Samu, N. M., Hadjerioua, B., DeNeale, S. T., ... & Smith, B. T. (2014). New stream-reach development: a comprehensive assessment of hydropower energy potential in the United States (No. ORNL/TM-2013/514). Oak Ridge National Laboratory (ORNL).

[viii] https://www.google.com/get/sunroof#p=0

[ix] https://www.hawaiianelectric.com/about-us/our-vision

[x] Helm, C., & Burman, K. (2010). Kauai, Hawaii: Solar Resource Analysis and High Penetration PV Potential (No. NREL/TP-7A2-47956). National Renewable Energy Lab.(NREL),.

[xi]http://puc.hawaii.gov/trending-dockets/2014-0183-instituting-a-proceeding-to-review-the-power-supply-improvement-plans-for-hawaiian-electric-company-inc-hawaii-electric-light-company-inc-and-maui-electric-company-limited/

[xii] https://atb.nrel.gov/electricity/2017/

[xiii] https://www.hawaiianelectric.com/about-us/our-vision

[xiv] http://dbedt.hawaii.gov/economic/energy-trends-2/

[xv] http://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

[xvi]http://puc.hawaii.gov/trending-dockets/2014-0183-instituting-a-proceeding-to-review-the-power-supply-improvement-plans-for-hawaiian-electric-company-inc-hawaii-electric-light-company-inc-and-maui-electric-company-limited/

[xvii] Francfort, J. (2014). 2014 DOE Vehicle Technologies Office Review - EV Project Data & Analytic Results (INL/MIS-14-31743). Idaho National Laboratory (INL).

[xviii] https://energy.gov/sites/prod/files/2014/07/f18/vss137_francfort_2014_0.pdf

[xix] https://www.energy.gov/sites/prod/files/2014/07/f18/vss137_francfort_2014_0.pdf

[xx] http://energypathways.readthedocs.io/en/latest/introduction.html

[xxi] Technology cost inputs correspond to the costs assumed for the electric power modeling portion of this analysis, fixed O&M expenditures are captured for utility-scale and distributed generation solar PV, onshore and off-shore wind, biodiesel, oil, and coal. Variable O&M costs are captured for coal, oil, and biodiesel.

[xxii] http://www.implan.com/

[xxiii] https://atb.nrel.gov/electricity/2017/approach-methodology.html

[xxiv] https://www.nrel.gov/analysis/jedi/

[xxv] Fuel cell and hydrogen cell are excluded from our job impact analysis, under the assumption that these technologies are manufactured outside Hawaii and installed by out-of-state technicians.

[xxvi]County-specific household spending patterns obtained from IMPLAN.

[xxvii] Share of consumer spending by visitors from Hawaii Tourism Authority, 2016.

[xxviii] Total consumer spending from Bureau of Economic Analysis, 2016

[xxix] State of Hawaii Energy Data and Trends, February 2017, Table 5.2.http://files.hawaii.gov/dbedt/economic/data_reports/reports-studies/energy- data-trend- 2017.pdf

[xxx] Based on 21 lb of CO2 emitted per gallon burned. https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v10-2017.pdf

[xxxi] https://www.eia.gov/state/analysis.php?sid=HI

[xxxii] Hawaii State Department of Transportation, Airports Division; Hawaii State Department of Business, Economic Development & Tourism, Statistics & Data Support Branch, Databook (annual).

[xxxiii] https://www.nature.com/articles/nclimate2865 ; https://www.rmi.org/wp-content/uploads/2017/07/RMI_Sustainable_Aviation_Innovative_Funding_SAF_2017.pdf

[xxxiv] http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf

[xxxv] 49 USC §41713 https://www.gpo.gov/fdsys/pkg/USCODE-2008-title49/html/USCODE-2008-title49-subtitleVII-partA-subpartii-chap417-subchapI-sec41713.htm

[xxxvi] 42 USC §7573 https://www.gpo.gov/fdsys/pkg/USCODE-2013-title42/html/USCODE-2013-title42-chap85-subchapII-partB-sec7573.htm

[xxxvii] http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-alternative-fuels.pdf

[xxxviii] Rocky Mountain Inst. https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.027.2.en.REV.pdf

[xxxix] https://www.theicct.org/sites/default/files/publications/Aviation-Alt-Fuels_ICCT_Briefing_16062017_vF_corrected.pdf

[xl] RMI https://www.rmi.org/wp-content/uploads/2017/07/RMI_Sustainable_Aviation_Innovative_Funding_SAF_2017.pdf; https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.027.2.en.REV.pdf

[xli] https://www.rmi.org/wp-content/uploads/2017/07/RMI_Sustainable_Aviation_Innovative_Funding_SAF_2017.pdf

[xlii] https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.008.1.en.Estimated%20prices%20of%20AAF.FINAL.pdf ; https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=eer_epjk_pf4_rgc_dpg&f=a

[xliii] https://www.theicct.org/sites/default/files/publications/Aviation-Alt-Fuels_ICCT_Briefing_16062017_vF_corrected.pdf

[xliv] Diederichs et al. Techno-economic comparison of biojet fuel production from lignocellulose, vegetable oil and sugar cane juice. https://www.ncbi.nlm.nih.gov/pubmed/27259188

[xlv] https://www.hbba.eu/study/index.html#pf55

[xlvi] https://www.astm.org/cms/drupal-7.51/newsroom/astm-aviation-fuel-standard-now-specifies-bioderived-components

[xlvii] State of Hawaii Energy Data and Trends, February 2017, Table 5.2.

http://files.hawaii.gov/dbedt/economic/data_reports/reports-studies/energy- data-trend- 2017.pdf

[xlviii] https://www.theicct.org/sites/default/files/publications/Aviation-Alt-Jet-Fuels_ICCT_White-Paper_22032017_vF.pdf

[xlix] https://www.theicct.org/sites/default/files/publications/Aviation-Alt-Jet-Fuels_ICCT_White-Paper_22032017_vF.pdf

[l] https://www.theicct.org/sites/default/files/publications/Aviation-Alt-Jet-Fuels_ICCT_White-Paper_22032017_vF.pdf; https://www.biomedcentral.com/track/pdf/10.1186/s13068-017-0739-7?site=biotechnologyforbiofuels.biomedcentral.com

[li] A University of Hawaii - Hawaii Natural Energy Institute (HNEI) study found that only the island of Oahu had sufficient municipal solid waste to merit the infrastructure to convert this waste to fuel. The waste volume on Oahu is only enough to produce 22 million gallons of jet fuel per year. (https://energy.hawaii.gov/wp-content/uploads/2011/10/ScenarioAcceleratedUseRenewableResourcesTransFuelsHawaii_2007.pdf This study reported the volume of ethanol that could be produced by from this feedstock. Because jet fuel has 167% of the energy content of ethanol by volume, the equivalent jet fuel yield volume is only 60% of the volume potential ethanol yield. (https://www.platts.com/IM.Platts.Content/MethodologyReferences/ConversionTables/Images/CCSS1015_Energy_Industry_Conversions_LRG.pdf) The same transformation is used throughout this analysis.) Moreover, most of Oahu's municipal solid waste is already being used to generate electricity though incineration. (http://www.opala.org/solid_waste/archive/How_our_City_manages_our_waste.html; https://energy.hawaii.gov/wp-content/uploads/2011/10/ScenarioAcceleratedUseRenewableResourcesTransFuelsHawaii_2007.pdf) Agricultural

waste is also limited. The HNEI study finds that if the waste from the HC&S plantation on Maui and the G&R plantation on Kauai could be economically harvested it would generate 6 million gallons per year of bio jet fuel. A further study estimates the total cellulosic waste in the state would be enough to produce approximately 59 million gallons per year of bio jet fuel. (https://energy.hawaii.gov/wp-content/uploads/2011/10/Hawaii-Biofuels-Assessment-Report.pdf) The total waste cooking oil in Hawaii is enough to produce only 2-2.5 million gallons of biodiesel per year. (https://energy.hawaii.gov/wp-content/uploads/2011/10/ScenarioAcceleratedUseRenewableResourcesTransFuelsHawaii_2007.pdf)

[lii] https://energy.hawaii.gov/wp-content/uploads/2011/10/ScenarioAcceleratedUseRenewableResourcesTransFuelsHawaii_2007.pdf

[liii] https://energy.hawaii.gov/wp-content/uploads/2011/10/ScenarioAcceleratedUseRenewableResourcesTransFuelsHawaii_2007.pdf

[liv] http://www.biofuelsdigest.com/bdigest/2017/02/26/pacific-biodiesel-begins-farming-hawaiis-biggest-biofuel-crop/

[lv] Hawaii's industrial-scale sugarcane producers have closed in recent years; this land would be turned back to production and may be sufficient. But crops grown for fuel production could take away land available for local food production.

[lvi] correspondence with Bob King

[lvii] https://www.bizjournals.com/pacific/news/2017/03/07/hawaii-s-largest-oil-refinery-owner-in-talks-with.html

[lviii] RMI https://www.rmi.org/wp-content/uploads/2017/07/RMI_Sustainable_Aviation_Innovative_Funding_SAF_2017.pdf

[lix] http://www.aviationpros.com/press_release/11283332/asig-general-manager-named-outstanding-fuels-station-manager-of-the-year; https://www.burnsmcd.com/projects/fueling-master-planning-and-system-upgrades

[lx] https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.027.2.en.REV.pdf

[lxi] Airports Council International https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.022.2.en.pdf

[lxii] https://aviationbenefits.org/newswire/2017/05/skynrg-fly-green-fund-and-swedavia-enable-sustainable-aviation-fuel-flights-from-gothenburg-landvetter-airport/

[lxiii] http://www.seattleweekly.com/news/sea-tac-wants-all-its-flights-run-on-biofuel-and-it-has-a-plan-to-do-it/ ; https://www.rmi.org/insights/reports/innovative-funding-sea-tac-2017/

[lxiv] https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.022.2.en.pdf

[lxv] https://www.arb.ca.gov/fuels/lcfs/lcfs.htm

[lxvi] https://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/031717handout.pdf

[lxvii] https://www.arb.ca.gov/lists/com-attach/27-lcfs2015-VzYAMl09VlpRNABv.pdf

[lxviii] https://www.faa.gov/airports/airport_compliance/media/airports-rates-charges-policy-with-amendments.pdf

[lxix] 49 USC §40116 https://www.gpo.gov/fdsys/pkg/USCODE-2011-title49/html/USCODE-2011-title49-subtitleVII-partA-subparti-chap401-sec40116.htm; see analysis in "Controlling Airport-Related Air Pollution," Northeast States for Coordinated Air Use Management and Center for Clean Air Policy.

[lxx] FAA policy doc https://www.faa.gov/airports/airport_compliance/media/airports-rates-charges-policy-with-amendments.pdf