HAWAIʻI PATHWAYS TO DECARBONIZATION

ACT 238, SESSION LAWS OF HAWAIʻI 2022

Report to the 2024 Hawaiʻi State Legislature

December 2023

HAWAIʻI
STATE
ENERGY
OFFICE

Table of Contents

Appendices

Executive Summary

The Hawaiʻi State Legislature passed Act 238 in 2022, a broad decarbonization measure that reinforced and expanded Hawaiʻi's leadership in climate mitigation action while alerting Hawaiʻi's communities of the need to adapt to the climate crisis. As 2023 concludes, measured surface temperatures will shatter climate records, making 2023 the warmest year in the 174 year-long records of the U.S. National Oceanic and Atmospheric Administration. These temperature increases come with dire consequences for communities across the globe – and Hawaiʻi is not immune to the consequences of a warming planet.

Act 238 affirms Hawaiʻi's role in the nationally determined contribution under Article 4 of the Paris Agreement for the United States to "achieve a fifty to fifty-two percent reduction in economywide greenhouse gas emissions (GHG) by 2030 compared to 2005 levels". The Paris Agreement's targets, established to prevent ecological collapse and the associated harm to humankind, reflect a scientifically determined effort to limit global surface temperature increases. Further, the state's emissions reduction target largely follows the same targets set forth by the nationally determined contribution set forth by the Biden-Harris Administration.

These emission reduction targets were not haphazardly set. Instead, the emission reduction targets were established based on scientific consensus among participating countries to limit global surface temperature increase well below 2 degrees Celsius above pre-industrial levels, with an effort to limit the increase to 1.5 degrees above pre-industrial levels. In 2023 the measured temperatures, up to the end of October, indicated that the year's average surface temperature was about 1.4 degree Celsius above the pre-industrial baseline.[1]

While Hawaiʻi's GHG emissions are small, the actions taken to mitigate them are not. First, avoiding the worst of climate change will require everyone working together. Act 238 allows Hawaiʻi to stand and be counted among those recognizing the importance of local action. Further, Hawaiʻi's leadership in decarbonization policies sends a clear signal that there is strong demand for climate-ready solutions. With estimates for global decarbonization investment reaching trillions of dollars per year, policies like Act 238 and the Renewable Portfolio Standard help attract investment in climate-ready business and technology.

This report presents aggressive scenarios of emission reduction targets that will be incredibly challenging, but are potentially attainable with shared commitment, coordinated investments and capitalizing on near-term opportunities. Accordingly, Hawaiʻi should maintain its current emission reduction targets (Act 238 – Item 11) based on the clear understanding that the longer the delay in meaningful reduction – the steeper the reduction curve will become in the future.

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[1] World Meteorological Organization (2023) *Provisional State of the Global Climate 2023.*

The results of the quantitative analysis in this report indicate and reaffirm that **demand or load reductions** resulting from **aggressive energy efficiency measures are the most cost-effective measures to reduce emissions**; with the second scenario which focused on demand reduction showing net-savings, compared to the reference scenario. While this may not be the most *glamourous* path forward, the results are clear – energy efficiency saves people money and provides the foundation for substantial emissions reduction potential.

The analysis further underscores the need to maintain the development timelines for renewable energy projects statewide as the primary way to lower the carbon intensity of each island's grid. In all scenarios, reducing emissions from - and ultimately retiring or mothballing - fossil fuel generators is the primary driver of emissions reductions. Ensuring zero-emission renewable energy projects and finding low carbon alternatives to oil should be prioritized.

In each mitigation scenario, reducing emissions in the ground transportation sector heavily relies on electrification, and the reduction of vehicle miles traveled (VMT). Achieving the necessary transformation in the transportation sector requires a focus on infrastructure enhancements to promote energy efficient transportation, such as prioritizing infill projects. The easiest way to save money and carbon is infrastructure that provides reliable, cost-effective, and desirable alternatives to solitary car commutes that produce the crush of traffic at the start and end of every workday. Further, ensuring access and investing in a diverse network of reliable and efficient public charging infrastructure is necessary to ensure electric vehicle adoption. To track the state's progress, a comprehensive economywide decarbonization report should be completed every 5 years, consistent with international standards.[2]

Before concluding, HSEO wants to recognize the stakeholders and community members who took time to share their manaʻo on decarbonization opportunities and challenges. The overwhelming interest, idea sharing, and feedback received underscores a sense of urgency from industry, community leaders, government, and community members. Not all ideas and views fully align in *how* we will reach our emission reduction goals; what is clear is that the state must keep pushing forward in a manner that is *pono* and effectively manages the cost of living while improving the quality of life in our islands.

Finally, this report acknowledges the many foundational policies that have contributed to Hawaiʻi becoming a national leader in climate action. While these existing policies will continue to be a driving force for carbon mitigation, the measures taken to date are not sufficient to meet Hawaiʻi's ultimate decarbonization objectives. A statewide commitment to new, immediate, and equitable policies and actions to save energy, reduce our reliance on oil, and incorporate energy-efficient transportation into infrastructure plans as outlined in this Report will be necessary for Hawaiʻi to achieve net-negative carbon emissions by 2045.

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[2] Article 4, Paragraph 9 of Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015.

Overview of the Report

The report is structured as follows:

Chapter 1 – Discusses decarbonization through the lens of community and indigenous voices and addresses current economic incentives, equity considerations, and affordability challenges associated with different policies and measures. This focus satisfies **Act 238 Item 8**, which requires the Hawaiʻi State Energy Office (HSEO) to *Consider impacts to environmental justice, frontline, and low-income communities and make recommendations for how to mitigate any impacts to these communities and to facilitate a just transition to a decarbonized economy*. Chapter 1 further discusses the workforce needs for the transition, in accordance with **Item 7**.

The chapter highlights the current incentives and economic frameworks which have inherent inequities and course-correcting and adjusting key policies can alleviate equity concerns. This section of the report further outlines carbon pricing options that can be structured in an equitable way.

Chapter 2 – Discusses abatement activities and lays out the current emissions sources and sinks in accordance with **Item 12**, which requires HSEO to *examine contributions of different carbon sources, how each source can be reduced, what entities are responsible for the reduction of each source, and how each source factors into the determination of statewide greenhouse gas reduction goals.* This report further disaggregates the current GHG inventory, completed by the Hawaiʻi Department of Health (DOH) in accordance with HRS § 342B-701, to better inform targeted policies, the responsible entities, and the possible measures for reduction.

This chapter highlights the role of the energy sector and the transportation sector as the largest contributors to emissions statewide. While abating emissions in these sectors is critical to achieving the state's economywide decarbonization goals, other actions to reduce emissions and increase the ability of our natural environment to absorb carbon will be needed.

Chapter 3 – Discusses four decarbonization scenarios evaluated, as well as the quantitative framework, input assumptions, and methodology conducted to evaluate the abatement measures discussed in Chapter 2. This analysis was conducted by Energy Environmental Economics, Inc. (E3) and National Renewable Energy Laboratory (NREL), and was informed by stakeholder feedback. Each scenario was used to evaluate different approaches to achieve net negative economywide emissions and to analyze the potential outcomes in a future where the state meets the emissions targets. The Reference Scenario serves as a comparison point to show the current emissions trajectory. The mitigation scenarios explore key tradeoffs among different mitigation measures based on the values informed by stakeholders.

The mitigation scenarios were not designed to represent the optimal or likeliest pathways to achieve the state's 2045 GHG target; instead, they explore key tradeoffs among different mitigation measures. Note that the models used the powerplant retirement dates set forth by Hawaiian Electric.

Chapter 4 – Presents the results of the results of the scenario analysis described in Chapter 3, to address ***Act 238 Item 2 -*** *Include measures to reduce emissions from electricity, including accelerating the adoption of clean energy and improving energy efficiency for residential, commercial, and government users;* ***Item 3 –*** *Include land use and transportation planning measures aimed at reducing emissions from the transportation sector;* ***Item 4 –*** *Recommend state actions to address emissions associated with air travel and shipping, including how to encourage electrification and adoption of alternative fuels; and* ***Item 5 –*** *Recommend best management practices in the agricultural sector*, this chapter quantifies the level of action needed across sectors to meet emission targets, inclusive of the quantifiable actions identified and qualitatively described in Chapter 2. It is noteworthy that not all actions described in Chapter 2 could fully be modeled with data readily available. In accordance with ***Item 9*** – *Determine the most cost-effective pathway to decarbonization,* the modeling also calculated the annual and total costs and benefits for each mitigation scenario relative to the reference scenario.

Chapter 5 – provides an overview of the emissions that are not accounted for in the current statewide GHG inventory. These emissions are inclusive of imported emissions as well as lifecycle emissions, which are of particular concern for biofuels, including sustainable aviation fuel. The chapter provides accounting alternatives to better account for these emissions, to ensure progress toward a lower emission economy does not result in resource shuffling and is more holistically accounting for emissions. This Chapter underscores the need for appropriate accounting from a life cycle carbon intensity perspective for alternative fuels, inclusive of biofuels and hydrogen.

Recommendations

Act 238 Item 1: *Recommend regulatory or other state action; that will ensure the attainment of the State's decarbonization goals*. The following table lists recommendations by economic sector, the chapter(s) in which the recommendations are discussed, and the high-level rationale for each recommendation.

Sector, Chapter	Recommendation	Rationale
HRS 225P-5 Goals, Chapters 3-4	Maintain the economy wide emissions reduction target of 50% by 2030.	While challenging to achieve, the analysis shows this ambitious schedule can be met.
Inventory and GHG Accounting, Chapters 3-5	Consider an additional consumption-based inventory to supplement the production-based inventory to more holistically account for imported emissions.	Resource shuffling and underestimating emissions from imports was a major concern of many stakeholders.
Inventory and GHG Accounting, Chapters 3-5	Update inventory requirements in HRS §342B-71 to include mandatory emissions reporting requirements for large emitters, and ensure stakeholders are adequately engaged in inventory development and emissions tracking. As part of this, a technical working group comprised of agencies with regulatory authority over emitters should develop a mandatory emissions reporting requirement/regulation for large energy users. All input data and spreadsheets from the inventory should be publicly available.	1) The GHG inventory serves as the primary accounting mechanism tracking progress toward decarbonization goals. 2) Mandatory emissions reporting for large emitters will improve the data quality of the GHG emissions inventory, and create a regulatory grade emissions accounting and reporting rules that could become the basis for other supportive policies, such as a carbon price (e.g. carbon tax and dividend or a cap and invest program).

Sector, Chapter	Recommendation	Rationale
Inventory and GHG Accounting, Large Stationary Sources, Chapters 2-4	As part of updating emissions reporting under HRS 342B-72, make related updates to HAR §11-60.1-201, Air Pollution Control: 1) For “affected sources”, GHG emission reduction plans should be electronically submitted and publicly available on DOHs website. 2) Incorporate data from large stationary sources in the inventory.	HAR 11-60.1 has not been updated since the passing of Act 238 to reflect interim GHG reduction targets. Best practice calls for facility level data when available.
All Sectors, Chapter 1	Ensure regulating agencies are adequately staffed and compensated to ensure thorough expert, timely approvals and robust enforcement.	Regulatory oversight is a critical component to decarbonization necessary for both consumer protection (e.g. energy prices), safety (e.g. building and electrical codes), and resource protection (e.g. water and land use); however, many of the agencies tasked with protecting public resources expressed an overwhelming staffing shortages and turnover – resulting in slow review timelines.
Energy (All Sectors), Chapter 1	Modify the barrel tax to include carbon intensity thresholds that increase over time, as lower carbon intensity fuels become commercially available. Any tax or surcharge to encourage behavior change must include policies to support the availability of cost-effective alternative options. Surcharge funds should be used for lower-carbon infrastructure development and dividends should directly flow to income qualifying residents.	A carbon surcharge incentivizes behavioral changes when appropriate enabling infrastructure (e.g. robust transit) is available to residents and visitors. “Sin taxes” are regressive and must include protections for low- and moderate-income households. Dividends are viewed by economists as a way to offset the day-to-day cost increases of a carbon surcharge. Due to the carbon footprint of tourism, a carbon surcharge should ensure tourism carries a fair share of the burden.

Sector, Chapter	Recommendation	Rationale
Buildings and Infrastructure – Energy Efficiency, Chapters 2-4	Extend, update, and strengthen supportive policies for energy efficiency, such as the Energy Efficiency Portfolio Standard (EEPS). "Net zero"- ready building energy codes can reduce embodied carbon in buildings and reduce "code fatigue" among developers. Building Performance Standards can guide the use of public funds that support energy efficiency retrofits for existing buildings. The state can introduce "Buy Clean" policies to favor bids that use the lowest carbon options available, and require all public buildings to reduce energy waste by meeting LEED gold or better, using ENERGY STAR appliances, and including distributed renewable energy on rooftops or over parking structures. Reporting and emissions standards for large commercial buildings could achieve emissions reductions over time. Grid-connected appliances, such as heat pump water heaters, can play an important role in grid flexibility.	In both this report and similar national strategies, such as the "The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050," near-term action on energy efficiency provides the foundation for cost-effective and on-schedule decarbonization. Energy smart buildings reduce total cost of ownership, and studies show that energy efficient homes reduce mortgage default rates. Energy efficiency savings in buildings represent a significant source of energy savings in the Hawaiʻi PATHWAYS scenarios, presented in Chapters 4 and 5 by 2030. Smart energy consumption also reduces the capital expenditures on energy generation and delivery infrastructure. Achieving this level of energy efficiency will require new policies and programs.
Electricity Generation, Chapters 2-4	Support the development of utility-scale renewable energy projects for selected Stage 3 projects and forthcoming IGP procurements, particularly paired solar projects. • Consider an interagency task force under HRS §196-1.5 to regularly monitor development timelines, permit status, and identify potential roadblocks. • Identify permitting improvements to meet RPS timelines, facilitate community benefits, and explore dispute resolution outside of court.	The regulatory and permitting process, with a mix of state and county jurisdiction, has been identified as a barrier to completing projects in a timely manner at both the state and county level. Delays in project approvals result in a domino effect, potentially impacting fossil fuel retirement timelines.

Sector, Chapter	Recommendation	Rationale
Electricity Generation, Chapters 2-4	Require efficiency improvements to power plants that use fossil fuels to ensure that power plant replacements significantly reduce energy waste, which will save fuel cost and emissions.	Because fuel costs are passed through to consumers, there can be a lack of incentive to invest in power plant efficiency. The state should require new fossil fuel burning plants to have combined cycle capabilities, as well as favor designs that can be retrofitted to use lower carbon intensity fuels.
Electricity Generation, Chapter 5	Update the HRS §269-91 to include lifecycle carbon intensity requirements for "renewable energy sources," specifically *(7) biomass and (8) biofuels, and (9) hydrogen produced from renewable energy*.	Certain biofuel and biomass energy sources exhibit lifecycle emissions higher than that of fossil fuels when evaluated "farm to pump." While the PUC is required to evaluate lifecycle emissions, a carbon intensity threshold would clarify carbon requirements for all parties involved. Setting a maximum carbon intensity threshold does not negate the need for appropriate evaluation under HRS §269-6.
Electricity Generation, Chapter 4	Support the co-development of renewable energy with agriculture through county property tax incentives (e.g. agrivoltaics are eligible for agricultural property tax rates).	The analysis demonstrates substantial build-out of utility scale solar, incentivizing dual use can alleviate concerns over lost agricultural land and can support agriculture statewide.
Electricity Generation, Chapters 2-4	Investigate state energy resources and keep options open for new technology adoption (e.g. geothermal slim hole drilling) and phased transition plans to progressively cleaner fuels and generation options.	Improving our understanding of Hawaiʻi's potential energy resources could substantially reduce the need for high cost and high-risk renewable energy alternatives, including biofuels that exhibit uncertain and variable emission reduction benefits. Accelerated phase-out of fuel oil and diesel is necessary to reduce carbon intensity and costs.

Sector, Chapter	Recommendation	Rationale
Energy – Fuels, Chapters 3-5	Establish carbon intensity standards for all fuels sold and distributed in the state, based on lifecycle carbon intensity. The carbon intensity standard should include all fuels, including gasoline, diesel, jet fuel, marine fuel/bunker fuel, methane gas, propane, and others.	Alternatives fuels have a wide range of life cycle carbon intensity, and in some instances exceeds the carbon intensity of fossil fuels. A low-carbon standard sets a threshold value to ensure the lowest carbon fuels are used.
Energy – Fuels, Chapters 3-5	Expand the Renewable Fuels Production Tax Credit. • Require renewable fuel to meet an established lifecycle carbon intensity threshold. • Lower the BTU qualifying threshold. • Remove or extend the 10-year eligibility limit.	Alternative fuels are still not cost-competitive with conventional fuels, and current production does not meet demand. Incentivizing local production through the existing RFPTC can boost biofuel production in state and minimize need for imports. Adjustments to the RFPTC should balance the economic benefits of local production with cost to taxpayers.
Ground Transportation, Chapters 2-4	Establish a VMT reduction target for total VMT applicable to light-duty passenger vehicles. Require rental car companies to report their VMT separately (based on annual aggregated odometer readings).	Similar to the power sector, energy efficiency in transportation is the cheapest way to decarbonize. It saves money day-to-day and reduces the energy delivery infrastructure needed. VMT reductions provide an important source of GHG emissions in the Hawaiʻi PATHWAYS modeling. Establishing a target and tracking change are the first steps in effectively improving transportation energy efficiency.
Ground Transportation, Chapters 2-4	Pursue incentives for and streamline permitting for public EV charging infrastructure.	Adequate public charging structure is needed to ensure people without access to home charging can use electric vehicles, whether owned or used through car-share programs.
Ground Transportation, Chapters 2-4	Incentivize hotels to use electric fleets for shuttle buses and to offer shared shuttle services to and from the airport, as well as popular tourist destinations.	Incentivizing alternative modes of transportation for tourists can relieve traffic congestion while reducing emissions.

Sector, Chapter	Recommendation	Rationale
Interisland Transportation, Chapter 2	Continue to pursue alternative mechanisms to interisland travel; Act 226 (2023) allows for further exploration in this space.	Reduction in interisland emissions and adoption of alternative modes of transportation between islands can reduce aviation emissions.
Marine, Chapter 2	Develop a port emissions inventory, using EPA Port Inventory Guidance to gain a better understanding of bunker fuel usage, energy consumption, and mitigation actions feasible for the ports.	Data is needed in the marine sector for prescriptive action to be informed.
Air Travel, Visitor Arrivals Chapter 2	Work with hotels to encourage longer stays on the island - discounts for multi-day stays, and higher costs for one and two-day visits.	Increasing length of stay can reduce emissions from air travel without impacting the economic benefit tourism brings.
Agriculture, Forestry, and Other Land Use, Chapter 2	Invest in infrastructure that facilitates climate-smart implementation practices, and increase access to resources for land stewardship and agricultural production. 1. Provide longer-term leases, up to 30 years, for farmers willing to commit to implementing appropriate climate-smart practices. 2. Set up a lease program for producers interested in producing locally sourced soil fertility and amendments that support climate-smart practices such as compost, biochar, mulch, fish/ bone meal, etc. 3. Provide access to specialized machinery that facilitates the implementation of climate-smart practices (e.g., crimpers, compost spreaders, waste gasifiers, etc.) 4. Support the development of on-island slaughterhouses to avoid the export of live feedstock.	The agricultural sector is typically a source of emissions, but can act as a sink. Shifting soil management and fertilizer application; adopting climate smart agricultural practices, and incentivizing landowners and lessees to adopt these practices can reduce emissions from the agricultural sector, and increase sink capacity. Two primary barriers exist for farmers wanting to adopt these practices: 1) Access to land and 2) the access to machinery to facilitate the implementation of climate smart practices.

Sector, Chapter	Recommendation	Rationale
Agriculture, Forestry, and Other Land Use, Chapters 2-4	Fund programs (state and community-led) that address fire prevention on abandoned lands and in the wildland-urban-interface. Consider: • Invasive species removal (particularly fire-prone species).[1] • Restoring fire-adapted lands. • Programs to place abandoned agricultural lands back in agriculture or active management, including the potential for biofuel feedstock production. Prioritize watershed and existing forest protection programs • Ungulate, invasive species, and pathogen management programs (DOFAW and Watershed Partnerships). • Continue urban forest initiatives	Forest fires are expected to be more prevalent with more prevalent drought conditions in the state, exacerbated by the climate crisis. Forest fires are also a contributor to climate warming emissions and can reduce the sequestration potential of NWL.
Industrial Processes and Product Use, Chapter 2-4	Pass the Refrigerant Management Bill, proposed 2023 legislative session to reduce emissions from high global warming potential refrigerants (HFCs).	Refrigerants have high global warming potential and managing their use, handling, and disposal is critical to reducing emissions in this sector.

Sector, Chapter	Recommendation	Rationale
Workforce, Chapter 1	Support additional energy literacy in grade and high schools - work with non-profit partners in the state, focus on the nexus between IT, energy, and analysis. UH and UHCC scholarships and funding for credit and non-credit training; career training navigators and employer intermediaries are critical to recruit sufficient trainees for each training session. Adjust state tax credits to incentivize quality jobs; e.g., recent federal changes for wage thresholds, tax incentives for employers that provide paid internships, state funds to pay for internships in private companies. Modify future energy procurements to prioritize bids that commit to providing quality local jobs; Hawaiian Electric Stage 3 RFP treats “local jobs, payment of prevailing wages, or improving community infrastructure“ as simply “other benefits”. Tax incentives, permitting priority for the development of training facilities. Explore opportunities to cross-train PV and efficiency skills for construction workers, which can result in more steady work and better delivery of state-funded incentive programs.	In the decarbonization scenarios modeled in this report, the energy sector of Hawaiʻi is transformed in a matter of decades. Solar, wind, and storage are deployed at an unprecedented rate, sales of internal combustion engine vehicles are phased out and replaced with new zero emissions vehicles, buildings in the state undergo widespread retrofits with more efficient and electrified equipment, and the jet fuel needed for air travel is provided by increasing quantities of sustainable aviation fuel (SAF). All these changes will have a profound impact on the number and types of jobs needed.

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Acronyms

Greenhouse Gases

CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
O_3	Ozone
PFC	Perfluorocarbon

Agencies and Entities

ACEEE	American Council for an Energy Efficient Economy
AFDC	Alternative Fuels Data Center
BTS	Bureau of Transportation Statistics
CARB	California Air Resources Board
CCH	City and County of Honolulu
CESP	Hawaiʻi Clean Energy Sector Partnership
COH	County of Hawaiʻi
COK	County of Kaua'i
COM	County of Maui
CTE	Career and Technical Education
DAGS	Hawaiʻi Department of Accounting and General Services
DBEDT	Department of Business, Economic Development and Tourism
DLNR	Hawaiʻi Department of Land and Natural Resources
DLIR	Hawaiʻi Department of Labor and Industrial Relations
DOA	Hawaiʻi Department of Agriculture
DOH	Hawaiʻi Department of Health

DOH	Department of Health
DOTAX	Hawaiʻi Department of Taxation
E3	Energy and Environmental Economics
EIA	Energy Information Administration
EPA	United States Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
HART	Honolulu Authority for Rapid Transportation
HDOA	Hawaiʻi Department of Agriculture
HDOE	Hawaiʻi Department of Education
HDOT	Hawaiʻi Department of Transportation
HEPF	Hawaiʻi Energy Policy Forum
HNEI	Hawaiʻi Natural Energy Institute
HPUC	Hawaiʻi Public Utilities Commission
HSEO	Hawaiʻi State Energy Office
HTA	Hawaiʻi Tourism Authority
IMO	International Maritime Organization
NHTSA	National Highway Traffic Safety Administration
NREL	National Renewable Energy Laboratory
PUC	Public Utilities Commission
SAB	Scientific Advisory Board
SSTI	State Science & Technology Institute
TRC	Tax Review Commission
UH	University of Hawaiʻi
UHCC	University of Hawaiʻi Community Colleges
UHERO	University of Hawaiʻi Economic Research Organization
USDOE	US Department of Energy
USDOT	US Department of Transportation

Rules and Regulations

CAA	Clean Air Act
CFR	Code of Federal Regulations
HAR	Hawaiʻi Administrative Rules

HRS	Hawaiʻi Revised Statutes
IIJA	Infrastructure Investment and Jobs Act
IRA	Inflation Reduction Act
SLH	Session Laws of Hawaiʻi
BIL	Bipartisan Infrastructure Law

Other Key Terms

ACC II	Advanced Clean Cars II
ACCU	Australian carbon credit units' scheme
AEG	Applied Energy Group
AEO	Annual Energy Outlook
AFOLU	Agriculture, Forestry, and Other Land Uses
ALICE	Asset Limited, Income Constrained, Employed
AMI	Area Median Income
BAF	Biogenic Assessment Factor
BAU	Business as Usual
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CBEI	Consumption Based Emissions Inventory
CEM	Capacity Expansion Model
CERAP	Community Energy Resilience Action Plan
CI	Carbon Intensity
DAC	Direct Air Capture
DACCS	Direct Air Capture with Carbon Sequestration
DER	Distributed Energy Resources
DFO	Distillate Fuel Oil
DR/GS	Demand Response and Grid Services
DSM	Demand Side Management
ECA	Emission Control Area
EE	Energy Efficiency
EEJD	Energy Equity and Justice Docket

EEPS	Energy Efficiency Portfolio Standard
EF	Emissions Factor
ETS	Emission Trading Systems
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FPL	Federal Poverty Level
GDP	Gross Domestic Product
GHG	greenhouse gas
GIVE	Greenhouse Gas Impact Value Estimator
GJHI	Good Jobs Hawaiʻi
GWP	Global Warming Potential
HDV	Heavy Duty Vehicle
HVAC	Heating, Ventilation, and Air Conditioning
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IGP	Integrated Grid Plan
LCOE	Levelized Cost of Energy
LDV	Light Duty Vehicle
LFG	Landfill Gas
LIHEAP	Low Income Home Energy Assistance Program
LMI	Low- to Moderate-Income
LNG	Liquefied Natural Gas
LPG	Liquified Petroleum Gas
LSFO	Low Sulphur Fuel Oil
MDV	Medium Duty Vehicle
MHDV	Medium- and Heavy-Duty Vehicles
NEM	Net Energy Metering
NET	Negative Emissions Technology
NPV	Net Present Value
NWL	Natural Working Lands
O&M	Operations and Maintenance

PBEI	Production Based Emissions Inventory
PBF	Public Benefits Fee
PBR	Performance Based Regulation
PHEV	Plug-in Hybrid Vehicle
PPA	Power Purchase Agreement
PRAS	Probabilistic Resource Adequacy Simulator
PV	Photovoltaic
RA	Resource Adequacy
R&D	Research and Development
RBCF	Results Based Climate Finance
RETITC	Renewable Energy Technologies Investment Tax Credit
RFO	Residual Fuel Oil
RNG	Renewable Natural Gas
RPS	Renewable Portfolio Standard
SAF	Sustainable Aviation Fuel
SCC	Social Cost of Carbon
SDP	Scheduled Dispatch Program
SEDS	State Energy Data System
SNAP	Significant New Alternatives Policy
SNG	Synthetic Natural Gas
SSTI	State Smart Transportation Initiative
TDM	Transportation Demand Management
TOU	Time of Use
USGS	United States Geological Survey
VMT	Vehicle Miles Traveled
WtE	Waste to Energy
WWTP	Wastewater Treatment Plant
ZEV	Zero Emission Vehicle

Units

btu	British thermal unit

GW	Gigawatt
GWh	Gigawatt-hour
kW	Kilowatt
kWh	Kilowatt-hour
MMBtu	One million British thermal units
MMT	Million metric tonnes
mpg	Miles per gallon
mpge	Miles per gallon equivalent
MT	Metric ton
MW	Megawatt
MWh	Megawatt-hour
Tbtu	Trillion British thermal units

Definitions

Abatement	The act or process of reducing something, in this case, abatement generally refers to abating GHG emissions, i.e. emissions abatement.
Additionality	An "additionality" in carbon accounting relates specifically to offset projects. It is a concept used to evaluate the integrity of carbon offset projects, ensuring they are contributing to emissions reductions beyond what would have occurred without the offset project. Additionality tests are used to determine if specific emissions reductions would have occurred without the offset project in place. The concept of additionality is necessary to maintain the integrity of carbon offsetting programs to ensure that projects are genuinely contributing to emissions reductions.
Biogenic Carbon Emissions	CO2 emissions related to the natural carbon cycle, as well as those resulting from combustion, harvest, digestion, fermentation, decomposition, or processing of biologically based materials.
Building Electrification	The transition away from fuels across the residential and commercial buildings sectors, for example using heat pump water heaters instead of natural gas or propane water heaters.
Capacity Expansion Model (CEM)	A tool or suite of tools used to model electric sector resource planning under different load scenarios. CEMs simulate generation capacity, given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation. Both E3's RESOLVE and NREL's ENGAGE models serve as CEMs.
Carbon capture and storage (CCS)	The process by which carbon dioxide is captured from a smokestack or flue from a power plant or factory and then sequestered underground. This is an industrial process. CCS captures emissions from a point source GHG emitter and not the atmosphere (see Direct Air Capture). It is not considered a net-negative action, rather CCS is a mitigative action aimed to reduce emissions from point source facilities such as factories, refineries, or energy production facilities.
Carbon capture and utilization (CCU)	The process by which carbon dioxide is captured and converted into useful products including sustainable aviation fuel, car-bon-negative concrete, or carbon dioxide for industrial and commercial use, such as use in beverages.
Carbon dioxide equivalent	a metric used to express the amount of various greenhouse gases in terms of the equivalent amount of carbon dioxide (CO2) that would have the same global warming potential over a specified time frame. This metric is used to compare and aggregate the impacts of different greenhouse gases based on their ability to trap heat in the atmosphere and contribute to climate change.

Carbon dioxide removal	The process by which CO2 gas is removed from the atmosphere and sequestered.
Carbon intensity	Carbon intensity refers to the amount of carbon dioxide (CO_2) emissions produced per unit of a specific activity, output, or energy generated. It's a measure used to quantify the environmental impact of various processes, activities, or sources by assessing how much greenhouse gas emissions they generate relative to their output. For example, in electricity generation, carbon intensity might be reported in CO_2e per MWh, for transportation, carbon intensity might be reported in CO_2e per passenger mile or CO_2e per unit of distance traveled. The terms emission factor, carbon intensity, or emissions rate are often used interchangeably.
Carbon sequestration	The process of capturing and removing CO_2 from the atmosphere for long-term storage. There are three types: 1) Biological - storage of CO_2 in vegetation, soils, and oceans; 2) Geological - storage in geological formations (underground rocks); and 3) Technological - storage in engineered molecules.
Climate Forcing	Climate forcing measures the degree of change in the Earth's energy balance and is calculated as the difference between the rate of energy received by absorption of solar radiation and the rate of energy emitted by the top of the Earth's atmosphere (W/m^2). It is used to quantify the influence of emissions and other factors like solar radiation changes have on the climate - positive forcing tends to warm the climate, while negative radiative forcing tends to cool it. Climate forcing can be thought of as the warming/cooling effect of a given emission in the atmosphere. GHGs have a warming effect.
Climate smart agriculture	Climate-smart agriculture (CSA) refers to an approach in farming that aims to address the challenges posed by climate change while also promoting sustainable agricultural practices. CSA involves the integration of three main objectives: 1) Increased productivity: To ensure food security and promote economic stability in agriculture. 2) Adaptation: To enhance the resilience of agricultural systems to the impacts of climate change, such as extreme weather events, changing precipitation patterns, and temperature variations. 3) Mitigation: To contribute to the reduction of greenhouse gas emissions from agricultural activities, thus helping to mitigate climate change. The third objective is the focus of this report. Implementing climate-smart agriculture involves the use of innovative and sustainable practices, such as precision farming, no-till / low-till practices, agroforestry, water conservation, and improved crop varieties.
Consumption-Based Emissions Inventory (CBEI)	A more holistic approach to estimating GHG emissions, as it accounts for life cycle GHGs associated with the local consumption of goods and services. CBEI is a method used to assess and account for the greenhouse gas emissions associated with the consumption of goods and services by individuals, households, businesses, or entire regions (i.e. State of Hawaiʻi). Unlike production-based

	emissions inventories, which focus on the emissions produced within a specific geographical area, consumption-based inventories consider the emissions that are indirectly generated throughout the entire supply chain of products and services, including those produced outside the reporting region.
De facto population	De facto population includes all people in the state, including visitors and excluding residents temporarily absent.
Decarbonized, Low Carbon, or Renewable Fuels	Fuels with lower net carbon emissions than fossil fuel alternatives (See Chapter 5 for caveats).
Demand Reductions	Actions or policies that decrease the total amount of fuel or electricity that customers use.
Demand side management (energy)	Strategies and programs used to control electricity demand from customers or energy users (levels and time of use patterns) through various methods including incentives to reduce demand (e.g. credits or rebates for energy-efficient appliances/commercial equipment), rate schedules to shift demand away from peak hours (e.g. time of use rates) or providing other incentives for energy efficiency.
Direct Costs	Costs required to implement a measure.
Emissions factor	A numerical representation of the amount of a specific greenhouse gas or air pollutant emitted per unit of activity. Emission factors are used to estimate the total emissions of a particular substance from a specific source or sector. Emission factors are crucial in environmental assessments, allowing researchers and policymakers to quantify and analyze the impact of human activities on air quality and climate change. They are typically expressed in terms of mass of emissions per unit of activity, such as kilograms of carbon dioxide emitted per unit of energy produced. The US EPA annually updates emission factors for various fuel types, vehicle types, other mobile combustion activities, and waste materials end-of-life treatment.
Emissions leakage (carbon accounting)	Emissions leakage is the net increase of anthropogenic emissions of GHGs occurring outside an established inventory system boundary, resulting from efforts to reduce GHG emissions in one location or sector that lead to an increase in emissions in another location or sector.
Energy Demand	The total amount of energy consumed, generally including both electricity and fuels.
Energy Efficiency	Measures that reduce the amount of electricity a customer is consuming.

Engage	NREL’s electric sector capacity expansion modeling tool.
Equity	Equity is a principle that seeks to ensure fairness and justice in various aspects of life, from social and economic matters to law, education, finance, healthcare, energy, and the environment. Achieving equity often requires proactive measures, policies, and interventions to address historical and systemic inequalities and to promote equal opportunities and treatment for all individuals and communities. As a key concept, equity recognizes that everyone has different circumstances and allocates the exact resources and opportunities needed to reach an equal outcome.
Fuel Blending	The blend of candidate fuels including fossil fuels and decarbonized fuels that make up the total demand for a certain type of fuel. For example, if there is a 50% fuel blend of sustainable aviation fuel, that means that 50% of the demand for aviation fuel is met by decarbonized fuel and the other 50% is met by fossil fuel.
Gap Closing Measures	Expensive measures that can be used to reach net-negative once all other measures have been exhausted, for example, negative emissions technologies or stock buy backs.
Global Warming Potential (GWP)	A measure of how much energy the emissions of 1 ton of a gas will absorb over a given time horizon, relative to the emissions of 1 ton of carbon dioxide (CO2). The Global Warming Potential (GWP) allows comparisons of the global warming impacts of different gases. The larger the GWP, the more a given gas warms the Earth compared to CO2 over the established time horizon. The time horizon usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.
Greenhouse gas	Any gas in the atmosphere that traps or emits heat and results in increasing Earth’s surface temperatures
Gross Emissions	The sum of all emissions sources, not including negative emissions or emissions sinks
Independent Power Producer (IPP)	Any entity that owns or operates an electricity generating facility, not included in the electric utilities rate base including but not limited to independent solar or wind electricity producers, independent co-generators or combined heat and power generators who sell electricity to the utility.
Indirect Costs	Costs that result as the impact of a measure

Intergenerational Equity	The concept that fairness and equity should exist between different generations in terms of access to resources, opportunities, and a sustainable future
Land-Based Mitigation	Measures that utilize nature’s ability to absorb carbon dioxide to reach net negative.
Levelized Cost of Energy (LCOE)	A metric used to assess the lifetime cost of generating electricity from a particular source, taking into account all relevant costs over the plant's operational lifetime. It is expressed in terms of the cost per unit of electricity produced (usually in dollars per megawatt-hour, $/MWh)
Lifecycle analysis	Method used to estimate the environmental impact of a product or fuel based on a set of established system boundaries for the product or fuel's value chain - which may include extraction and processing of raw materials, manufacturing and processing, transportation and distribution, lifetime use, recycling, and final disposal. For the purposes of this study, lifecycle analysis (LCA) will refer to life cycle GHG analysis; however, some LCAs include water or other resources.
Measure	A discrete action or policy that can be included in a scenario.
Mitigation Scenario	A scenario that with new policies or actions that reduce emissions relative to the reference scenario.
Negative emission technology	A technology that removes more carbon out of the air than it emits during its full life cycle, also known as greenhouse gas removal technology. NETs include DACCS and CCS.
Net Emissions	Refers to the estimated balance between the emissions produced or released into the atmosphere, subtracted from the emissions sequestered through natural and technological processes. Sum of emissions sources and emissions sinks.
O&M Costs	Ongoing costs to run and maintain equipment
PATHWAYS	E3’s economywide decarbonization modeling tool
Production Based Emissions Inventory (PBEI)	Also known as a territorial emissions inventory, is a systematic record of greenhouse gas (GHG) emissions that are produced within the geographical boundaries of a specific region (i.e. within the State of Hawai‘i). PBEI is essential for assessing and managing local sources of GHG emissions, however, it may not capture the full extent of a region's indirect emissions.
Progressive action	Refers to a policy, tax, or measure that places a proportionally larger burden on individuals or households with higher incomes while offering relatively less impact on those with lower incomes.

Reference Scenario	A scenario that mirrors current policies and trajectories with no changes to policy.
Refrigerants	The fluid used inside of an air conditioning or heat pump system. Usually in the form of hydrofluorocarbons (HFCs) which are high global warming potential greenhouse gases.
Regressive action	Refers to a policy, tax, or measure that disproportionately impacts lower-income individuals or households compared to those with higher incomes. In other words, as the policy is implemented, the burden or cost falls more heavily on people with lower financial resources, often exacerbating income inequality. Regressive actions are generally considered to have negative social and economic consequences, as they can widen the gap between different income groups, increase inequality, and potentially lead to social unrest. Policymakers often aim to design policies that are progressive, meaning they place a larger burden on higher-income individuals or provide more substantial benefits to lower-income individuals to promote a fairer distribution of resources.
Resource Adequacy	The ability for the grid to maintain reliable electric service.
Resource shuffling	Any resource switch (e.g. fuel switch or source switch) that results in an "in-boundary" reduction in GHG emissions but has a corresponding increase in "out-of-boundary" emissions. Resource shuffling is a type of leakage. The concept typically applies to cap-and-trade programs; however, it can apply to any policy or program with goals and incentives to reduce emissions (e.g. the RPS and the Clean Economy Target). An example of resource shuffling that might apply to Hawaiʻi involves the closure of the sole refinery. If the refinery closes and there is still substantial demand for liquid petroleum fuel, the refining of the fuel will occur outside the system boundary and refined fuels will be imported, the emissions associated with both the fuel production (refining) and transportation to Hawaiʻi will not be accounted for in the State inventory, while this may appear to be a substantial reduction in the PBEI it may not be a meaningful reduction that is realized globally.
Social Cost of Greenhouse Gases	Societal harm of increasing greenhouse gases, including impacts to health, property damages, agricultural productivity, and other climate change impacts.
Stock Buy Back	A program where the program administrator, usually the local or state government, pays customers to turn in their used devices before reaching end-of-life to encourage increased adoption of new devices.
Stock Rollover	A modeling tool that calculates the number of devices in use relative to the share of sales for that device. How long it takes for old devices to be replaced depends on how long a customer keeps their device before replacing it with a new one.

System boundary	Refers to the demarcation line that defines the extent of the area being assessed for carbon emissions or removals. It delineates the physical or operational limits of the system under consideration. Establishing a clear system boundary is crucial to accurately measure and account for carbon emissions or sequestration associated with specific activities, processes, or entities. A system boundary may apply to inventory accounting, for example, the "emissions occurring in the state". Alternatively, a system boundary might apply to a life cycle analysis, system boundaries delimit the processes to be included in a lifecycle analysis of a product or fuel system. For example, in transportation fuels common lifecycle boundaries are "well-to-wheel", which breaks down fuel production and processing, fuel delivery, and vehicle operation. The system boundary typically includes the direct emissions resulting from the activities within the defined scope, as well as indirect emissions that are closely linked to the primary operations but occur outside the boundary. It helps in avoiding the omission or double counting of emissions, ensuring that all relevant sources and sinks are appropriately considered in the carbon accounting process. Defining the system boundary is essential for maintaining consistency and comparability in carbon reporting and facilitating the development of effective carbon management strategies.
Temporality	Temporality in emissions accounting involves a systematic consideration of time-related factors when measuring, analyzing, and planning for greenhouse gas emissions. It helps stakeholders assess both short-term and long-term emissions trends, evaluate the effectiveness of emissions reduction strategies, and make informed decisions to address climate change.
Transportation Electrification	The transition away from fuels across the transportation sector, may include electric vehicles, electric aviation, electric transit, and other types of electrification.
Vehicle Miles Travelled (VMT)	A measure of total vehicular travel that accounts for the number of vehicle trips and the length of those trips. VMT measures the amount of travel for all vehicles in a geographic region over a given period, typically one year.
Zero emission technology	Zero emissions technologies refer to technologies that have zero tailpipe or stack emissions. These technologies include solar or wind. Zero-emission technologies may also include zero-emission vehicles. This report recognizes all "zero-emission technologies" have life cycle emissions associated with resource extraction, manufacturing, and end-of-life.
8760 Analysis	8760 analysis, also known as an "hourly analysis" or "8760-hour analysis," is a method used in the energy sector to assess and understand the performance of a power system over the course of a year, considering each hour individually. The term "8760" refers to the total number of hours in a year.

Introduction and Purpose

Act 238 SLH 2022, enacted in July of 2022, is predicated on the unambiguous statement of the Hawaiʻi Legislature in Section 1 of the legislation that climate change is the overriding challenge of the twenty-first century. Passage of Act 238 follows fifteen years of adopted decarbonization legislative measures: 2007 (Act 234), 2015 (Act 97), 2018 (Act 15), and 2021 (Act 74); that together are intended help mitigate immediate and long-term threats to Hawaiʻi's economy, public health, natural resources, environment, and way of life.

Act 15 (2018) effectively established a net-negative greenhouse gas (GHG) emissions target "to sequester more atmospheric carbon and greenhouse gases than emitted within the State as quickly as practicable, but no later than 2045." The target includes an interim GHG emissions limit, to be achieved no later than 2030 of at least fifty (50) percent below the level of statewide GHG emissions in 2005."

This report addresses the provisions of Act 238 that the Hawaiʻi State Energy Office (HSEO) shall "analyze pathways and develop recommendations for achieving the State's economywide decarbonization goals." In particular, the thirteen (13) specific requirements of Act 238 noted in Table 1 are evaluated in this report with the intention to be a foundation and guiding resource for decision makers, local agencies, communities, individuals, climate action groups, industries, and other stakeholders.

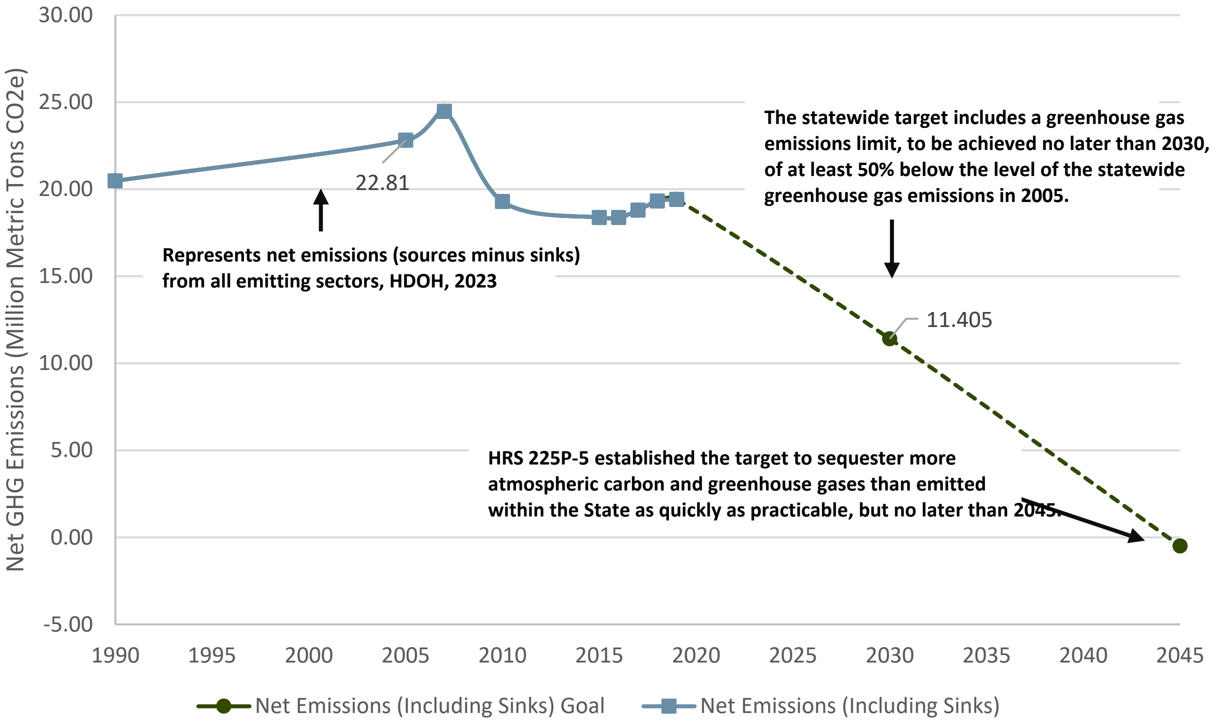
Table 1: Thirteen requirements of the Decarbonization Report pursuant to Act 238 SLH 2022.

1	Recommend regulatory or other state action; that will ensure the attainment of the State's decarbonization goals;
2	Include measures to reduce emissions from electricity, including accelerating the adoption of clean energy and improving energy efficiency for residential, commercial, and government users;
3	Include land use and transportation planning measures aimed at reducing emissions from the transportation sector;
4	Recommend state actions to address emissions associated with air travel and shipping, including how to encourage electrification and adoption of alternative fuels;
5	Recommend best management practices in the agricultural sector;
6	Include long-term carbon sequestration and carbon capture and utilization opportunities;
7	Make recommendations to aid in the transition of the state workforce to meet the needs of a decarbonized economy;

8	Consider impacts to environmental justice, frontline, and low-income communities and make recommendations for how to mitigate any impacts to these communities and to facilitate a just transition to a decarbonized economy;
9	Determine the most cost-effective pathway to decarbonization;
10	Rank recommendations based on level of impact, cost, and ease of implementation;
11	Make recommendations on whether the goals established pursuant to section 225P-5, Hawaiʻi Revised Statutes, should be adjusted, or if additional interim goals between the completion of the analysis and 2045 should be adopted;
12	Examine contributions of different carbon sources, how each source can be reduced, what entities are responsible for the reduction of each source, and how each source factors into the determination of statewide greenhouse gas reduction goals; and
13	Include other relevant considerations as deemed appropriate and necessary.

Statewide GHG Emissions and Current Decarbonization Goals

Statewide GHG emissions are currently tracked annually by the Hawaiʻi Department of Health (DOH). Pursuant to HRS 342B-71, DOH shall complete a GHG emissions inventory report each year beginning after 2017 to track emissions and determine the State's progress in GHG emission reduction. Accordingly, the quantitative analysis in this report is benchmarked to the most recently published Statewide Greenhouse Gas Emissions Report covering in-state emissions up to 2019. While HSEO has benchmarked the quantitative analysis to the state inventory, Chapter 5 of this report provides a qualitative discussion of the inventory's limitations and important steps to improve GHG accounting. This report assumes the GHG inventory is the tracking mechanism for emissions statewide and HRS §225P-5 applies to both the public and the private sectors.



The statewide target includes a greenhouse gas emissions limit, to be achieved no later than 2030, of at least 50% below the level of the statewide greenhouse gas emissions in 2005.

Represents net emissions (sources minus sinks) from all emitting sectors, HDOH, 2023

HRS 225P-5 established the target to sequester more atmospheric carbon and greenhouse gases than emitted within the State as quickly as practicable, but no later than 2045.

***Figure** 1 Line graph showing Hawaiʻi statewide net GHG emissions from all sectors (sources minus sinks) from 1990 to 2019 and net emissions goals by 2045. The solid blue line shows estimated net emissions (CO_2e) from 1990 to 2019 as estimated by DOH's GHG program. The green dotted line shows emission goals pursuant to HRS 225P-5. Notably, for the past 30 years there have been few substantial changes in emissions, reaching the 2030 and 2045 targets will require substantial changes.*

Chapter 1. Community Input, Equity, and Transition Costs

1.1. Community and Indigenous Knowledge

Hawai'i's resolve to address decarbonization as a matter of law, like the consensus on the scientific understanding of climate change, is indisputable. Communities throughout the Pacific region are increasingly challenged by climate change exacerbated by human-made GHG and its harmful impacts on local culture and livelihoods.

While emissions from Hawaiʻi are small when compared to the rest of the globe, Hawaiʻi is globally recognized as a leader and pioneer in clean energy policy and deployment, and the actions taken by Hawaiʻi to address the global climate crisis can be replicated beyond Hawaiʻi's coastline. Consistent with Hawaiʻi's reputation as a global innovator and test bed, decarbonization solutions deployed in Hawaiʻi can inform policies, workforce development, and technological innovation in the rest of the United States and throughout the world.

Mitigation strategies also have significant impacts on Hawaiʻi communities which make community involvement in determining Hawaiʻi's decarbonization mechanisms and approaches an imperative. Engagement of the kānaka maoli or persons of Native Hawaiian ancestry is especially important as the indigenous people of Hawaiʻi have influenced generations with Hawaiian values of environmental sustainability, land use, navigation, and management techniques. For that reason, Hawaiʻi-specific context and values are pervasive in this report.

Community Inclusion

HSEO has sought input on this report through the following online and direct public engagement and outreach activities:

- HSEO Decarbonization website.
    - December 2, 2022 (launch date) to present.
    - Online open public comment form (June 2023 to November 17, 2023).
- Individual stakeholder discussions:
    - Twenty-five (25) meetings – July 2023 through December 2023.
- Sector-specific Priority Climate Action Plan (PCAP) groups:
    - Thirteen (13) combined meetings - June 2023 to October 2023.
- Fifty-nine (59) participants focused on Equity, Land Use, Transportation, and Decarbonization Tradeoffs:
    - Four (4) targeted convenings (Equity, Land Use, Transportation, and Decarbonization working groups).

- Two (2) public webinars with 100+ distinct participants total (over 200 invitees):
    - Webinar 1 on September 12, 2023.
    - Webinar 2 on November 14, 2023.
- Public Presentations and Updates:
    - Hawaiʻi Energy Equity Hui (EEH) - July 7, 2023. (The EEH, established in 2020, is a statewide public-private collaborative network of individuals and organizations working towards an equitable clean energy transition).
    - Update at the Hawaiian Islands Humpback Whale National Marine Sanctuary Advisory Council meeting - November 8, 2023.
    - Hawaiʻi Pacific University student body presentation - October 2023.

The input received through these community inclusion activities is documented in more detail in Appendix A.

Ongoing community engagement will be required to successfully implement the measures discussed in this report toward achievement of a decarbonized Hawaiʻi. HSEO welcomes public comments on the report post-publication and will make feedback publicly available via the HSEO Decarbonization website.

Beyond this report, successful community engagement must be rooted in values that define the culture of Hawaiʻi. Native Hawaiian values and ways of being center connection and responsibility to ancestors and descendants, to place, and to the peoples of a place. Communities have expressed their distaste for "*check-the-box*" engagement commonly associated with development actions, such as those requiring environmental review under HRS 343 – Environmental Impact Statements. Instead of check-the-box engagement after projects have been fully formulated, decarbonization projects and activities should all strive to ensure impacted communities have a voice at the table during all stages of development, from early planning through implementation and even after completion to integrate their priorities and elevate their concerns into policy, project development, and decision-making.

Going outside the box and ensuring agencies have regular interaction with the communities their policies impact is one method to ensure community empowerment in the future. As an example, HSEO's Clean Energy Wayfinders program is inspired by Hawaiʻi's rich cultural and historical tradition of wayfinding in which trained navigators help led their communities to a new place where they can sustain a better quality of life. HSEO has developed the Energy Wayfinders Program by assembling staff and community organizations at two levels of engagement to share information and provide technical assistance. The initial cohort of Wayfinders primarily served as emissaries on each county to share information and opportunities for participation in the clean energy transition with Hawaiʻi's schools, community organizations, and households. HSEO prioritized outreach in low- to moderate-income (LMI), asset-limited, income-constrained, employed (ALICE), and under-resourced communities to stimulate the following activities:

- Greater energy conservation and efficiency and lower monthly energy utility bills, increase access to clean transportation and renewable energy resources, promote green career training and employment opportunities, and increase awareness about the renewable energy policymaking and regulatory process.

Indigenous Knowledge

It is simply not feasible to separate a comprehensive decarbonization plan covering all economic sectors in Hawaiʻi from the health and well-being of Native Hawaiians. In contemplating a new future in the aftermath of the pandemic, Native Hawaiian community leaders have expressed the need "to have Native Hawaiian voices, values, and experiences influence the economic recovery for our ʻāina aloha or beloved homeland."[3] These Native Hawaiian leaders have also carried out a series of online community engagements including HSEO staff that set the foundation for what became known as ʻĀina Aloha Economic Futures (AAEF). The AAEF vision aspires to create a strong, self-sustaining economy in Hawaiʻi that "decouples economic growth from environmental degradation;" makes housing accessible for all; invests in its youth; cultivates partnerships between communities, the business sector, and the military to restore and protect the environment; facilitate and plan alternative energy projects with collaborating communities and that engender strong community support where located. An AAEF policy playbook[4] built upon these values along with an Assessment Tool[5] that allows individuals, policymakers, businesses, and governmental agencies to view a project or policy initiative from a Hawaiʻi-centric perspective to ensure alignment with ʻāina aloha. Together they form a framework to evaluate various dimensions including:

- Are the activities or policies consistent with ʻāina aloha goals to mālama (take care of) the immediate and long-term well-being of Hawaiʻi's environments?
- Do the activities or policies address historical injustices and protect the constitutional rights of Native Hawaiians, including water rights, shorelines, and natural resource access?
- Do the activities or policies create positive systemic improvement to support healthy and safe communities and the overall quality of life for all citizens?
- Does the development process engage community self-determination, have community support, and advance ʻāina aloha goals to care for Hawaiʻi's environments and communities?

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[3] ʻĀina Aloha Economic Futures Declaration (2023) ʻĀina Aloha Economic Futures Declaration. Accessed June 2023.

[4] ʻĀina Aloha Economic Futures, Policy Playbook January 2021. Accessed June 2023. AAEF Policy Playbook - Google Docs

[5] ʻĀina Aloha Economic Futures, Assessment Tool for Policies, Projects, and Programs. Accessed June 2023. AAEF Assessment Tool for Policies, Projects, and Programs

- Do the activities or policies diversify Hawaiʻi's economy, especially in ways that nurture food, energy, and environmental sustainability and improve the immediate and long-term well-being of Hawaiʻi's communities?

According to Case-Scott et al. (2022) from The White House:

> "Indigenous Knowledge—also referred to as Traditional Knowledge or Traditional Ecological Knowledge—is a body of observations, oral and written knowledge, innovations, practices, and beliefs that promote sustainability and the responsible stewardship of cultural and natural resources through relationships between humans and their landscapes. Indigenous Knowledge cannot be separated from the people inextricably connected to that knowledge. It applies to phenomena across biological, physical, social, cultural, and spiritual systems. Indigenous Peoples have developed their knowledge systems over millennia and continue to do so based on evidence acquired through direct contact with the environment, long-term experiences, extensive observations, lessons, and skills." [6]

In the Hawaiian world view, ʻIke Hawaiʻi:

> "Traditional Hawaiian knowledge encompasses a broad scope, including knowledge of native species diversity, knowledge of ecological processes and patterns, and knowledge of management of land and sea. Such knowledge was originally transmitted purely in an oral, transgenerational manner, and remains embodied in the names of species and places, and in vast indigenous datasets in the form of oli (chants), moʻolelo (stories), and ʻōlelo noʻeau (proverbs). There recently has been a development of explorations on the process of Hawaiian inquiry: on how traditional knowledge is gathered, assessed, and promulgated. This "Hawaiian Science" can be correlated to conventional "Western Science'' in terms of observation, manipulation, testing, and promulgation of knowledge, but also bears its own unique elements. One key difference is "Hawaiian Science" has been observed and practiced for almost a thousand years here in the same land and seascapes that we steward today. An example of this kind of exploration in the *Papakū Makawalu* inquiry method promises to create a multi-tiered training approach in traditional knowledge that honors and reinstates ancient knowledge and is applicable for contemporary times."[7]

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[6] Case-Scott, H., Daniel, R. A., Goldman, G., Hinzman, L. & Wilhelm, ʼAulani T. (2022, December 2). *What is "Indigenous knowledge" and why does it matter? integrating ancestral wisdom and approaches into federal decision-making*. The White House OSTP Blog.

[7] Culturally Grounded Conservation (n.d.). Hawaiʻi Conservation Alliance.

The important and integral intersectionality between both land and Native and or Indigenous peoples is not only evident within the framework of Indigenous worldviews, but also in the daily activities of Hawaiʻi's societies.

In Mary Kawena Pukui's *ʻŌlelo Noʻeau*: Hawaiian Proverbs & Poetical Sayings [8] she says in one of her ʻ*Olelo No'eau* or Hawaiian proverbs that within the context of ʻāina or land, "*He aliʻi ka ʻāina, he kauwā ke kanaka* (#531)." The English translation is, "The land is chief, and people are its' servant." This demonstrates the importance of the relationship between land and people in the everyday worldview of Kānaka Maoli, or Native Hawaiians. It also epitomizes how humans should view global decarbonization as a duty to serve the planet.

The traditional *Ahupuaʻa* system (land-dividing system) and the *Lo'i Pa'akai* (Salt Beds) on Kaua'i, which is a microcosm stemming from the macro *Ahupua'a* systems, are prime examples of this important relationship between land and people. Within the *Ahupuaʻa* system, the land was divided from the *Wao Kanaka* (mountains) to the *Kahakai* (sea) by the Ali'i Nui (high chief) who was under the *Mōʻī* (King) of the island and the God *Lono* (God of agriculture, fertility, abundance and more). The *Ali'i Nui* then appointed *Ali'i ʻAi* who designated a *Konohiki* (Headman) who was a general manager of the *Luna* (specialist) for each designated responsibility. For example, the Luna Wai was the water specialist.[9] Regarding the *Lo'i Pa'akai* (Salt Beds) located on the island of Kaua'i, the recent Luna Pa'akai explained that without the traditional *Lo'i Pa'akai* (Salt Beds), *Kānaka Maoli* cannot prepare foods, make medicine, and much more.

For *Kānaka Maoli,* salt is also a key component for physical and spiritual health. The Hawaiian salt can heal a person of illnesses as well as have use in spiritual practices. However, with the Sea Level Rise, change in weather patterns, and much more, the *Lo'i Pa'akai* has been flooded. This means little to no production of traditional salt, which is detrimental to Native Hawaiians. In congruency with these issues related to climate change, pollution caused by GHG Emissions from vehicles parked near the *Lo'i Pa'akai* (Salt Beds) as well as littering from visitors causes pollution to whatever traditional salt is made. Therefore, climate change and GHG emissions are not only a cultural problem for Kanaka and other Indigenous peoples within Oceania, but also a social justice and health equality issue as well. Most of the time, Native and Indigenous voices are not heard on a larger scale, and if so, are not taken seriously because traditional knowledge is not always quantifiable. However, this document puts into perspective that these voices are dire to the conversation.

According to Case-Scott et al. (2022) from The White House:

> "..it is estimated that, currently, at the global scale, Indigenous Peoples – and long-standing, place-based communities – manage over 24% of land, which contains ~40% of all ecologically intact landscapes and protected areas left on the planet, and a staggering

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[8] Pukui, M. K. (1983). *ʻŌlelo Noʻeau: Hawaiian proverbs & poetical sayings*. Bishop Museum Press.

[9] Muller-Dombois , D. (2007). *The Hawaiian ahupuaʻa land use system: Its biological resource zones and the challenge for silviculture restoration.* Bishop Museum Bulletin in Cultural and Environmental Studies 3:23-33.

> ~80% of the world’s biodiversity. In short, evidence suggests that the most intact ecosystems on the planet rest in the hands of people who have remained close to nature historically. And Indigenous Knowledge is not just applicable to land and water use; it is relevant to all human systems.”[10]

The compelling record of Indigenous Peoples in ecosystem management underscores why indigenous voices and knowledge have such an important role in this report and in the ongoing conversation and implementation of decarbonization infrastructure and projects in Hawai‘i. When Native Hawaiian *Luna* then *Konohiki* were consulted, the constituents within that *Ahupua’a* were not only witnesses but bearers of the decisions that were made by both the *Ali’i Ai* and *Ali’i Nui*. Witnessing and informing people about the change of weather patterns, crop growth, etc. was an integral part of the decision-making made by those in charge. Similarly, nowadays people have that same power; however, the system of government and land is a lot different and affects these Native Hawaiian communities immensely.

The most important voices coming from Native Hawaiians are heard mostly by their leaders and not necessarily heard by those within the state or emitting sectors. This means that these voices do not render the same fruits of labor as the traditional Native Hawaiian *Ahupua’a* System because they now share space with other local community members within their *Ahupua’a*. This also means different needs, desires, opinions, and thoughts about how the government is run, regarding how land is used, as well as the distribution of resources. This then translates to Native Hawaiian community members having equality, but not necessarily equity.

Native Hawaiians have historically been displaced from their *Ahupua’a* due to the rising cost of living and the traditional way of living not aligning with the Westernized way of living. Although Native Hawaiians are adaptable, the generational trauma of this displacement is evident in the extremely high rates of violence, incarceration, and homelessness within the demographics of Hawai’i. Greater self-determination is achievable by working within and with these communities using a traditional worldview and epistemology to further learn about the needs not only of these marginalized peoples but also how we can further bridge the gap between these communities and the government agencies for better *Ahupua’a* within Hawai’i. Any decarbonization actions implemented must not exacerbate affordability challenges already burdening Native Hawaiians.

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[10] Case-Scott, H., Daniel, R. A., Goldman, G., Hinzman, L. & Wilhelm, ’Aulani T. (2022, December 2). *What is “Indigenous knowledge” and why does it matter? integrating ancestral wisdom and approaches into federal decision-making*. The White House.

1.2. Equity

As an essential priority and guiding principle of all future decarbonization activities, projects, and programs in Hawaiʻi, equity initiatives have recently emerged such as the Energy Equity and Justice Docket (No. 2022-0250) (EEJD), a proceeding opened by the Hawaiʻi Public Utilities Commission (PUC) in 2022, and the Energy Equity Hui supported by HSEO and many other community, private, non-profit, and governmental partners. Likewise, equity considerations in all other sectors have appropriately gained traction and where absent require prompt attention by other commissions and agencies responsible for overseeing Hawai'i's natural resources, tourism, and other economic activities including but not limited to the Department of Land and Natural Resources (DLNR), the Department of Agriculture (DOA), and the Department of Business, Economic Development, and Tourism (DBEDT) including its attached agencies such as the Hawaiʻi Tourism Authority (HTA).

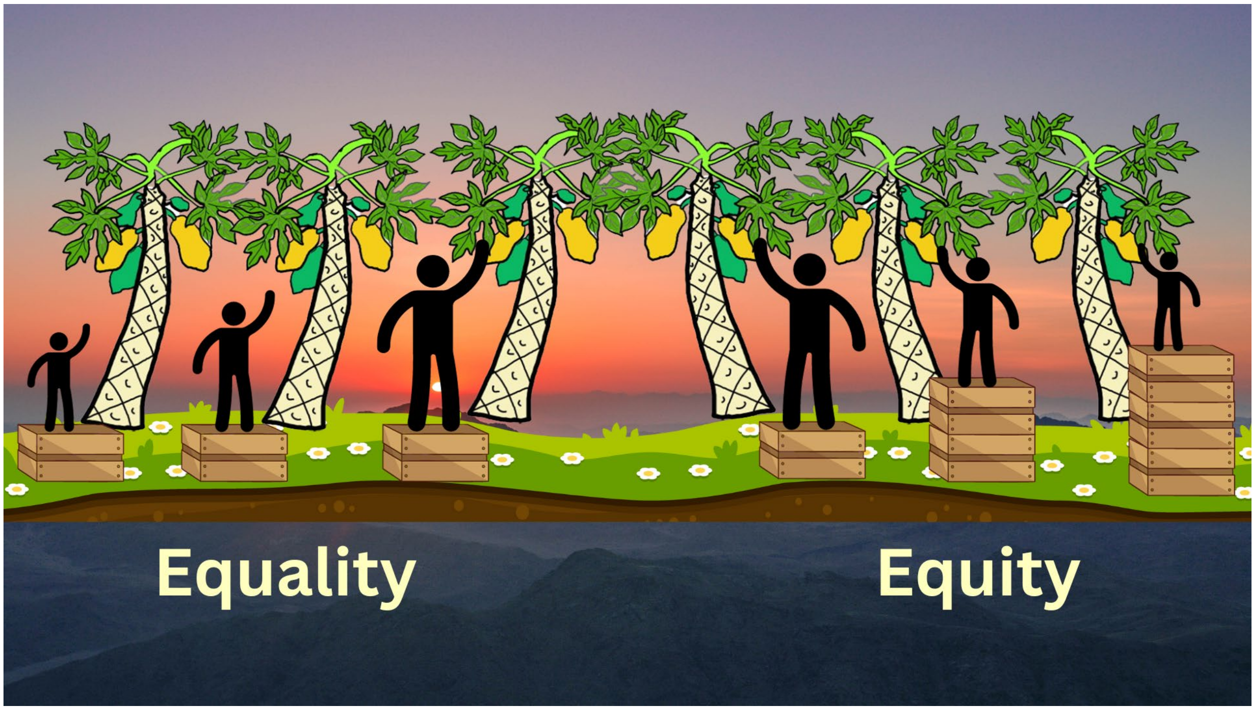

Figure 2: Graphic depiction illustrating the difference between equality and equity. Adapted from Interaction Institute for Social Change.

Equity means achieving the fair distribution of benefits and burdens regardless of social identity, and in a manner that respects and acknowledges each island's cultural practices, historical experience, community values, and democratic participation *(Energy Equity Hui)*. In general, progress toward a more equitable economic system requires both the recognition and remediation of the unequal distribution of benefits and burdens based on access, social identities, and historic systems of economic and racial oppression *(Energy Equity Hui).*

While the EEJD applies to utilities regulated by the PUC, the PUC established a five-tier framework that may be applicable to entities beyond the regulated utilities. The five tiers include 1)

Procedural Equity, 2) Energy Affordability and Direct Payment Assistance, 3) Equitable Siting and Hosting of Energy Infrastructure, 4) Equitable Access to Clean Energy, and 5) Utility Performance and Tracking. How the tiers can apply beyond public utilities is described in Figure 3.

Affordability & Equitable Finance Structures

- Ensuring all residents are not excluded fromm the transition regarless of income.
- Appropriately placing safety nets for priority communities during transitions.
- Ensure policies do not disproportionately impact low and middle income communities.

Equitable Siting of all Infrastructure

- Remediating social, economic, and health burdens on those historically harmed by the current system.
- Ensuring the placement of new infrastructure supported by host communtities?

Action Tracking & Transparency

- Increased reporting and transparency
- Includes transparency on contributions to GHG emissions by state government.
- Ease of public access to progress reports

Procedural Equity

- Improving access to project approvals and regulatory proceedings.
- Ensuring communities are engaged at all points in the process (planning, development, operation, and decomissioning).

Equitable Access to Public Goods

- Expanding access to all public goods, inclusive of clean energy and local food.
- Ensuring all regardless of income can afford to take part in decarbonization actions.

Figure 3: Framework for equity adopted by the Public Utilities Commission, Energy Equity Docket.

Affordability

While the Affordability & Equitable Finance Structures focuses on the individual energy consumer, affordability is also highly impacted by technology and approaches that may most efficiently be effectuated at the system level, such as powerplant efficiency. Accordingly, the EEJD should be seen as an appropriate vehicle to address a broad range of approaches, strategies, innovations, and technologies to reduce the costs of energy generation and distribution as well as burdens to energy consumers. While the EEJD continues to move forward in its quest to address equity and justice concerns, the PUC issued Decision & Order No. 40290 as an interim follow-up on outcomes from initial deliberations in the docket – with highlights that include:[11]

- HECO provides a list of its programs and special rates, including discounted rates for Low Income Home Energy Assistance Program (LIHEAP) recipients.
- Exploration by the Public Benefits Fee Administrator on short-term bill assistance.

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[11] Hawaii Public Utilities Commission (n.d.) Energy Equity and Justice (Docket 2022-0250)

- Recommendations for equitable access to clean energy programs, such as rooftop solar, with a focus on making these options more accessible to underserved households.
- Evaluation of DER and CBRE programs to ensure fair participation in the clean energy transition.
- Consideration of storing the NEM (Net Energy Metering) program in some form while addressing the disparities among ratepayers who have and have not benefited from clean energy programs.

Affordability Proceedings in Other Jurisdictions

The California Public Utilities Commission (CPUC) is addressing the need for affordable utility services to ensure public health, safety, and societal participation. Initiated through Order Instituting Rulemaking 18-07-006 on July 12, 2018, the CPUC's comprehensive approach involves three phases. Phase 1, concluded in July 2020, established an affordability framework for essential energy, water, and communications services. Phase 2 focuses on implementing this framework in various CPUC initiatives, while Phase 3 explores energy rate mitigation proposals discussed in recent hearings addressing California's ongoing energy affordability concerns.[12]

Some of the issues associated with the TOU program (explored by HPUC under DER Policies: Advanced Rate Design Track), can be attributed in part to other underlying issues. When customers install rooftop solar panels, they benefit from tax credits and indirectly receive financial support from other customers through the tariff structure. While the tax credits support public policy objectives for distributed renewable generation and consumer choice, the taxpayer subsidy that has been contributed by ratepayers who do not have rooftop solar installations have been criticized on equity grounds. Others also criticize the subsidies as an excessive promotion of self-generation when more economically efficient grid-scale alternatives are available[13]. HSEO has taken the position that self-generation and community based renewable energy (CBRE) programs are less relevant and cost-effective in jurisdictions like Kauaʻi where there is a near-term (i.e., by 2030), credible island-wide plan to reach an extremely high penetration or even 100% renewable generation. In areas where electricity demand is not well aligned with renewable generation and near-term high penetration of renewables is not likely, such as O'ahu, CBRE and self-generation should be vigorously pursued.

Because low- and moderate-income residents may be less capable of shifting household energy demand during the day, additional expenses from proposed TOU programs should be clearly disclosed and applicable to all customers. One approach involves modifying per-kilowatt-hour (kWh) rates to accurately account for the avoided costs in the first place. As an example, an initiative in California intends to lower per-kWh charges, raise the fixed monthly customer

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[12] California Public Utilities Commission (n.d.) Affordability Rulemaking

[13] Roberts, M., Tarui, N. Hartely, E. (2023) Economic Research Organization at the University of Hawaiʻi (UHERO) Embracing TOU: Nudges, Rates, and Renewable Energy

charge, and introduce a progressive structure to the fixed charges, ensuring wealthy households pay more than lower-income households. This progressive income graduated fixed charge would be applied uniformly, regardless of whether customers have rooftop solar.

Equitable Siting of Infrastructure

In the past and in the present, communities with lower income as well as Native Hawaiian and Pacific Islanders have historically borne a disproportionate impact of industrialization. These same communities are typically the first approached to host new development including but not limited to new energy and transit projects, gentrifying developments in transit corridors, among others. The scale and speed of large-scale energy developments in Hawaiʻi have raised scrutiny on the equity and justice implications of proposed energy and development plans. The timing and way host communities should be engaged must be directed by the individual communities themselves; recognizing that doing this appropriately can slow development and can further place a burden on the host community. Further, defining the host community and the representatives for host communities must be done mindfully – noting communities do not have homogenous views; those who are most vocal may not be the representatives of the communities they speak for.

In the context of energy, energy sovereignty sourced by local sources of energy is in Hawaiʻi's best interests for many reasons. This starts with a full understanding of all our local renewable energy options and aggressive energy conservation requiring behavioral change. In addition to global urgency, there is local urgency. Much of Hawaiʻi's energy and fuel infrastructure is old, inefficient, and in need of replacement. Now is the time to assess the most appropriate, resilient, and cost-effective replacements. While Hawaiʻi has limited manufacturing and production resources, Hawaiʻi does have an abundance of indigenous sources of energy that can be captured for decades once the infrastructure is in place.

It is important to note that the status quo leaves people vulnerable to criteria air pollutants, most notably diesel particulate matter.[14] While Hawaiʻi in general has very good air quality due to persistent trade winds, there are localized air pollutants associated with the combustion of fossil fuels, areas of particular concern include localized pollutants near industrial areas, as well as areas near major transportation corridors. The US EPA EJScreen viewer shows some areas of Oʻahu fall above the 90th and 95th percentile compared to national levels, demonstrating localized criteria pollutants.

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[14] U.S. Environmental Protection Agency (EPA), 2023. Environmental Justice and Mapping Tool (Version 2.2).

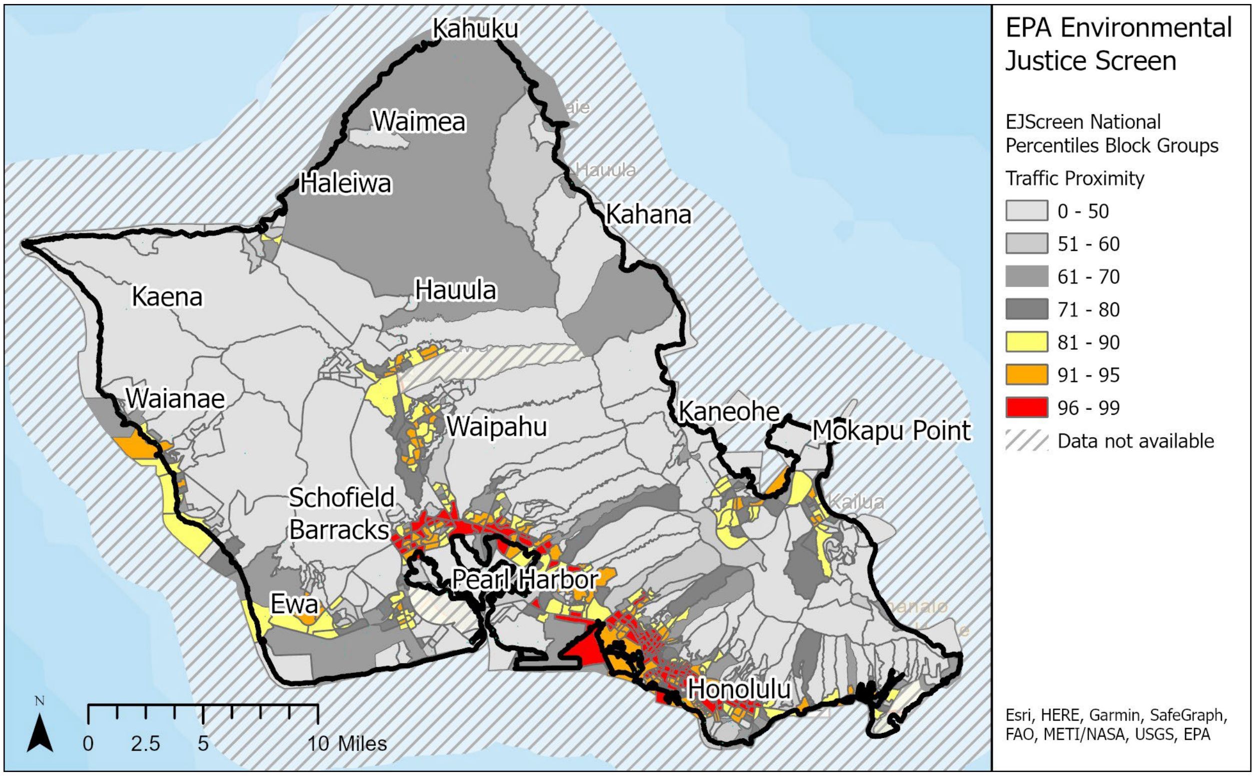

Figure 4 EJScreen traffic proximity. National percentiles for O'ahu. https://ejscreen.epa.gov/mapper/

Intergenerational Equity

Intergenerational equity is the concept that fairness and equality should exist between different generations in terms of access to resources, opportunities, and a sustainable future. The Hawaiʻi State Constitution states "*For the benefit of present and future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the State. All public natural resources are held in trust by the State for the benefit of the people*" (Article XI Section I, Hawaiʻi State Constitution). The concept of intergenerational equity is embedded in the Hawaiʻi State Constitution, which acknowledges the intergenerational impacts of decisions made by current generations can have lasting impacts on the well-being and opportunities of future generations.

The following components of intergenerational equity are most applicable to decarbonization:

1. Sustainability and Development: Generational equity encourages a balanced approach to development that meets the needs of the present without compromising the ability of future generations to meet their own needs. An example of this is ensuring development

does not lock in future generations to transportation methods that have extensive GHG impacts and increasing costs.

2. Environmental Stewardship: This involves making choices that protect and preserve natural resources and ecosystems for the benefit of present and future generations. Ensuring generational equity in environmental stewardship means considering the long-term consequences of actions taken today, such as reducing greenhouse gas emissions to mitigate climate change or preventing the depletion of finite resources – noting that this can be contradictory.
3. Long-Term Planning: Generational equity encourages long-term thinking and planning in decision-making processes. This means looking beyond short-term gains and considering the long-range impacts of policies and actions on future generations.

In 2018, Life of the Land (LOL) formally filed a complaint against regulated respondents including Hawaiian Electric and subsidiaries as well as Hawaiʻi Gas, on the basis that the respondents violated their constitutionally protected right of intergenerational equity, established by Article XI, of the State Constitution.[15] In the complaint, LOL requested that "*Each respondent must submit a plan to reduce their system-wide lifecycle greenhouse gas emissions by fifty percent within ten years. The Commission must ensure that the commitments are achieved. All projects submitted to the Commission for approval must include their lifecycle greenhouse gas emissions. Consideration of the greenhouse gas emissions ("emissions") must be of paramount importance.*" The PUC determined if the formal complaint complied with Hawaiʻi Administrative Rules (HAR) 6-61-67 and never issued an order requiring a response to the complaint. To date, the respondents, including Hawaiian Electric and Hawaiʻi Gas do not report their system-wide lifecycle GHG emissions to the PUC; instead, GHG reporting is based on direct (or tailpipe) emissions from sources that supply electricity to the service territory grids.[16] Requiring reporting of the lifecycle emissions of system-wide operations could substantially reduce the risk of resource shuffling and GHG emission leakage by regulated utilities. Resource shuffling occurs when GHG emissions are placed outside the boundary of what is accounted for further discusses appropriate GHG accounting for system-wide emissions.

A 2022 complaint cited intergenerational equity concerns driven by youth's and future generations' explicit right to future public trust resources that are directly threatened by GHG emissions. A youth plaintiffs' complaint against the State of Hawaiʻi purporting to violation of Hawaiʻi constitutional mandates to protect public trust resources and the environment"[17]

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[15] PUC Docket 2018-0406, Life of the Land's Greenhouse Gas Complaint, Re Intergenerational Equity Affidavits & Certificate of Service. Filed December 13, 2018.

[16] Hawaiian Electric Companies (2023), Performance Based Regulation (PBR) Scorecards and Metrics. GHG Reduction

[17] HRS §26-19 Department of Transportation. "*The department shall establish, maintain, and operate transportation facilities of the State, including highways, airports, harbors, and such other transportation facilities and activities as*

underscores the risks of costly litigation when there is a public perception of inaction on carbon mitigation efforts, whether merited or not.

To successfully implement action, executive branch agencies should have the appropriate policy frameworks in place to dedicate adequate resources to address climate challenges written in their guiding statutes. For example, the PUC’s responsibilities are established in HRS §269. HRS §269-6 (General Powers and Duties) explicitly requires the PUC to “explicitly consider, quantitatively or qualitatively, the effect of the State’s reliance on fossils fuels on (1) price volatility; (2) export of funds for fuel imports; (3) fuel supply reliability risk; and (4) greenhouse gas emissions.[18] Similar requirements requiring decisions to evaluate Hawaiʻi agency actions on GHGs could apply to agencies that have both direct and indirect impacts on GHG emissions, such as the Hawaiʻi Department of Transportation (HDOT), the Hawaiʻi Department of Taxation (DOTAX), the Hawaiʻi Department of Accounting and General Services (DAGS), the Hawaiʻi Department of Education (HDOE), the Hawaiʻi Department of Agriculture (HDOA), the Hawaiʻi Department of Hawaiian Home Lands (DHHL), and the Hawaiʻi Department of Land and Natural Resources (DLNR).

1.3. Equity & Transition Costs

Decarbonization of Hawaiʻi’s economy will inherently require significant investments; however, there are also significant costs of inaction, both direct and indirect. It is essential to emphasize fairness in determining the current financial burden of decarbonization.

Energy Sector

For the energy sector in Hawaiʻi, the continued reliance on the highest tier of price volatile petroleum-based fossil fuels exposes those with the greatest energy cost burdens (e.g. LMI and ALICE community members) to extreme price volatility. For these communities, the apparent tolerance of the status quo is an unacceptable risk. Direct costs of inaction include price volatility associated with the geopolitical events and natural disasters, costs of inefficient energy generating facilities and maintaining those that are past their useful life, and the economic and social distress associated with bearing those costs.

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may be authorized by law. The department shall plan, develop, promote, and coordinate various transportation systems management programs that shall include, but not be limited to, alternate work and school hours programs, bicycling programs, and ridesharing programs. The department shall develop and promote ridesharing programs which shall include but not be limited to, carpool and vanpool programs, and may assist organizations interested in promoting similar programs, arrange for contracts with private organizations to manage and operate these programs, and assist in the formulation of ridesharing arrangements. Ridesharing programs include informal arrangements in which two or more persons ride together in a motor vehicle.

[18] Hawaiʻi Revised Statutes §269-6

In answering the question about how to mitigate any impacts to these communities and to facilitate a just transition to a decarbonized economy, it is important to establish a baseline of all segments of the population relative to their share of costs and benefits. Critical questions are who are paying a fair share of total costs associated with energy and who are paying beyond their fair share or burdened by the costs of the transition, especially if those community members are not receiving the full benefit. As an example, the adoption of renewable energy has been successfully encouraged through the state's Renewable Energy Technologies Investment Tax Credit (RETITC), which offsets a portion of the up-front costs of the initial investment. The RETITC has been an important incentive in the adoption of solar technologies and building the portfolio of renewable generation; however, the benefit of the tax credit has historically benefitted higher income groups, which have led to criticism by some that it has been a regressive tax policy Figure 5. Since its adoption, the RETITC has largely been claimed by high-earning households versus households with lower incomes as seen in Figures 5 and 6.

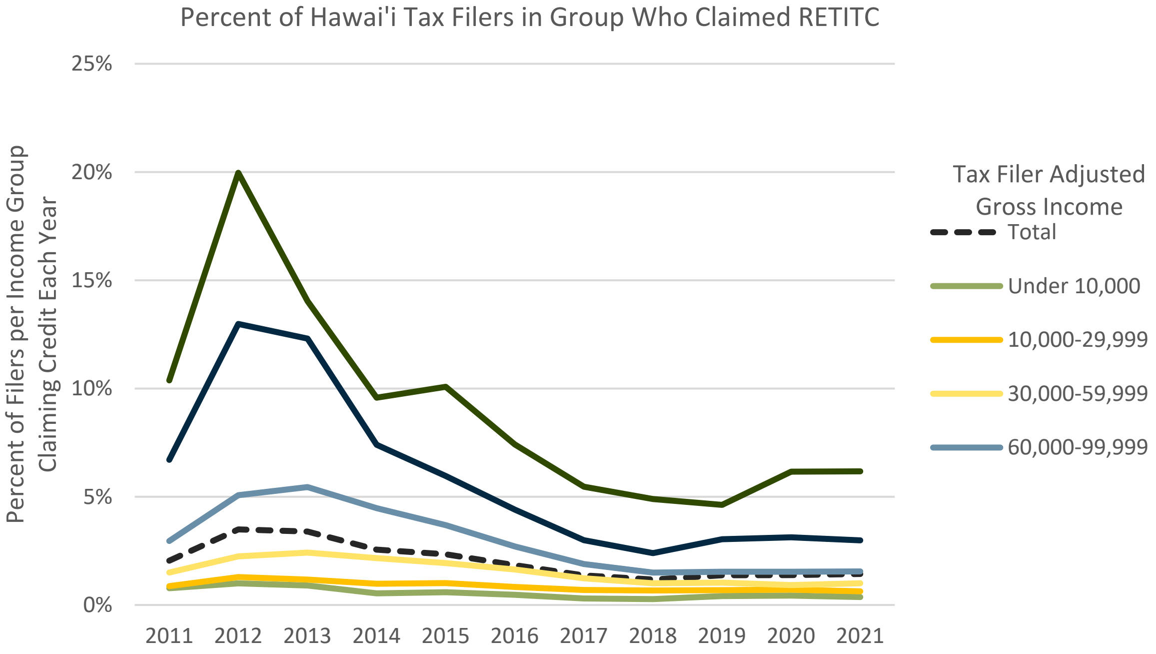

Figure 5 Percent of Tax Filers Claiming RETITC Source: Tax Credits Claimed by Hawai'i Taxpayers, Department of Taxation, See Footnote for estimation techniques used.

After balancing for the additional tax revenues high earners pay in taxes, the benefits of the tax credit still accrue disproportionately toward higher-earning *households group,* Figure 6.

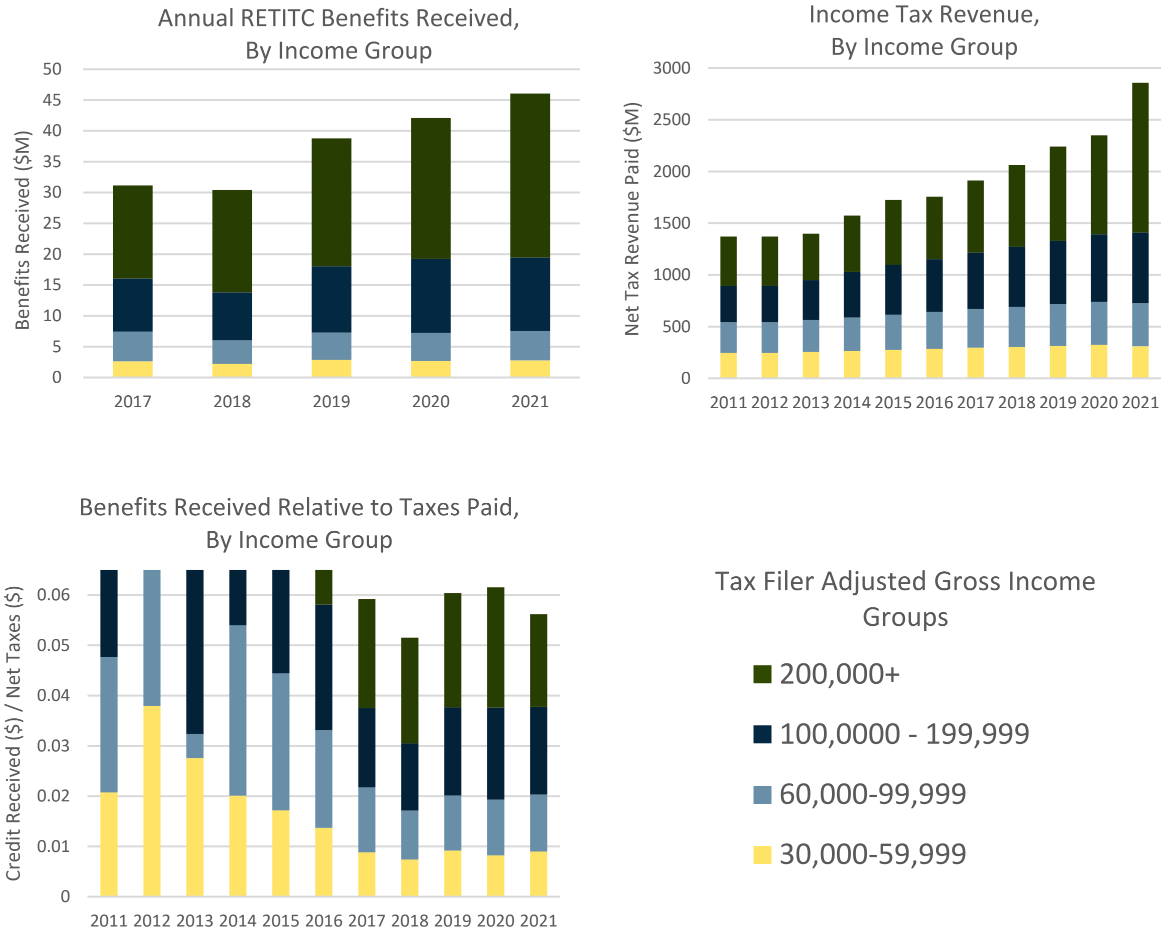

Figure 6 Renewable Energy Credit Benefits Received by gross income groups.[19]

Distinct from the RETITC is the Public Benefits Fee (PBF) established by HRS §269-121. The law authorizes the PUC, by order or rule, to require that all or a portion of the demand-side management surcharge imposed on electric utility ratepayers and collected by Hawaiʻi's electric utilities be transferred to a third-party administrator contracted by the public utilities commission. The PBFs that are collected shall be used to support clean energy technology, demand response technology, and energy use reduction, and demand-side management

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[19] State of Hawai'i, Department of Taxation. 2022 *Tax Credits Claimed by Hawaiʻi Taxpayers | Department of Taxation*

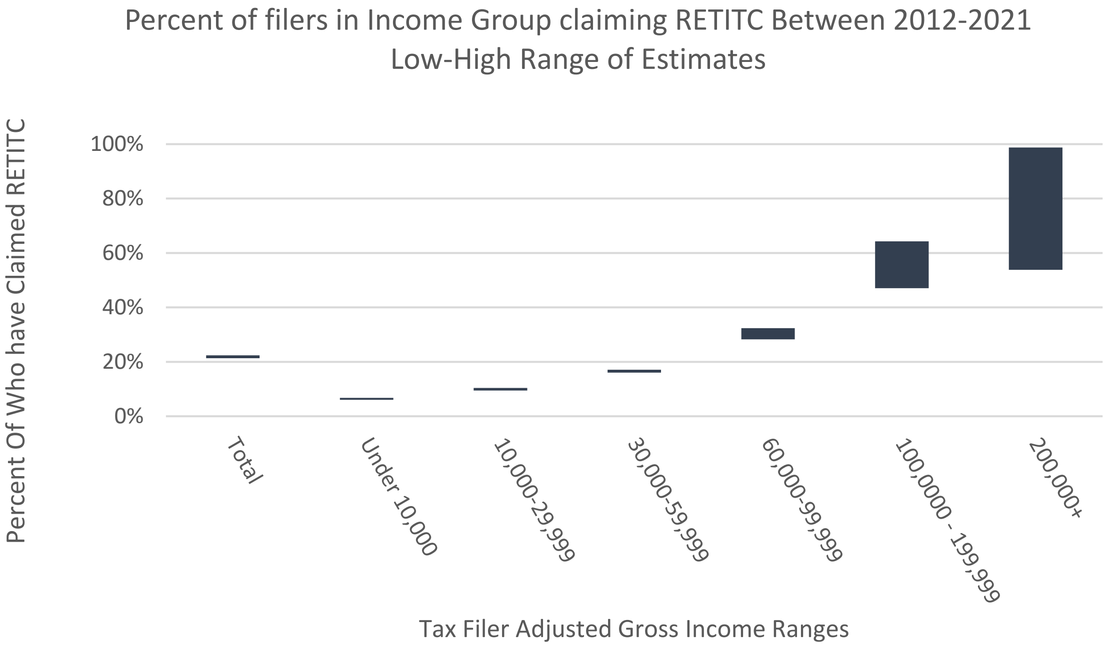

Figure 7 Percent of Filers who have claimed the RETITC. Graphs show range between 2012-2021 (Source: Tax Credits Claimed by Hawai'i Taxpayers | Department of Taxation). Due to individuals moving towards higher brackets from 2012-2021, estimation was done using three methods: 1) Accumulating Percentages from Figure 1, 2, the total who had claimed in the bracket each year divided by the total number of people in the bracket in 2021, & Figure 3, the total who had claimed in the bracket each year adjusted for the change in bracket size each year, divided by the total population in the bracket in 2021.

infrastructure, programs, and services, subject to the review and approval of the PUC. "Clean energy technology" under the PBF statute means any commercially available technology that enables the State to meet the renewable portfolio standards (RPS), established pursuant to section 269-92, or the energy-efficiency portfolio standards (EEPS), established pursuant to section 269-96, and approved by the public utilities commission by rule or order. Accordingly, it is reasonable to consider the PBF as a potent funding source for decarbonization that can be achieved by means of clean energy technologies in pursuit of RPS or EEPS targets. HRS §269-122 further authorizes the PUC to contract with a third-party administrator to operate and manage any programs established under section 269-121.

Unlike the RETITC, the incentives or rebates to offset initial capital investments and the adoption of new energy-efficient technology through the PBF administrator (PBFA) may have a wide range of benefactors and are not subject to whether the energy consumer has state tax liability. To date, however, the PBFA only serves customers in the Hawaiian Electric service territory. The PBFA has provided instant rebates for LED lighting, for example, from retailers such as Ace Hardware, City Mill, Costco, Home Depot, Lowes, Target, True Value Hardware, and Walmart that are available to all customers. Rebates are also available for energy efficient appliances that are only available to residential electric utility ratepayers on Hawaiʻi Island, Lānaʻi, Maui, Molokaʻi and Oʻahu. Under HRS 269-125, the PUC established on-bill financing program for ratepayers subject to the PBF that permits customers to acquire an allowable renewable energy system or energy-efficient device to be billed and paid through an assessment on the electric utility company customer's electricity bill. On-bill financing provides greater access to energy efficiency and renewable energy subject to underserved markets. The PUC provides guidance to the PBFA on the levels of service intended for underserved markets. Currently, such programs for hard-to-reach businesses and residences served by the PBFA account for approximately 30% of all program funds.[20] Another equity consideration of the PBF has been the method in which the surcharge is imposed as a per kilowatt-hour fee on each electricity customer's bill. The Residential PBF Surcharge for the 2020-21 Program Year was 0.5882 cents per kilowatt-hour (kWh) and the commercial and industrial ("C&I") PBF surcharge for the 2020-21 Program Year was 0.3441 cents per kWh. The total PBF Surcharge amount of $44,496,000 for the Program was allocated 45% to residential demand side management (DSM) programs, and 55% to C&I DSM programs. There has been some concern that ratepayers who have installed distributed or rooftop solar and have greatly reduced their electricity bills, particularly early adopters (i.e. NEM customers) contribute substantially less or nothing to the PBF relative to other ratepayers.23 Yet, all are eligible for PBFA programs that encourage lower energy use. Hawaiian Electric and other key stakeholders have been engaged in a Technical Advisory Group and proposals to equitably reshape how the PBF is paid have included a flat fee and a hybrid of a flat fee and per kWh fee.[24]

To date, both the PBF and the RETITC have played significant roles in incentivizing energy-efficient technologies and renewable energy. As Hawaiʻi continues to decarbonize, a more equitable allocation of financial incentives will require a clearer understanding of those who have been underserved thus far and methodology to ensure a more equitable allocation in the future. Without participation from everyone, the goals will be extremely difficult if not impossible to achieve given the adoption rates of energy efficiency and demand reduction assumed in all mitigation scenarios contemplated in Chapter 4.

Financial Assistance Programs in Hawai'i

The 2022 closure of the last coal plant revealed a need to provide a safety net to LMI and ALICE families and businesses during times of major transition when there are substantial cost increases over a short time frame and high-cost uncertainty. When prices rise, there must be robust and accessible safety net in place for residents and businesses who cannot easily absorb increased electricity costs that may (or may not) occur in the short term, as facilities face closure. Programs such as LIHEAP[21] and payment plan options are existing programs to provide this safety net.

LIHEAP is an initiative providing a one-time allocation that is applied as credit towards electric bills for qualifying low-income households. Recipients of LIHEAP credit on Rate Schedule R are automatically enrolled in the Tier Waiver Provision program for 12 months, offering the lowest

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[20] Data courtesy of Hawaiʻi Energy. (2023)

[21] State of Hawai'i Department of Human Services, Benefit, Employment & Support Services. Low Income Home Energy Assistance Program (LIHEAP)

tiered rate on the non-fuel energy charge of their electric bill. HECO enrolls customers in the tier-waiver program, that offers an energy credit of 0 ¢/kWh for the first 350 kWh per month, -1.15 ¢/kWh for the next 850 kWh per month, and -3.03 ¢/kWh for all kWh above 1200 kWh per month.

Examples from other jurisdictions

Other jurisdictions in the country are evaluating income-based rate structures, applied to certain fixed charges, to address energy burden more holistically for income qualifying ratepayers.[22],[23] An evaluation of dynamic income-based graduated rates would be best discussed within the Energy Equity Docket. The rate design would ultimately be the responsibility of the PUC.

Notably the financial assistance programs offered by Hawaiian Electric (Hawai'i's investor-owned utility) are very small compared to California's CARE program ($2bn/year), which provides a 30-35% discount on electric bills. Additionally, California's income-graduated fixed charge proceeding, explained in the sections below, could lead to even greater bill reductions for low-income customers.

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[22] California Public Utilities Commission. Demand Flexibility Rulemaking R.22-07-005. 2023.

[23] Lazenby, R. (August 2023), Legal Planet - Berkeley Law and UCLA Law. Income-Based Electric Bills: Fact and Fiction.

Levelized Costs

Fortunately, for the electricity sector, most of the major remaining fossil fuel generating plants exhibit levelized costs substantially *higher* than the levelized cost of renewable intermittent energy sources.[24] However, for certain high-capacity-factor resources generation costs tend to be more costly.

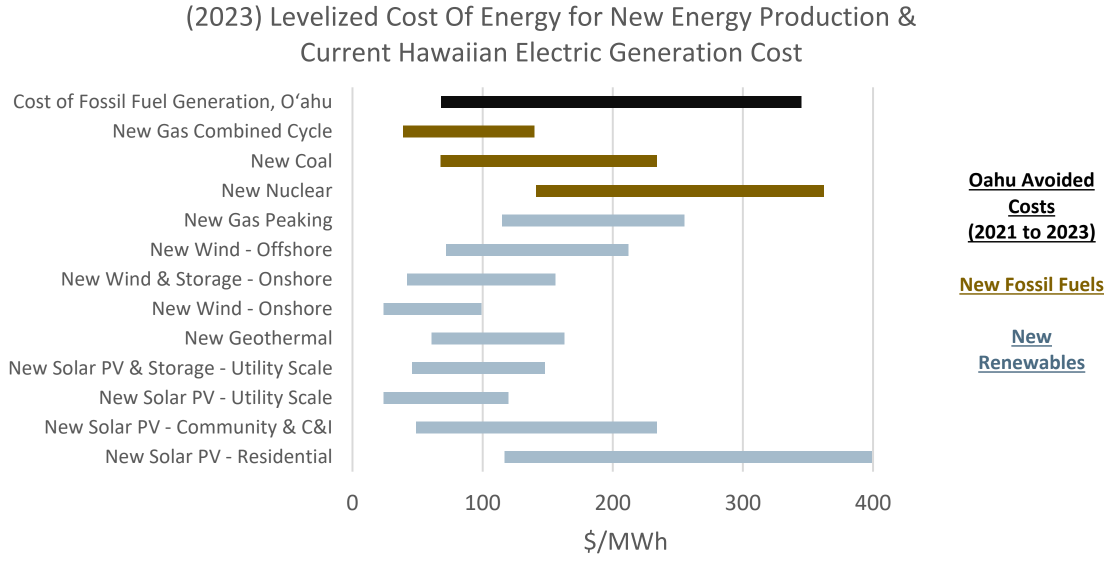

Figure 8 Levelized cost of energy for new energy production, in dollars per MWh. Data sources: Lazard LCOE and Hawaiian Electric Avoided Costs of Energy Reports.[25, 26]

Given that utility scale solar and storage has the lowest costs, prioritizing these projects in the near term can result in lower electric bills and stabilized costs, benefitting all residents, but giving the greatest benefit to those with the highest energy burdens.

Stakeholder feedback indicated that energy affordability is a major concern and a vital consideration for environmental justice in comparison to air quality and other metrics. The modeling framework (both PATHWAYS and Engage), presented in Chapter 4, is focused on total costs rather than the distribution of costs among different customer groups. Chapter 1 narrative provides a discussion of energy affordability in the context of decarbonization. Future analysis could take rate forecasts of annual generation costs from Engage and conduct detailed revenue requirement modeling to understand the quantitative impacts of customer affordability.

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[24] Levelized Cost of Energy Analysis, Lazard (2023)

[25] Hawaiian Electric Avoided Energy Costs (2023)

[26] Levelized Cost of Energy Analysis, Lazard (2023)

In this qualitative analysis, in-house previous work in decarbonization affordability is leveraged to outline key areas of concern for environmental justice communities and make recommendations for how these impacts can be avoided. This narrative also discusses a review of several regulatory actions and rate changes relevant to affordability for environmental justice communities.

1.4. Carbon Pricing

As a complement to directed regulatory and programmatic actions (Chapters 2-4), carbon pricing policy is a means to change the behavior of residents, businesses, and visitors towards reducing emissions through less consumption of GHG-polluting goods and services and demand side management. A carbon pricing mechanism works by estimating a cost that captures the external costs of emitting carbon, such as loss of property due to sea level rise, loss to crop yields, and increased damages from climatological events. The cost is then placed or imposed at the source, those responsible for emitting.[27] Referred to as the social cost of carbon (SCC), the additional cost represents the economic damage of emitting one additional ton of CO_2[28] and is meant to serve as a price signal for GHG emissions reduction. In short, carbon pricing creates a market-based financial case for shifting investments away from high-emission fossil fuels towards cleaner technologies and approaches.

Carbon pricing aims to disincentivize further use of carbon-intensive goods and make substitutes more price-competitive, persuading all players in the economy to decarbonize using financial incentives.[29] When applied in the correct context, carbon pricing exhibits a low administrative burden, whereas regulating every individual and business can be cumbersome and less adaptable to economic and social dynamics. Additionally, for certain sectors such as transportation, regulatory authority at the state level is limited by federal preemption (Section 2.3 Transportation). As a result, alternative actions can be limited to often expensive incentives (e.g. rebates and tax credits) and often regressive disincentives (e.g. parking fees, and road usage charges based on mileage), etc.

Types of Carbon Pricing

1. Carbon Tax and Dividend are taxes generally applied to the carbon content of fossil fuels combined with a dividend payment to residents. When applied "upstream", as fossil fuels enter the market, carbon taxes are dispersed economy wide. The carbon tax increases the costs of goods and services based on their lifecycle carbon emissions, influencing the

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[27] About Carbon Pricing. United Nations Climate Change. Collaborative Instruments for Ambitious Climate Action (CiACA) (n.d.).

[28] Coffman, M., Bernstein, P., Hayashida, S., Schjervheim, M., & La Croix, S. (2021). Carbon Pricing Assessment for Hawaiʻi: Economic and Greenhouse Gas Impacts. Prepared for the Hawaiʻi State Energy Office.

[29] World Bank Group. (2021). What is Carbon Pricing? Carbon Pricing Dashboard.

decisions of both consumers and businesses in the economy.[30] Carbon taxes are often regressive and must be paired with an income distribution or dividend to offset the carbon tax burden to those most adversely affected, with a small portion of the collected money allocated to administrative costs.[31] Carbon tax burden can be measured as the percentage of a household's income that is spent on the tax. But the case for a carbon tax that has an effective dividend mechanism is that by increasing the prices of fossil fuels, carbon taxes promote switching to lower-carbon fuels in power generation and conservation in the electricity sector and shifting to cleaner vehicles in the transportation sector. Currently, Hawaiʻi places a tax on each barrel of fuel imports, and the proceeds of that tax are intended to support decarbonization activities (see HRS §243-3.5).

2. <u>Emissions Trading Systems</u> (ETS), also known as cap-and-trade, set an amount of approved carbon emissions to be allowed each year through tradeable permits issued to companies. Companies can trade these permits, creating a market incentive to reduce emissions efficiently. While carbon taxes provide cost certainty to consumers, ETS provides "quantity certainty" over the emissions permitted by regulators, for entities within the system.[32] With the cap-and-trade mechanism companies in "hard-to-abate" abate sectors may continue to emit CO_2 and pay for others to not in their stead.[33] However, ETS systems have been criticized for various reasons including their overall efficacy in reducing climate polluting emissions, the overallocation of carbon allowances, low allowance prices (not consistent with the SCC), and questions regarding the integrity of offsets, which lead to leakage and environmental justice concerns.[34] While certain ETS pitfalls can be addressed, they require extensive regulation to do so. Since ETS programs have been implemented in the California market, emissions trading has not met its early emission reduction promises and has been arguably burdensome to regulators. Further cost concerns from consumers and industry have led to conservative design choices in the California market.[35]
3. <u>Crediting Mechanisms</u> issue credits for GHG emission reduction projects or program-based activities according to an accounting protocol within a managed registry. These credits can then be sold elsewhere: statewide, nationally, or internationally.[36] One

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[30] Id

[31] Coffman et al., 2021.

[32] Id

[33] World Bank Group, 2021.

[34] Wang, A., Carpenter-Gold, D., & So, A. (2022). Key Governance Issues in California's Carbon Cap-and-Trade System. UCLA Law and California-China Climate Institute

[35] Id

[36] World Bank Group, 2021.

example of an established carbon crediting program is the Australian Carbon Credit Units Scheme (ACCU). Under the scheme, you may earn ACCUs for either emission avoidance, or capture and storage through vegetation & soil. Benefits of the program include rewarding entities acting as sinks while simultaneously encouraging abatement from polluters. However, drawbacks to carbon credits exist, including a large need for regulatory oversight, coupled with criticism of the integrity of the offsets and reduction projects.[37]

4. Results-Based Climate Finance (RBCF) offers financial incentives to demonstratable emissions reduction objectives and strategies. Only upon achieving emissions reductions are payments made available. The World Bank has identified that this works best for natural climate solutions (e.g., reforestation or afforestation projects), sustainable infrastructure paired with the closure of fossil fuels, and in conjunction with other financial programs that mobilize resources for climate action, like carbon taxes.[38] RBCF is a more common practice in developing countries, but results-based approaches can ensure that rewards are paired with verifiable outcomes.
5. Internal Carbon Pricing is generally an organization-level tool that guides internal decisions relating to climate change impacts. While not necessarily a policy lever, Internal Carbon Pricing guides many organizational decisions in terms of where and how they invest resources.[39] According to a study by McKinsey sampling 2,600 worldwide companies, 23% indicated they are using internal carbon prices with 22% more planning to do so in the next two years.[40] The study indicates an understanding of the social cost of carbon and the need to account for future implications.

Carbon Pricing in the United States

Nationally, carbon pricing has only been implemented through ETS, rather than through carbon tax programs. ETS markets require additional administrative requirements including the allocation of allowances and resources dedicated to monitoring and enforcement. Those who have implemented ETS often need to join an alliance that allows the trading of permits in a bigger market and similar carbon accounting. For example, California, Oregon, and Washington formed the regional Western Climate Initiative in 2012.

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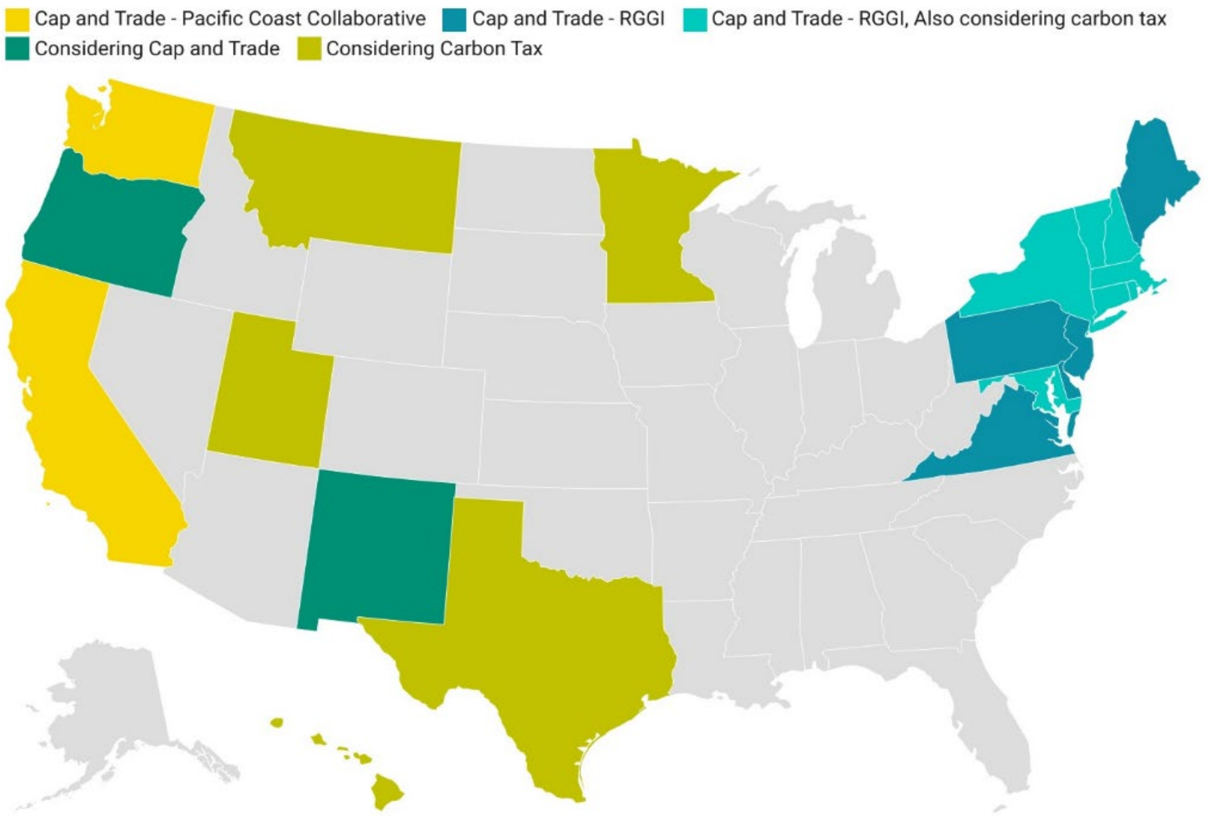
[37] About the ACCU Scheme - How Does it Work? Clean Energy Regulator Crest. (n.d.).

[38] World Bank. (2022) What You Need to Know About Results-Based Climate Finance.

[39] World Bank Group, 2021.

[40] Fan, J., Rehm, W., & Siccardo, G. (2023). How companies can use internal carbon pricing to manage transition risk. McKinsey & Company.



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Slow uptake on the carbon tax can be attributed to the difficulty in advocating for a tax coupled with the difficulty of enforcement; including when the tax is administered and how to limit tax evasion across borders. From that perspective, a carbon tax in Hawai'i may be easier to administer due to the proliferation of imported petroleum and petroleum products and the fact that a functional petroleum tax is already in place. Alternatively, an appropriately priced carbon tax at the national level could achieve the same effect through a process that would affect all citizens in a similar manner.

Figure 9 US Policies on Carbon Pricing. Data Source: Price on Carbon, 2020.

Carbon Surcharge and Dividend in Hawaiʻi

A peer-reviewed research article[41] in the journal Climate Policy discussing carbon pricing in Hawai'i was published by a team of researchers from UHERO, based on a study in 2021. This article evaluates a carbon tax or surcharge set at the federally established social cost of carbon

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[41] Coffman, M., Bernstein, P., Schjervheim, M., Croix, S. L., & Hayashida, S. (2022). Economic and GHG impacts of a US state-level carbon tax: the case of Hawaiʻi. *Climate Policy*, *22*(7), 935-949.

(SCC) ($56-$79/ton over the study timeline of 2025-2045). In comparison to the current federal and state greenhouse gas-related policies, the analysis demonstrated that if Hawaiʻi were to implement a carbon surcharge aligned with the 2021 federal SCC, the state's cumulative emissions would decrease by an additional 10% between 2025 and 2045.

The financial impacts and well-being changes among the population heavily hinge on income level and how the carbon surcharge revenues are redistributed to LMI and disadvantaged communities. Fundamental decisions would need to be made distribution options such as equal-share dividends to households or allocation to EV charging or other measures. When revenues are distributed to households, the surcharge has the potential to be progressive and can benefit the average household across all five income categories. This is primarily because visitors contribute to the carbon surcharge during their Hawaiʻi vacations, representing roughly one-third of the total revenue collected.

The increased revenue derived from the imposition of a carbon surcharge on visitors can serve to bolster financial resources dedicated to assisting low-income customers. This not only acknowledges the existing funding deficit in addressing energy affordability challenges among this demographic but also underscores the importance of facilitating access to capital to inform economically sound decisions and mitigate the externalities associated with the accelerated adoption of electric vehicles (EVs), particularly when targeting a broad consumer base.

While there are multiple systems to introduce carbon pricing into personal and business decisions discussed above, the proposal and implementation of carbon pricing as a policy in the United States has been limited to carbon taxes and ETS. In 2019, a full study on carbon pricing was commissioned by the Hawaiʻi State Legislature through UHERO[42], and in 2022, the Hawaiʻi Tax Review Commission (TRC) recommended a carbon tax be implemented in accordance with the study.[43] Due to the extensive research into the implementation of a carbon tax, the rest of this section emphasizes the impacts of a carbon surcharge with a cash dividend returned to households.

The TRC's recommendation included guidance that any carbon tax or surcharge be:

1. Levied as far upstream as possible.
2. Priced at the social cost of carbon.
3. Designed to mitigate economic impact on the state.
4. Designed primarily to disincentivize carbon-intensive activities, as opposed to raising revenue.

Under the additional guidance, the ability for a carbon surcharge to be implemented far upstream on fuels entering Hawaiʻi would limit the liability falling on a select few and limit the impacts on

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[42] Coffman et al., 2021.

[43] State of Hawaiʻi Tax Review Commission. (2022). Report of the 2020-2022 Tax Review Commission.

specific products. Historically, incentivizing decarbonization through tax credits promoting electrification was viewed as a regressive policy, favoring higher-income earners disproportionately to lower-income earners.[44, 45] However, a carbon surcharge as designed by the University of Hawaiʻi Economic Research Organization (UHERO) & TRC redistributes the revenue to households in an equal share to make such a surcharge progressive, meaning lower-income earners benefit more than higher-income earners.[46]

Local Impacts of a Carbon Surcharge

GHG Impacts

In practice, a surcharge at the federal SCC (\$56 per $MTCO_2$) would add \$0.57[47] and \$0.50[48] to a gallon of diesel and gasoline, respectively.[49] The comparatively higher fuel price would aid VMT reduction goals and encourage the growth of alternative fuels over time. Modeling from the UHERO 2021 study using a SCC equal to \$70 per $MTCO_2$ (\$2012) estimates 14% (1.5 MMT CO_2e) greater GHG reduction if implemented.[50] The same modeling also explored an alternative SCC price of \$1,000 per $MTCO_2$ which found 69% (7.7 $MMTCO_2e$) lower emissions compared to the no-action alternative in 2045.[51]

Further, these reductions are not limited to a single industry, but instead result in an economywide tendency to consume less fossil fuel. This suggests a carbon surcharge would not interfere with other efforts that encourage decarbonization, but rather complement them. One exception is the Federal Corporate Average Fuel Economy (CAFE) Standards because they are implemented as a national fleetwide average.[52]

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[44] Xing, J., Leard, B., & Li, S. (2021) What Does an Electric Vehicle Replace? (NBER Working Paper 25771). National Bureau of Economic Research.

[45] Zhou, S., Gao, X., Wellstead, A. M., & Kim, D. M. (2023). Operationalizing social equity in public policy design: A comparative analysis of solar equity policies in the United States. *Policy Studies Journal*.

[46] Coffman et al., 2021.

[47] *Assumes .01018 MTCO2 / gallon diesel, US EPA GHG Equivalencies Calculator*

[48] *Assumes .00887 MTCO2 / gallon gasoline, US EPA GHG Equivalencies Calculator*

[49] U.S. Environmental Protection Agency. (n.d.). *US EPA GHG Equivalencies Calculator* - Calculations and References.

[50] Coffman et al., 2021.

[51] Id

[52] Id

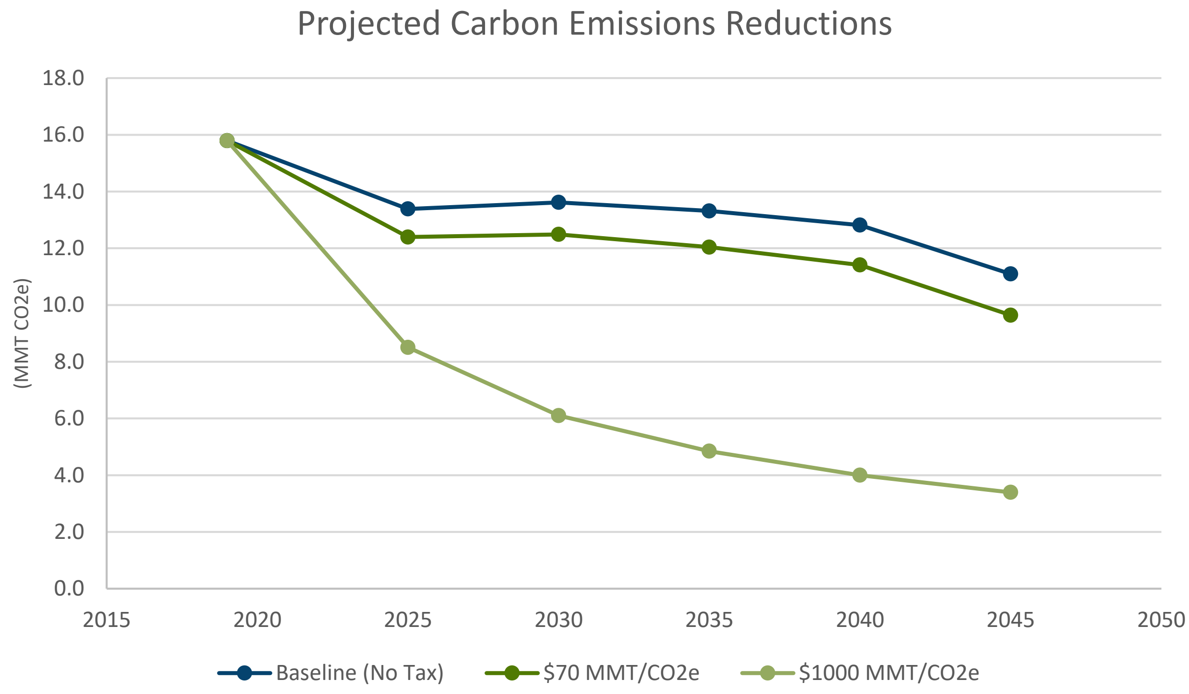

Figure 10 Projected emissions reductions from carbon tax set at various carbon prices. Significant taxes are necessary to make substantial change. Source: Coffman et al., 2021, Data courtesy of Dr. Paul Bernstein.[53]

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[53] Coffman et al., 2021., raw data courtesy of Paul Bernstein.

Revenues & Dividends

As proposed by the Hawaiʻi TRC in 2021, a carbon surcharge could be set at the federal SCC[54] at $56 per metric ton of carbon, increasing to $79 in the 20th year of implementation.[55] From the recommendation of the TRC, whereby 20% of the carbon surcharge revenue is withheld by the state and 80% is returned to households, revenues are estimated as follows:

Revenue Raised and Retained by State Government (millions)					
	Year 1	Year 2	Year 3	Year 4	Year 5
Total Revenue Raised	$464	$472	$480	$488	$496
Revenue Retained by State (20%)	$92.8	$94.4	$96.0	$97.6	$99.2

Table 2 Revenue raised and revenue retained by the State of Hawaiʻi presented in 2012 dollars, based on the TRC study.

Household payments would depend on whether dividends are returned to all households or only those in the bottom 80% of earners:

Annual Cashback per Household					
Payment Redistribution:	Year 1	Year 2	Year 3	Year 4	Year 5
Equally, across all 5 income quintiles	$744	$757	$770	$783	$796
Equally, to only the bottom 4 income quintiles.	$948	$964	$980	$996	$1,009

Table 3: Estimated annual cashback per household.

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[54] Ongoing research on the Social Cost of Carbon may suggest future raises to the federal SCC.

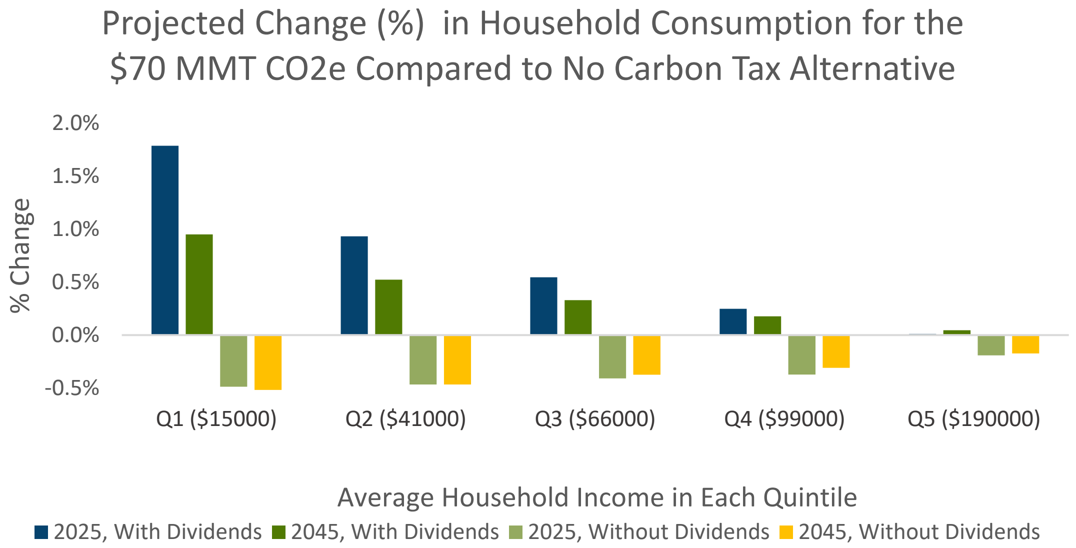
[55] State of Hawaiʻi Tax Review Commission. (2022). Report of the 2020-2022 Tax Review Commission.

Visitor Impacts

Under the carbon surcharge and dividend approach, visitors to Hawaiʻi would pay for the proportional amount of CO2 emitted from their activity in Hawaiʻi. Since they would not be eligible for a dividend, Hawaiʻi visitors and the tourism industry would subsidize the dividend for residents. Carbon cashback proponents estimate the tax would increase costs to Hawaiʻi visitors by about $1.40 per day, contributing up to 15-20% of total dividend revenues. Meanwhile, it may do very little to dampen tourism demand as Hawai'i-specific research from UHERO has found that demand for Hawaiʻi vacations is largely unresponsive to changes in air travel costs.[56]

Equity Impacts

Figure 11 Changes in consumption for various carbon tax rates & incomes. Adapted from Coffman et al., 2021.



The UHERO studies find that, on average, all but the wealthiest households would come out ahead financially, even with higher energy prices of fossil fuel products. This unlikely outcome is possible in part because of tourism: visitors would pay the carbon surcharge through their purchases of goods and services, but in general would not receive dividends. The carbon surcharge and dividend would help the lowest-income households the most because the wealthiest tend to consume the most fossil fuels directly (e.g., gasoline and electricity) and indirectly through purchases of goods and services and therefore would pay the most. Figure 11 shows that by

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[56] Fuleky, P., Zhao, Q., & Bonham, C. S. (2014). Estimating demand elasticities in non-stationary panels: The case of Hawaiʻi tourism. Annuals of Tourism Research, 44, 131–142. https://doi.org/10.1016/j.annals.2013.09.006

returning a dividend to households, it is possible to add consumption across households of all income groups.

Electric Sector Impacts

In the UHERO study, it was modeled that the decisions from Hawaiʻi's electric utilities would not add any additional price to the residential bills as future decisions will likely be guided by the overarching Renewable Portfolio Standard (RPS) instead.[57] In accordance with the RPS, the portion of electricity from petroleum will continue to decline as power plants and generating units retire or fuel switch and petroleum for electricity generation is phased out by 2045 (HRS 269-91). Until then, fuel inputs to electricity are paid by the consumer through electricity rates. In 2022, Hawaiʻi generated 61%[58] of its electricity from petroleum, using 6.6 million barrels of fuel oil and 2.7 million barrels of diesel[59], causing around 3.8 MMT CO_2e.[60] The mix of fuels and generators is constantly changing; however, based on 2022's fuel mix and emissions, the carbon surcharge set at $56 per MT CO_2e would have added approximately $202 million to total electricity costs, approximately 5.7% of total utility revenues that year.[61, 62]

Under the current regulatory framework, fuel costs and fuel cost fluctuations are passed through directly to the electricity customer through the Energy Cost Recovery Clause. If a carbon surcharge was administered in the same manner, it would be paid almost entirely by electricity ratepayers, which may dampen the desired substitution from fossil fuels to electric use. Since consumers have limited choice in the composition of electricity generation for the grid, taxing electric usage may not discourage fossil fuels, only total consumption generally. Similarly, if this cost is imposed at a per kwh rate, the growing portion of entities with customer-sited generation may not be subject to the surcharge, despite being connected to the electric grid. If instead the surcharge was not allowed to be passed through and was paid entirely by the utility, it would be greater than all total utility profits.[63, 64, 65, 66] Given that electricity bills in Hawaiʻi are the highest in the nation and are subject to high levels of price volatility due to reliance on oil, there is also potential to defray these costs with an exemption for the electric industry. This exemption may

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[57] Coffman et al., 2021.

[58] Department of Business, Economic Development & Tourism. DBEDT Data Warehouse

[59] Id

[60] Assumes .01018 $MTCO_2$ / gallon diesel & .00887 $MTCO_2$ / gallon gasoline, *US EPA GHG Equivalencies Calculator*

[61] Assumes: .01018 $MTCO_2$ / gallon diesel & .00887 $MTCO_2$ / gallon gasoline, *US EPA GHG Equivalencies Calculator*

[62] Fuel use & revenues from Department of Business, Economic Development & Tourism. DBEDT Data Warehouse

[63] *Given 2022 fuel mix usage and finances.*

[64] Hawaiian Electric Industries, Inc. (2023) HEI Reports 2022 Results

[65] KIUC (2023) Looking back, looking forward KIUC 2022 Annual Report

[66] Department of Business, Economic Development & Tourism. DBEDT Data Warehouse

further encourage electrification by making electric appliances and vehicle alternatives relatively less expensive when compared to paying additional for fossil fuel.

Alternative methods of imposing the surcharge on the electric sector would have substantial implications for the overall revenues generated, the dividends redistributed, and the level of progressivity of the surcharge. The electricity sector is one of the major users of fossil fuels, so any exemptions could dramatically impact the policy's effectiveness. While more analysis may be required to assess the optimal choice for implementing the surcharge with an exemption, a carbon surcharge minus the exemption remains the most effective option with the lowest administrative burden.

1.5. Affordability Challenges of Decarbonization

Decarbonization hinges on a transition in energy use with lower or zero carbon intensity and the adoption of new technologies that conserve energy or sequester carbon. To achieve the state's net negative target, a comprehensive transformation of the entire economy is necessary, involving substantial changes in how we produce and utilize energy. It is important to assess the implications for customer costs, including potential additional costs for purchasing new technologies. These impacts are expected to change over time as economywide transitions intensify.

Key metrics used to assess customer costs include upfront capital costs, i.e., the cost of retrofitting a building shell and purchasing new appliances to transition to efficient building cooling, lighting, and water heating systems, and electric vehicles.

Customer cost impacts of decarbonization in the energy sector fall into the following three categories: 1) Increased Electricity Rates, 2) Electric Vehicle Adoption, 3) Building Technologies.

Increased Electricity Rates

- Transmission and distribution (T&D) expansion, necessary to accommodate new resources and loads within the system, tends to result in upward pressure on electricity rates.
- Electrification and an improved load factor for some resources could also lead to downward pressure on rates in the near-term but can potentially increase rates as load growth expands due to the need to procure more power. Energy efficiency is an effective remedy.

The prospect of increasing electricity rates is closely tied to the degree of continued reliance on petroleum resources subject to oil price volatility and infrastructure investment choices to be made in the ongoing energy transition to renewable and low-carbon technologies. This pace and means of the shift in energy sources is pivotal in how well deployment aligns with the State's goal of achieving net zero. Investment will be required in new T&D resources alongside retirement and replacement of the fossil fuel fleet, whether a factor of the energy transition or whether the asset is beyond its useful and permitted life. T&D expansion enables the integration of new resources and accommodates the growing demand within the system from electrification. Depending on the choices made and the relative resource cost and the cost per kilowatt hour, energy transition impacts could have upward or downward pressure on rates. Another factor can adversely affect electricity rates are post-Maui Wildfire impacts to finance costs of future power purchase agreements and utility investments in the Hawaiian Electric service territory. It should also be noted that load growth, and particularly peak load growth due to electrification can be offset with efficiency and demand response measures.

Additionally, if the electrification transition is planned well relative to the electric system, costs for transmission and distribution upgrades can also be mitigated or reduced. The transition to zero carbon resources will put pressure on rates in both directions and can and should be properly managed to limit impacts.

Building Technologies

- Electrification of natural gas and propane appliances will lead to increased electric loads for water heating.
- Installing higher efficiency electric equipment for both cooling and water heating end uses will result in a decrease in electric load. However, the significant upfront cost presents a risk to affordability.

The transition to electrifying natural gas and propane appliances for service water heating is expected to increase electric loads. This transition, however, is expected to lead to a reduction in customer gas bills associated with water heating. Simultaneously, the installation of more efficient electric equipment for cooling and water heating can mitigate the impacts of the increased electric load due to the fuel transition.

Despite the potential benefits in terms of operational cost savings for customers due to efficient equipment, a notable challenge arises in the form of upfront cost associated with this upgrade. This financial burden, particularly pronounced for low- and moderate-income customers, poses a significant barrier to electrification adoption. Even though the shift in building technologies is conducive to lowering customer electric bills over the long term, the immediate affordability challenge requires attention to ensure equitable access and easier transition for all income groups.

Electric Vehicle Adoption

- A higher rate of EV adoption will lead to an increase in customer electricity usage, leading to an increase in customer bills, coupled with a reduction in gasoline purchases due to vehicle fuel switching.
- The upfront cost of EV, coupled with the significant cost of installing chargers will lead to additional challenges around customer affordability.

To achieve net-zero in Hawai’i, a swift transition is imperative, particularly in electrifying nearly all of transportation sector demands. This entails a simultaneous increase in electric load and a reduction in gasoline purchases, marking a fundamental shift in vehicle fuel. However, the adoption of EVs poses technological and economic challenges. These challenges range from higher upfront vehicle purchase and EV charger installation costs to the energy system level electrical grid modifications and installation of networks of public charging infrastructure.

For Low to Moderate Income (LMI) customers, these challenges are compounded, as the lack of sufficient incentives can hinder their ability to embrace electric transportation. The affordability hurdle is emphasized when considering that LMI individuals, who may lack access to home charging solutions, would need to rely on public charging stations, incurring additional expenses. Therefore, addressing the cost barriers associated with EV adoption, both in terms of upfront cost of vehicle and charging infrastructure, is important to ensure an inclusive and equitable transition to transportation electrification.

Additional Metrics

The DBEDT "Electricity Burden on Hawai'i Households" assessment,[67] released in July 2021, relies on the 2018 LEAD dataset from the Department of Energy (DOE). This assessment's objective is to scrutinize the average monthly electricity expenditures and the associated electricity burdens encountered by households on all Hawaiian Islands. This examination extends across households with diverse characteristics, structural attributes, and income levels, operating at both the county and census tract levels within the state of Hawai'i.

Crucial insights derived from this analysis encompass the following points:

- Kauaʻi County registers the most substantial electricity burden at 3.0%, followed by Hawai'i County at 2.9%, Maui County at 2.5%, and Honolulu County at 1.5%.
- On average, households residing in rental properties exhibit a higher electricity burden of 2.5% in comparison to households of homeowners, who bear a 1.6% electricity burden. Furthermore, households occupying condominiums or apartments experience a slightly greater electricity burden of 2.0% compared to those dwelling in single-family residences, where the burden stands at 1.8%.
- Households characterized as extremely low-income shoulder a notably heavier electricity burden. Those earning less than 30% of the Area Median Income (AMI) allocate a substantial 11% of their income to electricity expenses, nearly five times more than the average expenditure of households in Hawaiʻi. Notably, households falling below the Federal Poverty Level (FPL) earmark a staggering 15.2% of their income for electricity costs, a figure seven times higher than the average spending in Hawaiʻi households.
- The 2018 LEAD data discloses that only 4.8% of households residing in single-family dwellings utilize solar energy as their primary heating source, in contrast to a mere 0.6% of households in condominiums.
- While electricity costs tend to rise with increasing income levels, the electricity burdens carried by households diminish as income levels increase. Households situated below the FPL

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[67] DBEDT (2021) Electricity Burdens on Hawai'i Households

spend up to 19% of their income on electricity if they are homeowners, compared to 13.5% for renters.
- The state of Hawai'i ranks 26th nationally concerning the average electricity burden, which stands at 1.9%.

The PUC has approved two metrics[68] to gauge yearly expenses: the mean electricity costs for households and an approximation of the usual bill for average electricity usage (measured in kWh) per island. The threshold for LIHEAP eligibility for a family of four is determined as the income level equivalent to 150% of the Federal Poverty Limit (FPL) in Hawaiʻi. Changes in the energy burden for low-income households are primarily influenced by the price fluctuations of the fuel used for electricity generation. The energy cost burden for customers across all the islands has surged, reaching levels comparable to those reported in 2013-2014. Among residential customers, Hawaiʻi County has had the highest percentage of payment arrangements, followed by Oʻahu and Maui. The disconnection rates across customer classes exhibit parallel trends to the percentage payment arrangements.

Alternatives for Metrics and Tracking Energy Burden

Although it is commendable that the state is tracking these metrics, there are several issues with the metric of average energy burden. This metric falls short of capturing the specific challenges faced by individual customers. Furthermore, it does not provide insights into the primary sources of high energy consumption that disproportionately affect low-income customers when assessing the energy burden. For example, as the State experiences increased electric vehicle (EV) adoption due to heightened electrification efforts, the utility of this metric may diminish. This is because it may indicate a significant rise in electricity-related expenses while failing to account for the potential savings achieved by customers who switch to EVs, reducing their gasoline expenditure. This raises concerns about the diminishing relevance of this metric in the future.

It is recommended to assess the energy burden metrics by using representative bills instead of average bills. The newly endorsed proxies for annual expense: average electricity bills for residential customers and a typical bill for average electricity consumption (kWh) by island somewhat cohere with the suggested approach. These metrics will help provide valuable insights into historical fluctuations in customers' energy burden and aid in understanding the demographic of customers facing challenges.

Another proposal involves the creation of an affordability ratio (AR), like the one pioneered by the California Public Utility Commission (CPUC), which elucidates the influence of an essential service bill on a household's budget. This ratio will represent the percentage of income allocated to each specific essential utility service, after housing plus other essential utility services.

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[68] Hawaiian Electric (2023) Performance Scorecards and Metrics, Affordability

1.6. Workforce – The Power of People

In the decarbonization scenarios modeled in this report, the energy sector of Hawaiʻi is transformed in a matter of decades. Solar, wind, and storage are deployed at an unprecedented rate, sales of internal combustion engine vehicles are phased out and replaced with new zero emissions vehicles, buildings in the state undergo widespread retrofits with more efficient and electrified equipment, and the jet fuel needed for air travel is provided by increasing quantifies of sustainable aviation fuel (SAF). All these changes will have a profound impact on the number and types of jobs in Hawaiʻi's economy.

The transition to a decarbonized economy will provide many good careers in Hawaiʻi's electricity, transportation, and agricultural sectors through the creation of new industries and upskilling of the current workforce. Education from grade-school through high school, higher education degrees, internships, apprenticeships, and vocational trainings can prepare Hawaiʻi's youth and currently employed for careers in Hawaiʻi's decarbonization industries that allow them to live in Hawaiʻi and contribute towards the betterment of our local environment and economy.

Statewide decarbonization will provide opportunities for Hawaiʻi residents to have good careers in attractive fields such as financing, engineering, design, regulatory compliance and oversight, government, project management, legal, skilled trades, construction, infrastructure installation and maintenance, fuels production, vehicle maintenance, land management, and operations.

Hawaiʻi's unique geographic and economic profile mean that the clean energy transition and its associated jobs impacts are likely to look different in Hawaiʻi than they do for the United States as a whole. However, there are still useful findings from the national studies that can be applied to Hawaii:

For the **electricity** sector, national studies show net job increases in electricity generation because of moving from fossil fuel combustion to wind, solar, and storage resources. The shift from fossil to renewables is also true of Hawaiʻi's electricity system in the pathways scenarios modeled in this report. Furthermore, increased annual and peak electricity demand is expected to lead to more jobs upgrading and maintaining the transmission and distribution system.

As noted in the WRI report, **building** energy efficiency and electrification measures are likely to lead to a net increase of jobs, although the building energy transformation in Hawaiʻi is not as large as in other states with significantly higher fossil fuel consumption in buildings.

If current assumptions around lower maintenance and fueling jobs for electric vehicles than internal combustion engine vehicles hold true, than jobs in the **transportation** sector in Hawaiʻi may decline as electric vehicles become a larger share of the on-road population.

The lack of near to mid-term decarbonization solutions for long-haul **aviation** means there will likely be high demand for low-carbon liquid fuels to replace fossil jet fuel consumption in a decarbonized economy. These fuels could come from a mix of sources, whether imported, produced, and refined fully in Hawaiʻi, or if the feedstocks are imported and refined into final product like the fossil petroleum fuels produced by Hawai'i's refinery. Locating a larger share of the low carbon fuel supply chain in Hawaiʻi would lead to more local jobs than if the final fuels were imported, but this must be balanced against concerns around cost, land use, and other environmental impacts.

As noted by the National Academies in their study of accelerating decarbonization in the United States, "providing employment options that meet workforce needs is important in maintaining the social contract necessary for accomplishing the coming decades of transition"[69]. Despite this, more than four out of five energy sector employers surveyed in the latest USEER reported that finding qualified candidates was "somewhat difficult" or "very difficult", with the most common reason cited frequently being either a small applicant pool or lack of experience, training, or technical skills[70]. State governments can help address these challenges through policy and legislative strategies. The Regulatory Assistance Project (RAP) offers four possible legislative options to advance clean energy workforce development[71]:

- Establish a clean energy jobs task force to create an energy strategy and jobs plan focused on clean energy, energy efficiency, and electrification.
- Develop a clean jobs workforce network program to ensure that residents disproportionately impacted by climate change, with job losses due to the energy transition, and economically disadvantaged communities have access to job opportunities in growing clean energy sectors.
- Authorize grants supporting clean energy apprenticeships and pre-apprenticeships with curriculum guidelines from the US Department of Labor Registered Apprenticeship Program.
- Set utility funding targets for clean energy and electrification workforce development.

Employment Impacts of Achieving Decarbonization

Multiple recent decarbonization studies have found that achieving net-zero emissions by midcentury will lead to a net increase in energy sector jobs nationally. The Princeton Net-Zero America project found that while around 1.5% of the country's labor force is currently employed in energy supply sectors like electricity generation, transmission, and distribution, fossil fuel extraction and processing, and biofuel production, this could increase to 2-4% by 2050 across a range of net-zero scenarios[72]. While there are net job losses in the extraction, processing, and distribution of fossil fuels like coal, natural gas, and oil, these losses are more than offset by the increased jobs in clean energy sectors like solar, wind, and electricity transmission and distribution, Figure 12. Additional reports commissioned by Decarb America and World

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[69] National Academies of Sciences, Engineering, and Medicine. (2021). Accelerating decarbonization of the US energy system.

[70] United States Department of Energy (2023). United States Energy & Employment Report 2023

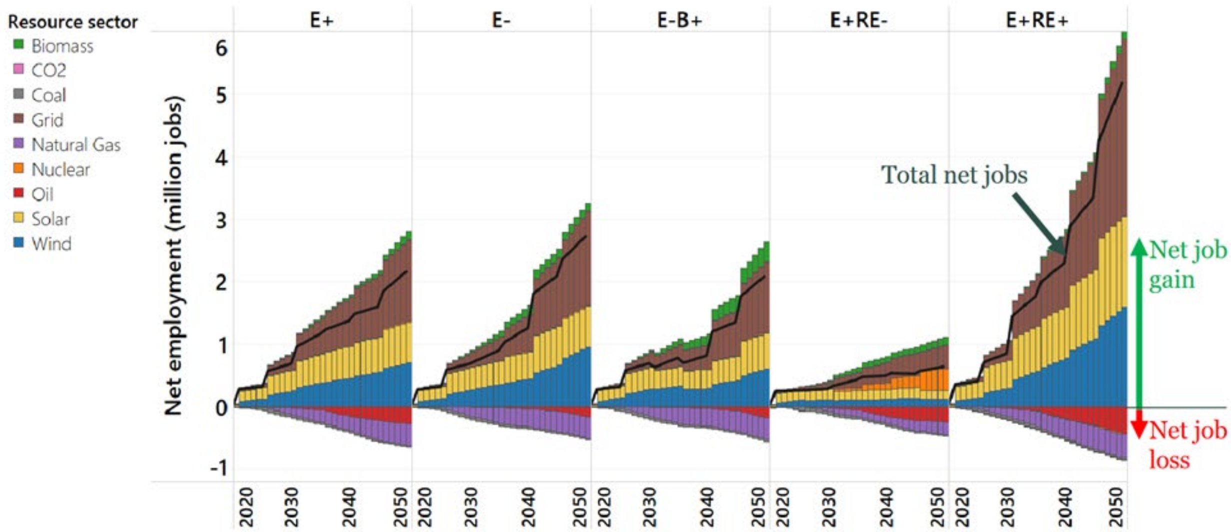
[71] Regulatory Assistance Project (RAP) Building Modernization (2023) Workforce Development to Enabling Building Modernization

[72] Larson, et al. (2020). Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Final Report Summary, Princeton University.

Resources Institute (WRI) that examined both energy supply sectors and key demand sectors like vehicles and buildings also found that economywide decarbonization would lead to a net increase in jobs for the United States[73,74].

In the WRI report, energy efficiency and electrification in buildings are the largest sources of increased jobs across the country as these are among the most labor-intensive clean energy measures. Both the Decarb America and WRI reports noted that jobs in some sectors are likely to decline. This is the case for the transition to electric vehicles, which are expected to require less labor to manufacture, assemble, and maintain than internal combustion engine vehicles. However, like the Princeton Net Zero America report, Decarb America and WRI find that job losses in traditional sectors like internal combustion engine vehicles are more than offset in aggregate by new jobs in clean energy sectors. Recent employment data from the US DOE's United States Energy & Employment Report (USEER) show that the clean energy transition is beginning to take shape across the country. Between 2021 and 2022, the number of clean energy jobs grew 3.9%, outpacing overall jobs (3.1%) and total energy sector jobs (3.8%)[75].

Figure 12 Net employment in energy supply sectors for net-zero scenarios compared to business-as-usual (Source: Larson et al. 2020)



Workforce Recomendations

Act 238 Item 7 requires HSEO to, "*Make recommendations to aid in the transition of the state workforce to meet the needs of a decarbonized economy.*" Accordingly, HSEO provides the following recommendations to the Legislature for consideration for construction and long-term

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[73] Decarb America (2022). Employment Impacts in a Decarbonized Economy

[74] World Resources Institute (2022). How a Clean Energy Economy Can Create Millions of Jobs in the US

[75] United States Department of Energy (2023). United States Energy & Employment Report 2023

employment in the clean energy sector, as well as some examples which warrant thorough public discussion and consideration:

1. Collect data on all decarbonization jobs and potential (public and private)
    a. Example: Amend the RETIC to require reporting of jobs like the Renewable Fuels Production Tax Credit (HRS §235-110.32) which requires claimants to provide HSEO, "The number of full-time and number of part-time employees of the facility and those employees' states of residency, totaled per state."
    b. Example: Leverage existing workforce data resources, e.g., the Hawai'i Clean Energy Sector Partnership recently established under Good Jobs Hawai'i, DBEDT's Research and Economic Analysis Division, University of Hawai'i organizations and community college system, Hawai'i Department of Labor and Industrial Relations (DLIR), federal organizations (US Department of Energy, NREL).
2. Support keiki to career pathway development in all decarbonization industries (from energy efficiency and generation to fuel production and movement to agriculture and carbon sequestration)
    a. Example: Support career technical education programs in government and non-government K-12 education institutions. HDOE has established Career and Technical Education pathways in Energy and Natural Resources.
3. Pursue and leverage federal workforce development funds and resources.
    a. Example: Good Jobs Hawai'i leverages federal funding to support costs for training and wrap around support costs for participants. Seeking additional funds to support the program can ensure program longevity.
4. Support government, non-government, and private workforce programs.
    a. Example: Incentivize on-the-job training, internships, and externships at private companies.
    b. Example: Support DLIR Registered Apprenticeship Program.
5. Support local workforce and prevailing wages for projects claiming state tax credits.
    a. Example: Amend the RETIC to require reporting of jobs like the Renewable Fuels Production Tax Credit (HRS §235-110.32) which requires claimants to provide HSEO, "The number of full-time and number of part-time employees of the facility and those employees' states of residency, totaled per state."
6. Support local workforce and prevailing wages for public utility procurements.
    a. Example: Incentivize use of local workforce and prevailing wages in public utility procurement.
7. Support apprenticeships, internships, externships converted to full time employees.
    a. Example: Incentivize on-the-job training, internships, externships at private companies.
    b. Example: Support DLIR Registered Apprenticeship Program.
8. Support the development of workforce development and training facilities.
    a. Example: Incentivize and/or provide regulatory relief or prioritization for new facilities and retrofitting of old facilities.

The recommendations above are largely in line with the recently published Hawaiʻi Skilled Trades Workforce Analysis (May 2023):[76]

Hawaiʻi Workforce Analysis

The SMS analysis also found solar energy and battery storage are the clean energy sectors with the highest projected workforce demand in Hawaiʻi. According to the National Renewable Energy Laboratory's Hawaiʻi's Clean Energy Jobs Potential Through 2030 projections,[77] from 2020 to 2030 the State's solar jobs must grow by at least 2,727 jobs and battery storage jobs must grow by 623 jobs to meet our 2030 energy goals.

According to the most comprehensive Hawaiʻi energy jobs report to date (USODE's US Energy & Employment Jobs Report),[78] in 2022 Hawaiʻi had 25,316 energy jobs statewide representing 4.1% of total employment. From 2021 to 2022, energy jobs in Hawaiʻi increased 856 jobs or 3.5%, of those 25,316 energy jobs 9,138 or 36% were construction jobs.

These jobs are described below:

Electric power generation (6,475 jobs)	• **2,877 construction jobs (44.4%)** • **2,246 utilities jobs (35%)**
Energy efficiency (5,517 jobs)	• 4,426 construction jobs (80%) • 766 professional services jobs (14%)
Transmission, distribution, and storage (5,430 jobs)	• 1,835 construction jobs (33.8%) • 1,107 utilities + 1,312 pipeline transport + 749 professional service jobs (58%)
Fuels (4,074 jobs)	• 0 construction jobs • 1,338 professional + 1,304 manufacturing + 735 agriculture/forestry jobs (83%)
Motor vehicles (3,821)	• 0 construction jobs • 3,130 repair and maintenance jobs (82%)

Of the 25,316 energy jobs in Hawaiʻi, 13,924 were clean energy jobs not including traditional transmission and distribution. This means *at least* 11,392 fossil fuel-related jobs would need to be replaced or trained to decarbonize Hawaiʻi's existing energy sector. It is difficult to forecast the jobs potential of total decarbonization in Hawaiʻi by 2045 given the unknowns in decarbonization pathways, mechanisms, and technologies to be deployed, policies, and other variables, e.g., timing, regulatory environment, statewide and global economy, resource

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[76] Hawaiʻi Skilled Trades Workforce Analysis (2023) SMS Hawaiʻi

[77] National Renewable Energy Laboratories (NREL) (2022) Hawaiʻi's Clean Energy Jobs Potential Through 2030.

[78] US Department of Energy (DOE) United States Energy & Employment Report (USEER) 2023.

availability. HSEO is now gathering additional data from Hawaiʻi employers to better understand Hawaiʻi's decarbonization career potential.

Decarbonization-related jobs in the energy sector have the potential to exceed the annual average wage in Hawaiʻi. In 2021, the "utilities" sector ranked as the highest annual average wage in Hawaiʻi at $108,941, which is well above the Hawaiʻi annual average wage of $59,641.[79] "Utilities" includes jobs in power generation and supply, natural gas distribution, and water, sewage, and other systems; all of which would be included or transitioned to decarbonization. In addition, jobs in the construction sector reported an annual average wage of $80,273. In contrast "Agriculture, forestry, fishing & hunting" jobs in Hawaiʻi which could include carbon sinks were on the lower end of the salary scale in Hawaiʻi in 2021 with an average annual wage of $42,629. The development and deployment of new agriculture-related decarbonization technologies could increase the average wages in this sector while creating new jobs in Hawaiʻi.

Good Jobs Hawaiʻi

A lack of quality career opportunities has caused much of Hawaiʻi's young and experienced talent to seek careers out-of-state. In response, Hawaiʻi's public and private leaders have invested in workforce development for high-demand industries including clean energy and transportation. Since January 2023, HSEO has been coordinating with local workforce development entities and employers in Hawaiʻi's energy sectors to identify priority workforce needs that can be met through the federally funded Good Jobs Hawaiʻi (GJHI). GJHI is a Statewide collaboration of over 70 employers, training providers, community-based organizations, and key stakeholders focused on developing systemic workforce solutions to ensure quality jobs in strategic economic sectors. The initiative is led by the University of Hawaiʻi Community Colleges (UHCC) and the Hawaiʻi Chamber of Commerce and is funded by various philanthropic and government partners including the US Department of Commerce - Economic Development Administration, US Department of Education, and the Hawaiʻi Workforce Funders Collaborative. GJHI is focused on developing "good" quality jobs and careers in four recession-resilient sectors in Hawaiʻi including clean energy.

Hawaiʻi Clean Energy Sector Partnership

Under GJHI, in 2023 HSEO and its partners established a new Hawaiʻi Clean Energy Sector Partnership (CESP) in May 2023 that, in addition to identifying workforce needs, will help Hawaiʻi education and workforce leaders better understand the job demand and career potential created by the shift towards decarbonization for electricity and fuel. The CESP is an industry-led group of employers, educators, and community organizations that strives to identify in-demand entry-level positions and develop career pathways for these positions, identify desired skills and training resources, provide on-the-job training, and support overall employment and career advancement. To date the CESP has identified nearly thirty (3) priority decarbonization workforce

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[79] Hawaiʻi Data Book (2021), Table 12.28 -- Employment and Wages, By NAICS Industry

development trainings and curricula, some of which are being offered or developed by UHCC and its partners.

Energy Education and Keiki-to-Career Pathways

Workforce development and education starts at a young age. Hawai'i's youth must be aware of the good careers in Hawai'i's energy fields, the required knowledge and skills to enter the workforce, and the available resources to support their career development. HSEO has been increasing its capacity for guiding Hawaiʻi's next generation of clean energy leaders by providing technical support and engagement capacity for a variety of programs. Below are collaborations HSEO has developed to leverage our resources in efforts to train and retain Hawaiʻi's clean energy workforce:

Maui Economic Development Board and HDOE. This collaboration was initiated in 2022. HSEO was tasked to develop and publish clean energy curricula and toolkits[80] to train teachers in primarily Title I K-12 schools in Hawaiʻi. The deliverables by HSEO are publicly available resources on energy self-sufficiency using localized resources for teachers, students, and families of students. These clean energy curricula and tool kits were used by 8 trainers to train approximately 150 teachers at 80 Title 1 schools to include energy learning into their curriculum and train additional teachers in the future. HDOE has reported to HSEO that the curriculum has reached over 9,500 students statewide as of the closing of the initial project period in July 2022.

HDOE Career and Technical Education (CTE)[81] Energy Pathway Advisory Council (PAC) HSEO serves as an Industry Representative on the PAC and Energy Pilot Project Team which provides a framework for incorporating career exploration into high school curricula. The Energy Pathway was developed with the support of industry, teachers, and administrative representatives and launched its pilot in the 2023-2024 school year with James Campbell High School, Kapolei High School, and Kealakehe High School. The Energy Pathway includes three Programs of Study – (1) Renewable Energy Technologies, (2) Alternative Fuels Technologies, and (3) Power Grid Technologies – each leading with a Foundations of Energy course in the first year followed by three subsequent courses. HSEO supports HDOE's CTE program by identifying industry standards and relevant certifications, curriculum development for individual teachers, coordination with employers in Hawaiʻi's energy industry to provide career exposure opportunities, and in-class on-campus engagement.

Finally, like many workforce entities in Hawaiʻi HSEO actively seeks federal funding to support a trained decarbonized workforce in Hawaiʻi; for example, the USDOE Home-Based Energy Efficiency Contractor Training Grant. Through this grant, HSEO is allocated $1,194,820 to train local energy efficiency contractor employees to ensure there is a sufficient qualified workforce to install the energy efficiency technologies available for subsidies from USDOE; specifically, the

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[80] Hawaiʻi State Energy Office 2023. Energy Education

[81] Hawaiʻi State Department of Education (2023) Career and Technical Education

$68 million in Home Efficiency Rebates and Home Electrification and Appliance Rebates[82] allocated to Hawaiʻi under the Inflation Reduction Act. In addition to training the workforce, HSEO will also be responsible for administering Hawaiʻi's rebates under these programs.

1.7. Leveraging Federal Funds to Benefit Hawaiʻi's People

The Infrastructure Investment and Jobs Act (IIJA) also known as the Bipartisan Infrastructure Law (BIL), signed into law November 2021,[83] and the Inflation Reduction Act (IRA), signed into law August 2022,[84] funds will play a crucial role in supporting Hawaiʻi's efforts to decarbonize.

The funding can generally can be broken into three categories: 1) Formula funds - funds designated to recipients (typically states, counties, and tribes) in which recipients do not compete for, but must submit applications to receive; 2) tax credits and rebate programs such as the energy Investment Tax Credit[85]; and, 3) competitive or discretionary grants (with and without cost share requirements).

Formula and Competitive Funds

While these federal investments are a game-changer – for competitive grants, competing for these funds and implementing the programs funded by the BIL and IRA during their performance period will require full understanding of the programs and substantial efforts from agencies eligible to receive the funding, as well as set up and design programs to distribute funding. Further, collaboration between agencies can strengthen applications. Executive Branch leadership must coordinate across state departments to ensure funds can adequately be dispersed across the state.

Tax Credits and Rebates

Under the Inflation Reduction Act (IRA), moderate income customers are eligible to receive substantial subsidies for electric vehicles and, if they are homeowners, heat pumps. The upfront capital costs for building appliances can be mitigated for a subset of customers through 2030 by IRA incentives for heat pump, water heater, and energy efficiency measures, bringing the upfront costs well below those for a conventional customer. However, the IRA does not provide incentives for efficient air conditioning systems, which is a key necessity for the State of Hawaiʻi, making the incentives less effective for the State.

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[82] US Department of Energy (2023) Home Energy Rebate Programs.

[83] The White House (2023) A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal and Territorial Governments, and Other Partners.

[84] The White House (2023) Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action Version 2.

[85] The White House (2023) Clean Energy Tax Provisions in the Inflation Reduction Act

Customers with battery electric vehicles are likely to spend less on fuel than a customer with a gasoline vehicle. Customers utilizing daytime home charging on TOU rates for electric vehicles can save significantly on energy cost. Post-2030, an expected expiration of these incentives will cause a jump in energy costs for this type of customer. Without the incentives, customers adopting electric vehicles face higher upfront costs than customers retaining gasoline vehicles. While the IRA offers substantial support to customers adopting electric technologies, many customers will still face upfront cost premiums that are prohibitive given their income levels or lack of access to financing. Moreover, low customer awareness of available incentives may slow the adoption of all-electric technologies.

Chapter 2. Hawaiʻi’s Carbon Economy

To examine the contribution of different carbon or greenhouse gas sources (Act 238 Item 12), data from the 2023 Department of Health Greenhouse Gas Inventory was used. This is ultimately the inventory used to determine whether the state is meeting its carbon reduction goals; however, it is important to recognize there are uncertainties in the data related to assumptions and input data availability. Further, the emissions inventory does not account for emissions from goods and services that occur outside of the state that are imported; the emissions which occur during product or material manufacturing and transportation to the state are not accounted for in the inventory Chapter 5.

The State Department of Health uses standards from the Intergovernmental Panel on Climate Change (IPCC) to provide estimation methods. The 2006 IPCC Inventory Guidelines are a nationally and internationally recognized standard accepted by the United Nations Framework Convention on Climate Change (UNFCCC) and the US Environmental Protection Agency (EPA). While these methods are standard, states can add additional metrics to better capture the unique circumstances and policy goals.

To analyze emission sources, the UN Intergovernmental Panel on Climate Change (IPCC) provides estimation methods for different economic “Sectors”. Sectors are further divided into individual categories and subcategories. However, it is important to note that estimates are as good as the granularity of input data available. Some data categories are harder to measure than others. For example, emissions from point sources such as power plants are heavily regulated, and thus tracked, whereas for transportation or agriculture sectors emissions are from nonpoint sources and therefore emissions accounting relies on standard multipliers (such as acres or population) to estimate annual emissions.

Policy recommendations to improve inventory accounting are included in the Key Recommendations list. Limitations of the current inventory accounting method are described in Chapter 5.

Table 4 Intergovernmental Panel on Climate Change (IPCC) Sectors, Categories, and Subcategories. Adapted from the IPCC Sixth Assessment Report.[86]

Sector	Categories (Hawaiʻi Specific examples)	Sub-categories (Hawaiʻi examples – not comprehensive)
Energy	1. Production / Stationary Combustion (mostly electricity) 2. Transportation 3. Waste Incineration 4. International Bunker Fuels	1a. Electric power plants 1b. Petroleum refineries (HI Inventory) 2a. Ground 2b. Marine 2c. Aviation
Industrial Processes and Product Use (IPPU) Hawaiʻi IPPU categories are few due to the lack of large industry. Categories not applicable to Hawaiʻi include – electronics, metal, chemical, and mineral industries.	1. Substitution of Ozone Depleting Substances (ODS) (Fluorinated gases) 2. Electrical Transmission and Distribution (different from combustion)	1a. Refrigeration 1b. Air Conditioning 1c. Aerosols 2a. Cement Production (mineral industries) (Hawaiʻi production ended in 2001, all cement clinker is imported)
Agriculture, Forestry, and Other Land Uses (AFOLU)	1. Land-based Agriculture (Soil Carbon) 2. Livestock 3. Forestry 4. Other Land Uses / Land Use Change	1a. Cropland – plant/nutrient management 1b. Grazing Lands 1c. Synthetic Fertilizer Application 2a. Enteric Fermentation 2b. Manure Management 3a. Deforestation 3b. Forest Management 4a. Fires
Waste	1. Landfills 2. Wastewater treatment 3. Composting	1a. Food Waste 1b. Garden Waste 1c. Paper Waste 1d. Textiles 1e. Plastics

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[86] Intergovernmental Panel on Climate Change (2006) IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1 General Guidelines and Reporting

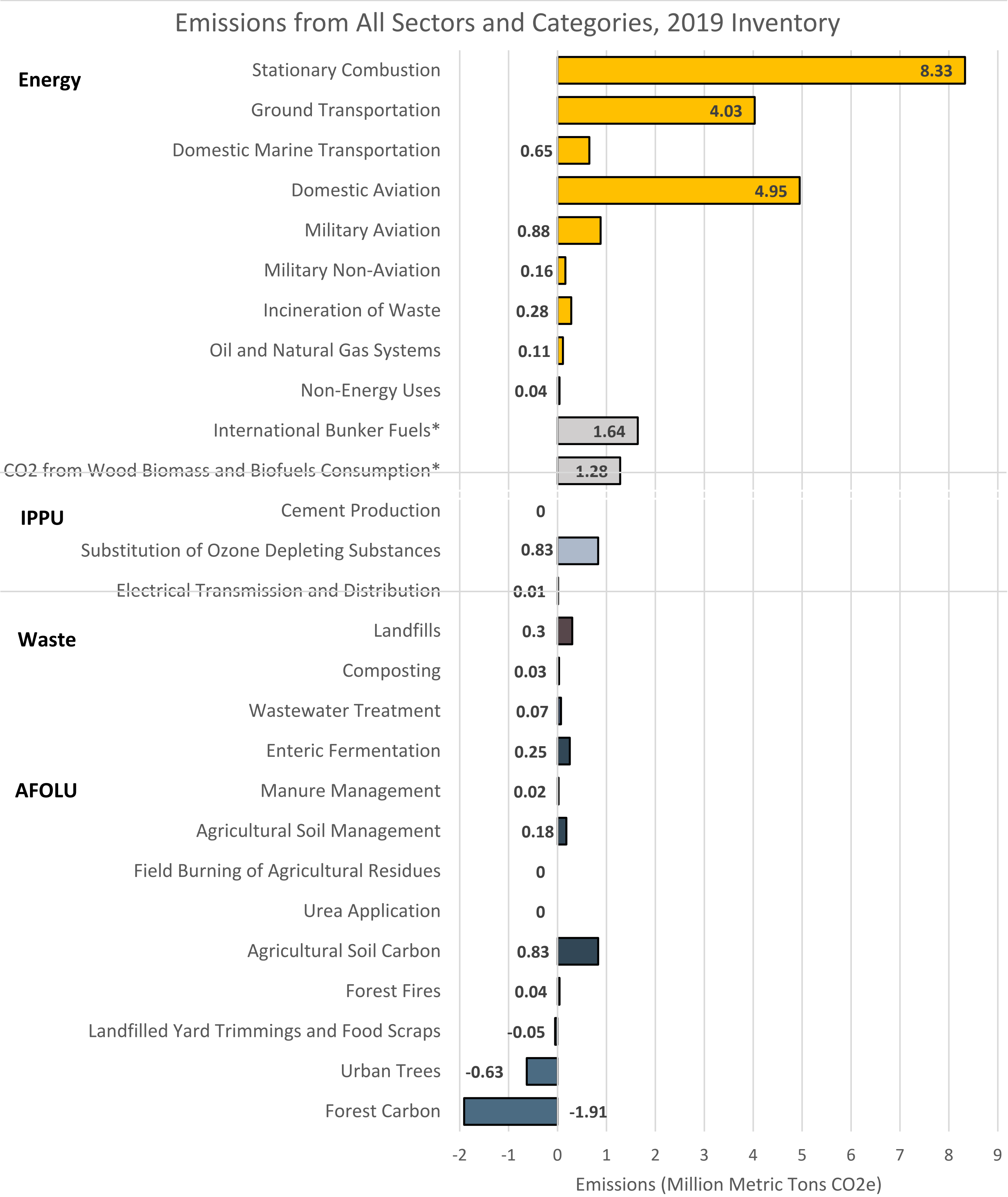

Figure 13 GHG Emissions by Sector and Category. From State Department of Health GHG Inventory.

2.1. Energy Sector Emissions

The energy sector consists of inclusive of stationary combustion (predominately for electricity generation), refining, incineration of waste (H-Power), transportation (ground, domestic marine, and domestic aviation), military aviation and military non-aviation, and non-energy use fossil fuel consumption. Non-energy use fossil fuel consumption emissions are included under the Energy sector, rather than the IPPU sector, consistent with the U.S. Inventory).[87] Emissions from non-energy uses represent a small portion (~0.2%) of total energy sector emissions. While transportation collectively (including ground, domestic aviation, and domestic marine) represents the largest single emitting category (~55%) of energy sector emissions, the single largest category remains stationary combustion as shown in Figure 13.

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[87] US Environmental Protection Agency (2022) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020. U.S. Environmental Protection Agency, EPA 430-R-22-003. "*Fossil fuels are also consumed for non-energy uses (NEU) in the United States. The fuels used for these purposes are diverse, including natural gas, hydrocarbon gas liquids (HGL), asphalt (a viscous liquid mixture of heavy crude oil distillates), petroleum coke (manufactured from heavy oil), and coal (metallurgical) coke (manufactured from coking coal). The non-energy applications of these fuels are equally diverse, including feedstocks for the manufacture of plastics, rubber, synthetic fibers, and other materials; reducing agents [to produce] various metals and inorganic products; and products such as lubricants, waxes, and asphalt... Emissions from non-energy use of lubricants, paraffin waxes, bitumen/asphalt, and solvents are reported in the Energy sector, as opposed to the Industrial Processes and Product Use (IPPU) sector, to reflect national circumstances in its choice of methodology and to increase [the] transparency of this source category's unique country-specific data sources and methodology*" (*2022 Report, Page 3-50)*

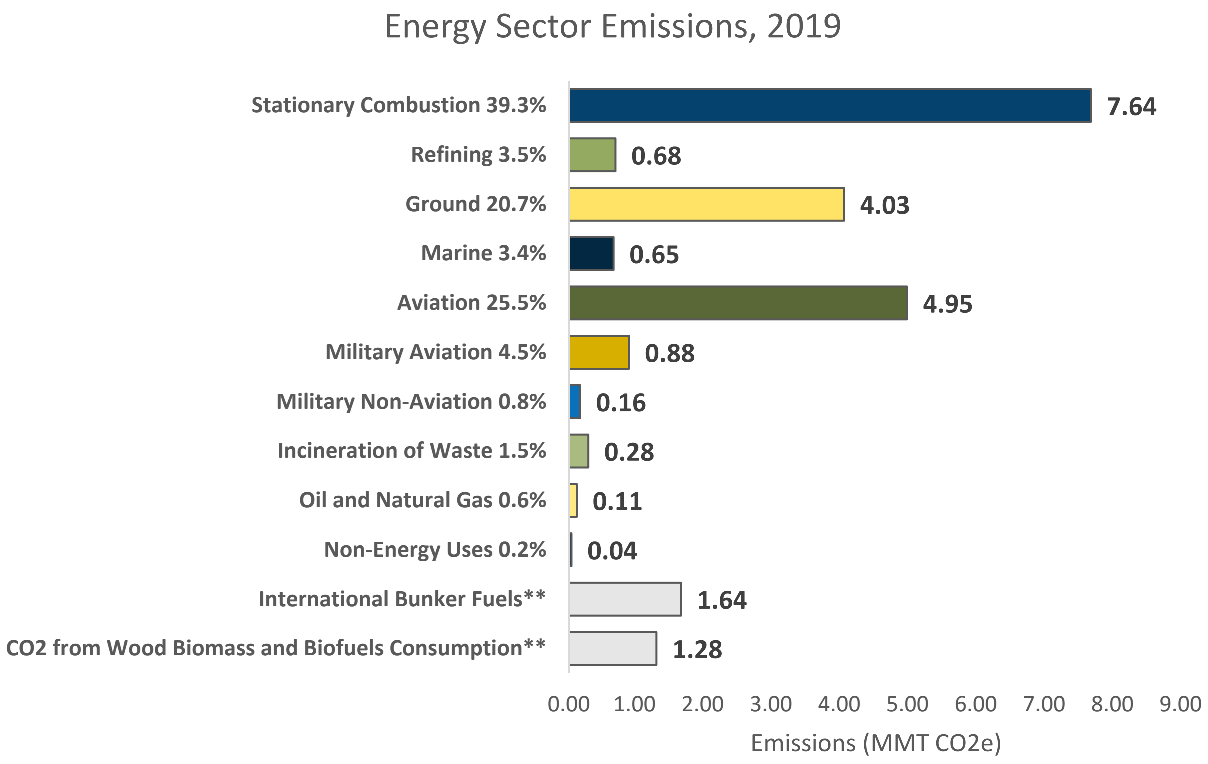

*Figure 14 Energy sector emissions from the Statewide GHG Inventory. Refinery data is separated from the stationary combustion category. The refining category includes combustion emissions from refining operations at Par West and Par East. Percentages represent the proportion of energy sector emissions. **International bunker fuels and CO_2e emissions from wood biomass and biofuels consumption are not included in totals.*

The State GHG Inventory includes combustion emissions from refining in the stationary combustion category rather than the IPPU category. For this report, emissions from the combustion of fossil fuels at refineries were separated – it is recommended future iterations of the inventory disaggregate this category to better track changes in the electricity / stationary combustion category (see Key Recommendations).

Energy Emissions Breakdown by County

Honolulu County contributes significantly more emissions from the energy sector than all other Hawaiʻi counties; however, when considering the energy emissions per person,[88] each county has an important role to play in the decarbonization effort. Further, reductions are necessary across all counties and will need to be aided by individual energy efficiency and conservation if the state is to achieve its decarbonization goals.

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[88] Per capita estimates throughout the report are based on de facto population estimates obtained from DBEDT Research and Economic Analysis Data Warehouse.

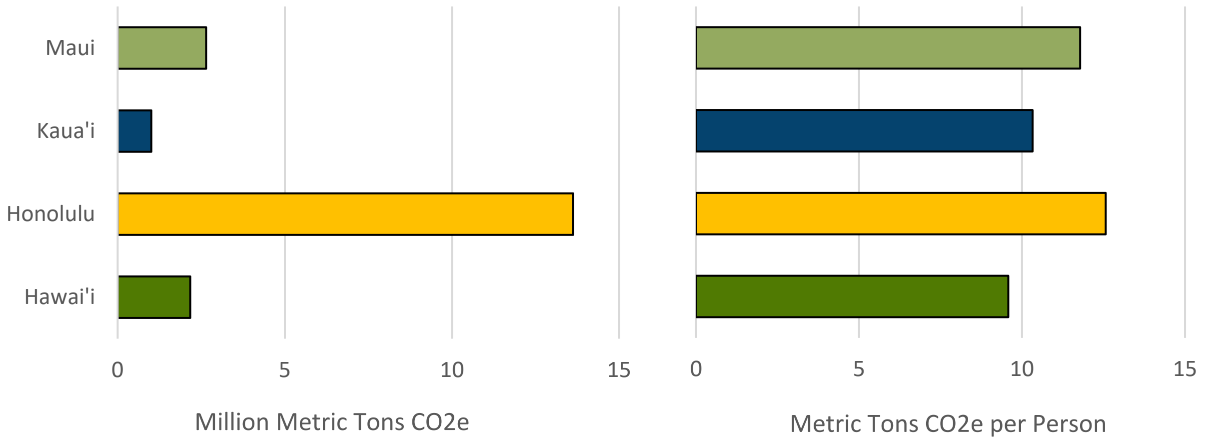

Figure 15 Total energy sector emissions (left) and energy sector emissions per capita (right) for 2019. Emissions data from the 2019 GHG inventory published 2023, and population data from DBEDT READ. Per capita figure based on de facto population.

Emission trends in the energy sector align directly with energy consumption from fossil fuel sources.

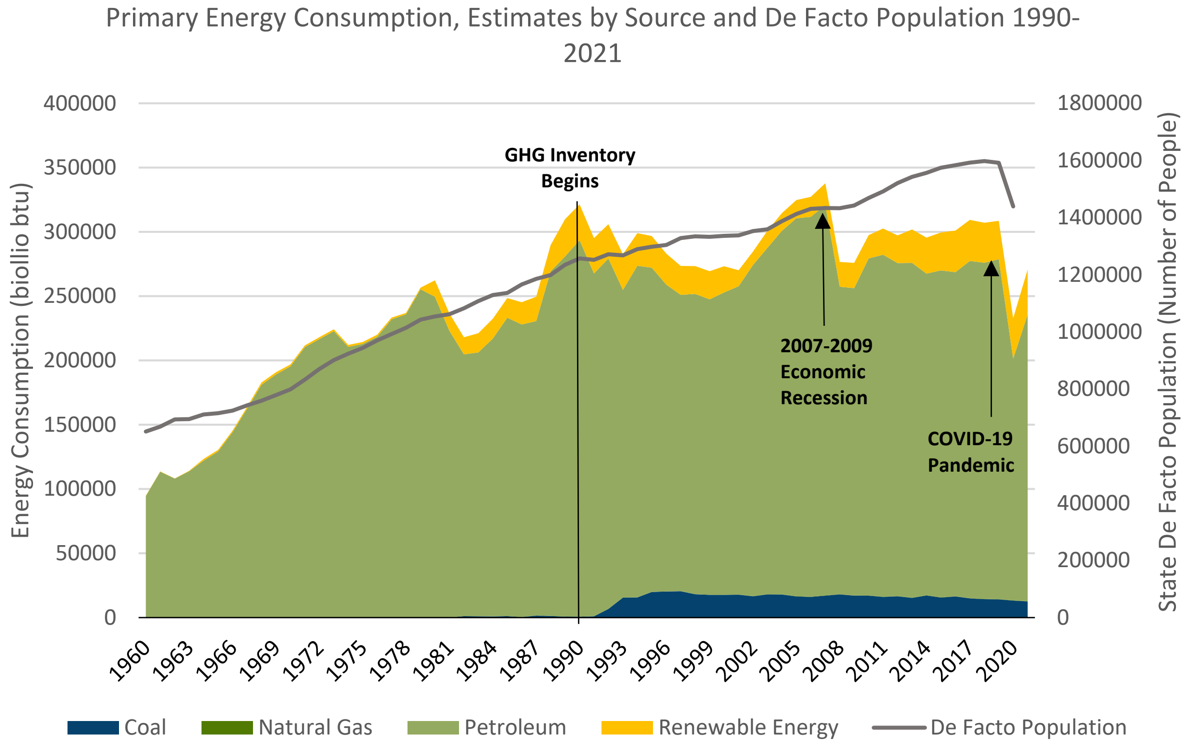

Figure 16 Primary energy consumption by resource, presented in billion btu. Petroleum liquids have dominated energy consumption for over 50 years.

2.2. Stationary Combustion

Electricity

Emissions from stationary combustion accounted for over 39% of energy sector emissions in 2019, making electricity the single largest emitting category (Figure 14). Emissions from stationary combustion have shown a declining trend since 2010 when the current methodology began tracking stationary facilities. Emissions for 2020 and 2021 have not yet been calculated for the Statewide GHG Inventory at the time of this report; however, for the purposes of this report values were pulled from individual facilities from EPA GHG Reporting Program (GHGRP).[89] Note, the GHG inventory estimates emissions from SEDS, it is recommended that future iterations of the inventory use facility level data when available.

Table 5 Shows powerplant facility level data from 2010 to 2021, Totals may not sum due to independent rounding.

		Facility GHG Emissions (MMT CO2e)											
HAR 11.60-1 Affected Facility (Currently in service)	**Island**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020 ***	**2021 ***
Kahe Generating Station	Oʻahu	2.52	2.63	2.41	2.22	2.13	2.02	2.03	2.01	2.00	1.87	1.89	1.72
Kapolei Hawaiʻi Coal Plant (retired 2022)	Oʻahu	1.53	1.68	1.82	1.69	1.77	1.64	1.93	1.47	1.29	1.31	1.19	1.07
Kalaeloa Cogeneration Plant	Oʻahu	0.95	0.99	0.91	0.96	0.92	0.95	0.85	0.86	0.88	0.9	0.79	0.84
Waiau Generating Station	Oʻahu	0.97	0.88	0.86	0.86	0.88	1.01	0.8	0.81	0.85	0.86	0.63	0.75
Maalaea Generating Station	Maui	0.56	0.55	0.52	0.49	0.46	0.49	0.48	0.48	0.47	0.49	0.38	0.43
Keahole Generating Station	Hawaiʻi	0.17	0.18	0.15	0.19	0.21	0.21	0.21	0.22	0.24	0.22	0.27	0.21
Hāmākua Energy Partners	Hawaiʻi	0.17	0.13	0.14	0.10	0.11	0.13	0.09	0.09	0.16	0.22	0.12	0.10
Kahului Generating Station	Maui	0.21	0.19	0.18	0.13	0.14	0.11	0.14	0.18	0.17	0.18	0.15	0.15
Kanoelehua Hill Generation Station	Hawaiʻi	0.2	0.19	0.17	0.17	0.17	0.18	0.23	0.18	0.16	0.18	0.18	0.15
Campbell Ind. Park Gen. Station	Oʻahu	NO	+	+	+	+	+	+	+	0.02	0.14	0.12	0.12
Kapaia Power Station	Kauaʻi	0.13	0.12	0.13	0.12	0.13	0.12	0.11	0.11	0.12	0.11	0.09	0.09
Puna Generating Station	Hawaiʻi	0.09	0.09	0.08	0.09	0.05	0.02	0.02	0.02	0.04	0.07	0.06	0.09
Port Allen Generating Station	Kauaʻi	0.15	0.15	0.14	0.14	0.13	0.12	0.08	0.08	0.08	0.05	0.03	0.03
Pālāʻau Generating Station	Molokaʻi	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Honolulu Generating Station (retired)	Oʻahu	0.12	0.10	0.05	0.06	None	None	None	None	None	None	None	None
Total		7.68	7.91	7.58	7.24	7.11	7.04	6.99	6.54	6.5	6.61	5.92	5.77

Subtotals presented in this table, which are based on GHGRP facility-level data, differ from the estimates by end-use sector presented in this inventory report, which are based largely on SEDS sector-specific fuel consumption data. The differences are a result of differences in how SEDS allocates its data by end-use sector. In addition, the

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[89] U.S. Environmental Protection Agency (2023) Office of Atmospheric Protection, Greenhouse Gas Reporting Program (GHGRP), FLIGHT.

data in this table only represent emissions from HAR 11-60.1 facilities (See GHG Inventory for further information). HSEO recommends future iterations of the GHG Inventory use facility level data when available.

**Facility level emissions data from 2020 and 2021 were pulled from the EPA GHGRP.*

Total emissions from power plants have shown a declining trend since 2010 (Figure 17). The largest power plant in the state, Kahe Power Plant, located in Nānākuli, West O‘ahu, produced the highest emissions; however, it also produced the most energy. The second largest emission source was the Kapolei coal plant "AES Hawai‘i". The coal plant retired in September 2022 and declines in emissions are anticipated because of the coal plant's retirement; however, because of the delay in renewable generation replacement projects, it is likely there will be a lag in associated GHG reductions from the coal plant's retirement due to the temporary replacement with petroleum at other plants to make up for the lost generation.

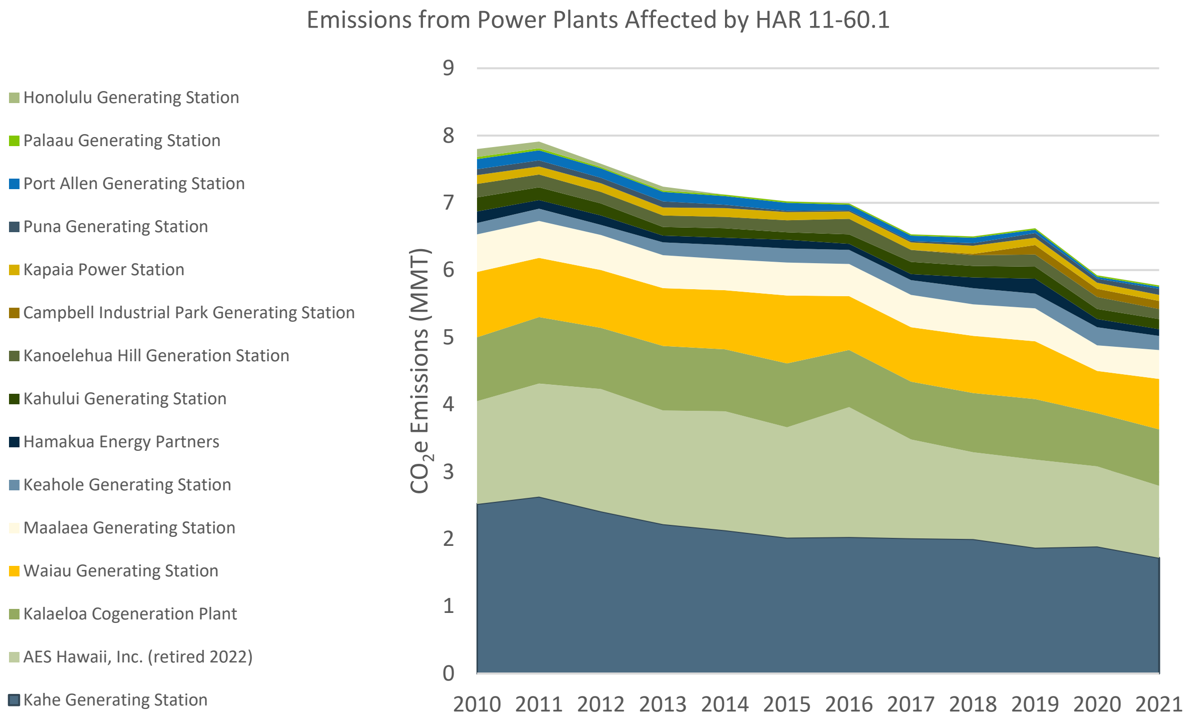

Figure 17 Emissions from regulated power plants wedge diagram (2010-2019). Does not include biofuel generation or refineries. Values are presented in Table 6.

Power Plant Emission Intensity

Emissions intensity, a measurement of emissions per unit of energy is an important metric for understanding the emission output of power plants relative to their overall energy production. Emissions intensity is used to compare emissions of power plants based on their output energy generation—like the mile per gallon (mpg) metric used for cars. Emission intensity for HAR-affected Power Plants is shown in Table 6. Values were calculated using official emissions estimates from the GHG inventory, and net generation values from EIA Form 923.[90] EPA also publishes emissions intensity for power plants nationwide in their eGRID database.[91] Incorporating an intensity measure estimate allows for a comparison of system efficiencies.

Table 6 Emission Intensities presented in kg CO_2e per kWh for HAR-affected facilities. Ordered from highest to lowest intensity based on 2019 values.

HAR Affected Facility	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HECO Campbell Industrial Park Generating Station	+	+	+	+	+	+	+	+	626.2	1371.0
MECO Kahului Generating Station	1090.3	1082.8	1065.5	1106.7	1106.2	1128.0	1128.5	1115.6	1108.3	1124.9
HELCO Puna Generating Station	1206.0	1077.9	1093.5	1069.4	1116.6	977.4	1227.7	1241.3	1102.4	1076.3
HELCO Kanaelehua Hill Generation Station	490.9	493.2	497.1	497.2	500.4	876.2	1178.6	1004.5	939.3	1035.6
Kapolei Hawaiʻi Coal Plant (retired 2022)	1012.8	1216.9	1214.3	1226.9	1192.7	1306.5	1276.1	1056.1	970.7	993.8
HECO Waiau Generating Station	853.2	852.7	828.4	832.0	845.0	851.0	874.5	891.7	863.0	855.4
HECO Kahe Generating Station	796.5	874.8	800.0	794.3	806.6	809.6	800.5	807.0	815.6	799.0
Kauai Island Utility Co. Port Allen Generating Station	746.6	770.0	755.6	755.2	757.3	833.8	745.2	744.4	739.4	734.6
HELCO Keahole Generating Station	890.6	898.2	738.3	716.4	698.3	712.4	705.1	692.1	693.2	724.6
Kalaeloa Cogeneration Plant	662.9	686.4	690.0	679.9	699.0	696.1	653.2	648.8	690.3	710.0
MECO Maalaea Generating Station	682.8	664.1	672.2	677.5	680.8	679.3	678.2	687.3	688.1	695.8
Kauai Island Utility Co. Kapaia Power Station	578.7	572.2	572.0	587.0	594.6	666.8	623.1	614.6	607.1	633.1
Hāmākua Energy Partners	580.0	588.0	604.7	562.8	579.1	590.7	660.6	618.8	589.0	559.2
MECO Pālāʻau Generating Station	741.5	745.6	744.5	752.4	755.1	747.8	752.7	750.6	757.5	378.4

The emissions intensity of power plants has remained relatively constant since 2010 for the respective power plants (Table 6).

When shown by electricity subregions (subregions are divided by Federal Energy Regulatory Commission (FERC) regions, i.e. areas that share the same grid), Oʻahu stationary combustion facilities have the highest average emissions intensity in the country when compared to other electricity subregions, and the outer islands collectively rank 8th. Emissions intensities are higher than the U.S. average; underscoring the need to retire the fossil generators in the state.

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[90] Energy Information Administration. API Browser Plant Level Annual Net Generation, 2010-2019.

[91] Environmental Protection Agency (EPA) (2023). EGRID data.

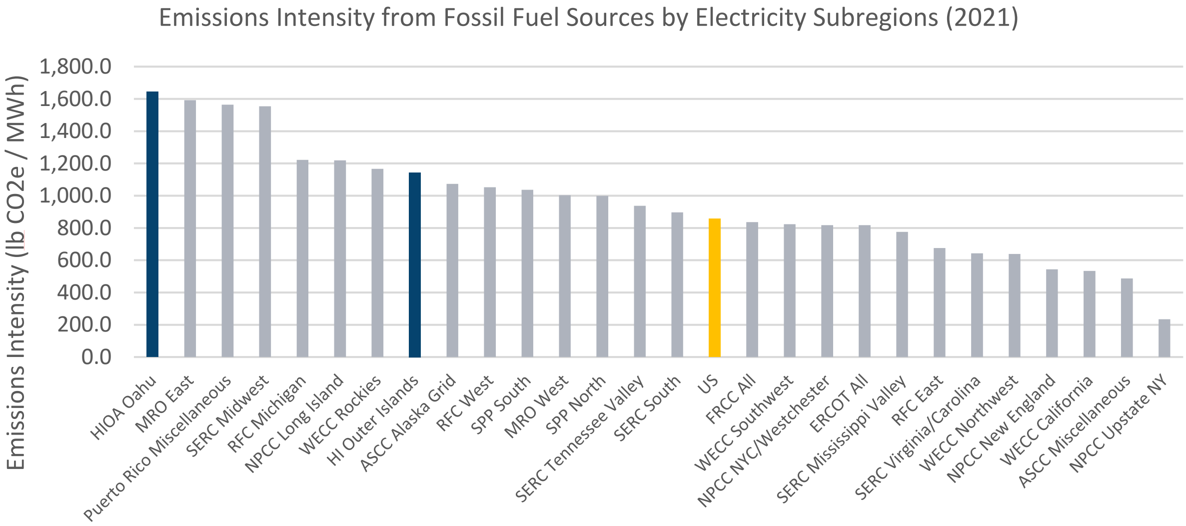

Figure 18 Emission intensities from fossil fuel sources by electricity subregions, as defined by the EPA base on electricity service territories and power profiles. HIOA O'ahu is O'ahu powerplants, HICC Miscellaneous is outer island powerplants. The higher emission intensity is largely driven by both coal burning and petroleum burning.

Emissions intensity in Hawai'i power plants is generally higher due to the reliance on petroleum. Areas with similar sources of fuel for power plants, like Puerto Rico, have similar emission intensity values for their power plants. The EPA eGRID subregions are established by the EPA based on electricity service territories.[92]

Fossil Fuel Generator Retirements

The timely retirement of stationary fossil fuel generators, or powerplants, is critical to achieving Hawai'i's emission reduction target. Delays in powerplant retirements not only impact emission reduction targets but have direct impacts to Hawai'i's residents and customers as the price of electricity is driven by the price of fossil fuel (See section 1.3 – Equity and Costs). Further, the thermal generators currently in operation range will be 37 years old to nearly 80 years at retirement. Hawaiian Electric states *"The existing generating fleet is becoming increasingly less reliable because of age and the way we now operate the grid",* page 255 IGP. Further, Hawaiian Electric has stated *"the age of the generating fleet may be unexpectedly subject to parts obsolescence in the future"*.[93] The statement by Hawaiian Electric underscores the need to develop replacement generation that can meet the needs of a new, more modern grid.

However, before the retirement of firm generation occurs, the utility must ensure sufficient resources are built and adequate to replace the loss of generation, staggering retirements are

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[92] US EPA Power Profiler (2023) Available at https://www.epa.gov/egrid/power-profiler#/

[93] Hawaiian Electric 2023. Integrated Grid Plan (full report) page 257. https://hawaiipowered.com/igpreport/03_IGP-Report.pdf

critical to minimize the risk of unserved energy to utility customers.[94] Therefore, if retirement is delayed for one generator due to inadequate generation, there is a possible domino effect that occurs for other unit retirements, further underscoring the importance of timely retirements and retirement scheduling. The estimated emissions reductions from planned retirements are shown in Table 7 and Figure 19.

Table 7 Projected GHG impacts from planned thermal generation retirements. GHG reduction estimates assume replacement with zero-emission technologies. Estimated reductions were calculated using the 4-year average emissions (2018-2021) obtained from EPA eGRID. Hawaiian Electric's estimated retirements are from the Integrated Grid Plan. KIUC estimated retirements assume 100% RPS reached by 2033 and other plants retired.

Plant	Generator Number	Projected Year Closed (IGP)	Island	Estimate Thousand MT CO_2e 4-Year Average	Generator Generation (GWh) 4-Year Average	Age at scheduled retirement (Years)
AES Hawaiʻi	1 & 2	2022	O'ahu	1329.01	1233.76	30
Waiau	3	2024	O'ahu	6.25	7.50	77
Waiau	4	2024	O'ahu	8.46	10.15	74
Waiau	5	2027	O'ahu	55.47	66.57	68
Waiau	6	2027	O'ahu	76.57	91.88	66
Waiau	7	2029	O'ahu	274.24	329.09	63
Waiau	8	2029	O'ahu	315.88	379.06	61
Puna Steam	1	2025	Hawai'i	30.83	29.69	37
Hill	5	2027	Hawai'i	51.55	51.34	62
Hill	6	2027	Hawai'i	110.87	110.42	53
Kahului	(1-4)	2027	Maui	161.19	145.13	61 - 79
Ma'alaea	10	2027	Maui	14.40	20.74	48
Ma'alaea	11	2027	Maui	14.40	20.74	47
Ma'alaea	12	2027	Maui	14.40	20.74	39
Ma'alaea	13	2027	Maui	14.40	20.74	38
Ma'alaea	1	2030	Maui	2.99	4.31	59
Ma'alaea	2	2030	Maui	2.99	4.31	58
Ma'alaea	3	2030	Maui	2.99	4.31	58
Ma'alaea	4	2030	Maui	6.45	9.29	57
Ma'alaea	5	2030	Maui	6.45	9.29	57
Ma'alaea	6	2030	Maui	6.45	9.29	55
Ma'alaea	7	2030	Maui	6.45	9.29	55

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[94] Hawaiian Electric 2023. Integrated Grid Plan (full report) https://hawaiipowered.com/igpreport/03_IGP-Report.pdf

Plant	Generator Number	Projected Year Closed (IGP)	Island	Estimate Thousand MT CO$_2$e 4-Year Average	Generator Generation (GWh) 4-Year Average	Age at scheduled retirement (Years)
Ma'alaea	8	2030	Maui	6.45	9.29	53
Ma'alaea	9	2030	Maui	6.45	9.29	52
Kapaia Power Station	All	2033	Kaua'i	99.28	140.85	31
Port Allen	All	2033	Kaua'i	47.76	58.21	69
Kahe	1	2035	O'ahu	198.76	250.80	72
Kahe	2	2035	O'ahu	214.55	270.73	71
Kahe	3	2040	O'ahu	224.07	282.73	70
Kahe	4	2040	O'ahu	275.68	347.86	68
Kahe	5	2045	O'ahu	498.03	628.42	71
Kahe	6	2045	O'ahu	426.98	538.77	64

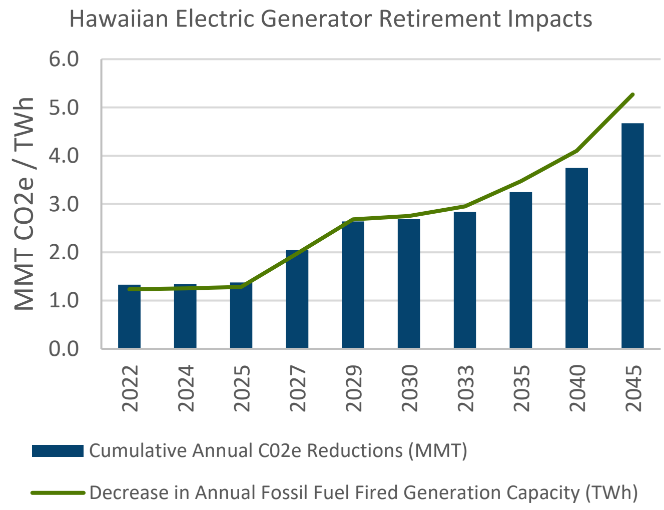

Figure 19 Data from Table 7 Values are taken using the 2018-2021 average emissions available through EPA eGRID. Closure dates follow the IGP projected schedule from Hawaiian Electric or assume 100% RPS Reached by 2033 for KIUC.

Applicable Electric Sector Policies

Decarbonization of the electricity sector has an existing regulatory framework to leverage progress, unlike any other emitting sector in the state. Future decisions in the electricity grid transition to renewables will largely be made in accordance with the Renewable Portfolio Standards (HRS 269-91), Performance-Based Regulation (PBR), grid planning proceedings (e.g. PSIP and IGP), Power Purchase Agreement (PPA) approvals, and the Competitive bidding frameworks[95], among others as regulated by PUC proceedings in accordance with HRS Chapter 269.

Energy Efficiency and Demand Management

Energy efficiency is driven by technological advancement and adoption (e.g. incandescent advanced to light-emitting diodes or LEDs), building efficiency and codes, retrofits, and consumer behavioral change. Hawaiʻi's current overall goal for energy efficiency is to reduce electricity consumption by 4,300 gigawatt-hours (GWh) by 2030 pursuant to the Energy Efficiency Portfolio Standards (EEPS). A new goal has not been established beyond 2030; however, energy efficiency and conservation are the single most important and most cost-effective measure to meaningfully reduce electricity demand, thus negating the need to develop more electricity generation. In 2023, a bill to extend the EEPS was introduced—HB193 (2023)—however, it did not pass but is expected to be revisited during the 2024 legislative session. Energy efficiency and conservation remains the most cost-effective reduction measure and should always be evaluated as the first option statewide. To facilitate energy efficiency, Hawaiʻi Energy administers the Public Benefits fee pursuant to HRS §269-96 (EEPS) and §269-121 through §269-124 (PBF).

Energy efficiency potential was evaluated by Applied Energy Group in the Hawaiʻi Market Potential Study (MPS) for the PUC in 2020. [96] The MPS evaluated the prospects for energy savings through efficiency programs and interventions up until 2040. It considered Hawaiʻi's unique energy market, emerging distributed energy resources (DERs), and changing policies to forecast energy savings and meet the Energy Efficiency Portfolio Standards EEPS targets. The MPS outlined key factors like customer segmentation and technology adoption, and it defined energy-saving potential at four levels: technical, economic, achievable–high, and achievable business-as-usual, with the latter two considering customer participation rates and market interventions. The potential of energy efficiency, and associated load reductions and load shapes were used in the modeling presented in Chapter 4. The market potential study is used to assess the potential for future savings from energy efficiency programs. These programs include energy savings not only inclusive of traditional energy efficiency (LED bulbs, ENERGY STAR® appliances, etc.), but also advanced rate designs (e.g., time of use), and demand response and grid services (DR/GS) programs. DR/GS programs include load shifting technologies such as battery storage and dispatch programs or direct load control programs which allow the program administrator to control customer equipment, such as central AC systems, water heaters, and pool pumps on short notice).

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[95] *PBR and Competitive bidding frameworks are not applicable to KIUC, since they are a customer-owned utility.*

[96] Applied Energy Group (AEG) (2020) State of Hawaiʻi Market Potential Study. Prepared for the Hawaiʻi Public Utilities Commission.

The MPS analysis began with market characterization, detailing electricity use by technology in residential and commercial sectors. This is followed by identifying demand-side resources across sectors and projecting baselines to measure future savings. The impacts of various potential energy savings – technical, economic, and achievable – are then estimated and an intervention assessment is conducted to understand the effects of policy and program interventions. The market characterization section provides a snapshot of Hawaiʻi's electricity usage in 2018, using market research and surveys to create detailed profiles of energy consumption across different sectors and technologies. A sophisticated 8,760 hourly model was developed to estimate the load on each island at the end-use level, utilizing various data sources and simulations to understand consumption patterns.

The outputs of Market Potential Study were projected to 2045 and used in the PATHWAYS modeling, presented in Chapter 4. The MPS estimated energy efficiency savings potential through 2040 and included four types of potential: technical, economic, achievable - high, and achievable - business as usual. Technical potential is the theoretical upper limit, economic potential includes cost-effective measures, while achievable potential refines economic potential by accounting for likely customer adoption of energy efficiency measures. Figure 21, taken from the MPS displays the cumulative persistent savings achieved from 2009 to 2030 for the Energy Efficiency Portfolio Standard as established (black-dotted line). It indicates that the interim target for EEPS was achieved through 2018, and the 2030 target is expected to be reached under a business as usual (BAU) scenario. While Hawaiʻi Energy has historically provided most of the EEPS savings, other entities such as Commission Regulated Entities and Non-Regulated Entities also contribute to achieving the EEPS goals. Codes and standards are embedded into the MPS models.

Figure 20 Various efficiency and demand reduction potentials. Adopted from AEG 2020 Hawaiʻi Market Potential Study.

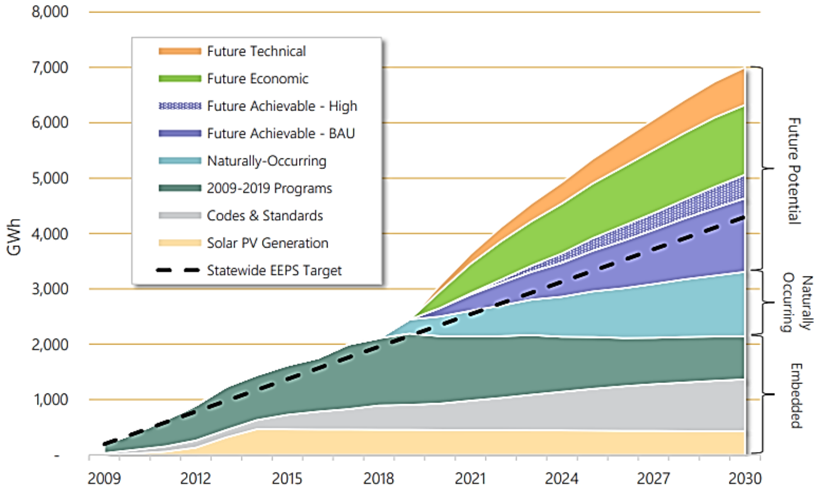

Figure 21: Cumulative persistent energy savings from energy efficiency and DSM programs. Image source: Applied Energy Group, 2020. Hawaiʻi Market Potential Study.[97] The aggressive demand reduction scenario presented in Chapter 4, assumed Economic Potential is achieved (green), while other mitigation scenarios assumed BAU – High (purple).

The Renewable Portfolio Standard and its Role in Decarbonization

Annual progress updates and the status of these goals are made publicly available through the PUC, and financial penalties exist for failure to meet targets through PBR performance incentive mechanisms. Accordingly, the electric sector is the only emitting sector with predicted declines in tailpipe emissions.

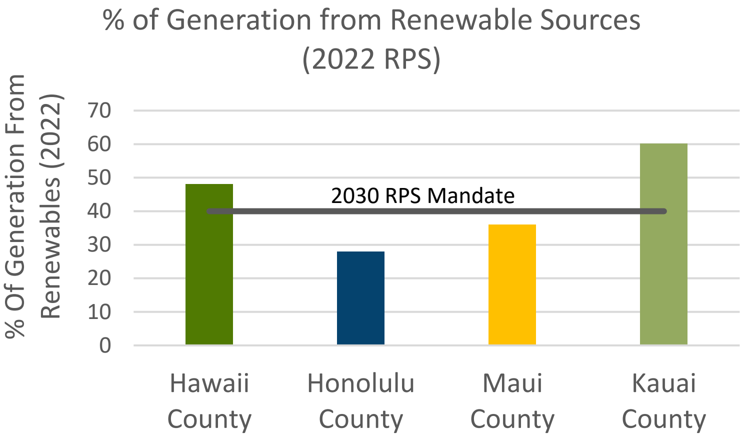

Figure 22 Generation from Renewable Resources as reported on the Hawaiʻi PUC Docket 2007-0008 2022 annual filing.

The RPS requires 100% of electricity generation to be from renewable sources by 2045, with additional interim goals to be met along the way in 2030 (40%) and 2040 (70%).[98] Progress

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[97] Id

[98] HRS §269-91 Renewable Portfolio Standards Definitions and HRS §269-92 Renewable Portfolio Standards

towards the RPS is tracked annually under PUC Docket 2007-0008, and both Hawaiian Electric utilities have maintained steady progress towards these goals (Figure 22).

Outlining actionable steps to achieve the RPS, Hawaiian Electric put forth the Integrated Grid Plan[99] which was monitored by the PUC under Docket 2018-0165, while KIUC recently produced its own strategic 2023-2033 strategic plan.[100]

While the RPS is an important driver of emissions reductions, it does not mandate zero-emission energy generation, it instead focuses on renewable generation. Importantly, there are renewable technologies, recognized by the RPS definitions, that are known carbon sources. This is of particular concern with energy from biomass or biofuels. HRS §269-91 defines biofuels and biomass as an eligible renewable energy source. Per statute, biofuels include *all liquid or gaseous fuels produced from organic sources such as biomass crops, agricultural residues, and oil crops, such as palm oil, canola oil, soybean oil, waste cooking oil, grease, and food wastes, animal residues and wastes, and sewage and landfill wastes.* Biomass includes *all biomass crops, agricultural and animal residues and wastes, and municipal solid waste, and other solid waste.*

While these emissions are recognized as "carbon neutral" in current accounting methodologies, the net emissions associated with bioenergy (biofuel and biomass) combustion should be carefully considered on a life-cycle basis. This concern is further discussed in Chapter 5, Section 5.3. Further, biogenic emissions, while recognized by the atmosphere equally as GHG, are not necessarily accounted for in the state inventory due to challenges associated with imports, temporality, and leakage. For example, biofuels brought in from out-of-state represent renewable generation for the RPS, but they do not necessarily signify a step towards achieving carbon neutrality. When considering the carbon accounting of bioenergy, the overall net emissions associated with biofuel production are highly dependent on many factors including temporality, or the time it took for the plant to store the carbon released into the atmosphere, the feedstock or the plant/crop used, agricultural methods for dedicated energy crops (e.g. soil tillage), and the inputs needed (or used) for growth, such as fertilizers.

As a result, the RPS alone may not lead to net-zero carbon emissions from the electricity sector in 2045, depending on the composition of the renewable portfolio.

Figure 23 (left) shows the total generation from renewable sources with gross GHG emissions in 2022 (PUC Docket 2007-0008), demonstrating that so far it is a small portion of the renewable generation; however, in the future could play a larger role. Figure 23 (right) shows Hawaiian Electric's preferred plan from the IGP, the portion of renewable generation expected to come from renewables with gross emissions.

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[99] Hawaiian Electric (2023). Integrated Grid Plan (full report)

[100] Kauai Island Utility Cooperative. (2023). KIUC 2023-2033 Strategic Plan Update

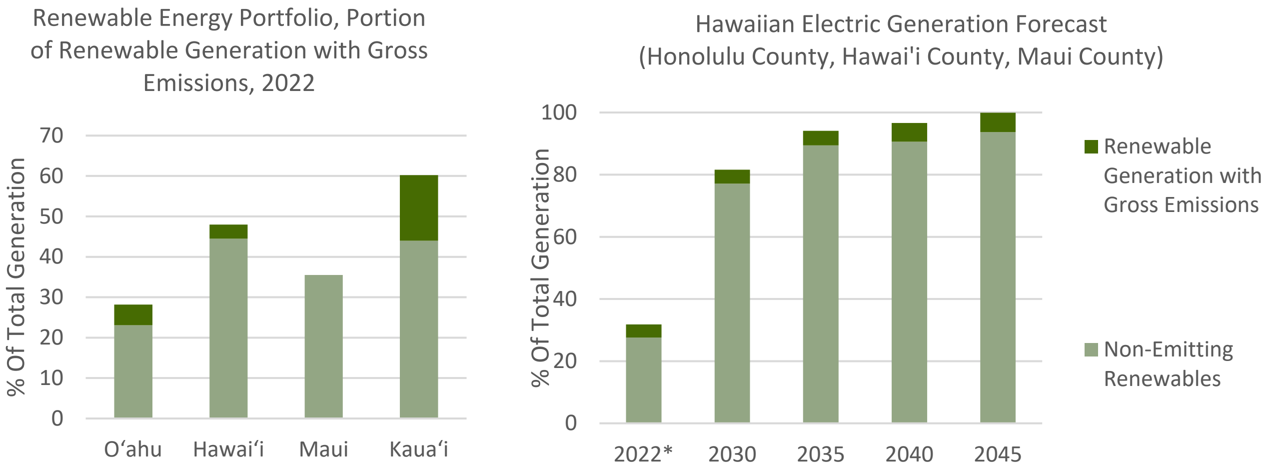

Figure 23 (Left) From Fuel Mix disclosures from Hawaiian Electric, RPS Filing from KIUC. Assumes Biomass & Biofuels emit, other renewables do not. KIUC values are adjusted for only system. (Right) Generation forecast with non-emitting and gross emitting generation, from the IGP Forecasted Consolidated RPS from today through 2045, preferred plan page 15.

Collectively, the current Hawaiian Electric Integrated Grid Plan (IGP) base assumptions of the preferred plan assumes that 4.5% and 6.2% of the renewable portfolio will be comprised of biomass or biofuels in 2030 and 2045 respectively.[101] KIUC did not have data ready at the time of the report; however, production forecast models were provided to run in the Engage capacity expansion model. Baseline models suggest 4.5% in 2030 and 2045.[102] KIUC's long-term planning and future portfolio breakdown are still in development. KIUC plans to release a development plan by December 2023 that will achieve 100% renewable energy generation by 2033, twelve (12) years ahead of the State of Hawaiʻi mandate. The development of the West Kauaʻi Energy Project alone could move KIUC to the 90% Renewable sourced generation threshold.

Distributed Energy Resources

A significant portion of both KIUC and HECO's ability to reach their goals necessitates coordination with its consumers including through Distributed Energy Resources (DER), Scheduled Dispatch Programs (SDP), and energy efficiency programs. DERs are small-scale generation resources that enable customer participation in the generation and delivery of electricity service. Most commonly, these are solar photovoltaic panels, sometimes paired with a battery energy storage (BESS) system, but it could also include small scale distributed wind. DER remains a core pillar of the decarbonization effort, particularly assisting the electric industry in

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[101] Hawaiian Electric 2023. Integrated Grid Plan (full report), Consolidated RPS from today through 2045. Pg. 15.

[102] *Capacity expansion modeling completed for KIUC based on Production Forecasts provided by KIUC. See Chapter 3 for details on inputs, and Chapter 4 for details on results.*

achieving renewable energy goals. The PUC has partnered with both electric utilities and their customers to find DER programs that encourage customer participation and are fair for ratepayers.

Numerous programs have been phased in and outfitted to the cost-effectiveness and grid needs at the time of implementation including Net Energy Metering, Net Energy Metering Plus, Standard Interconnection Agreement, Customer Grid Supply, Customer Grid Supply Plus, Customer Self Supply, Interim Smart Export, and others. The next phase of DER programs approved by the PUC will include a Smart DER Tariff, and a Bring Your Own Device (BYOD) Tariff both launching November 1, 2023.[103] DER programs have assisted in the fast-tracked penetration of residential solar photovoltaic installations while providing significant financial incentives. The Battery Bonus Program and future BYOD programs are considered a Scheduled Dispatch Program (SDP) which allows the utility to utilize customer battery storage at a specific time during peak electricity demand. This system helps the utilities compensate for the void when electricity demand is high, but solar energy production is low.

The success of the Battery Bonus Program exemplifies the efficacy of incentives, see Figure 18. However, concerns regarding equity and access to incentives such as battery bonuses and NEM have been raised, as discussed in section 1.3 Transition Costs.

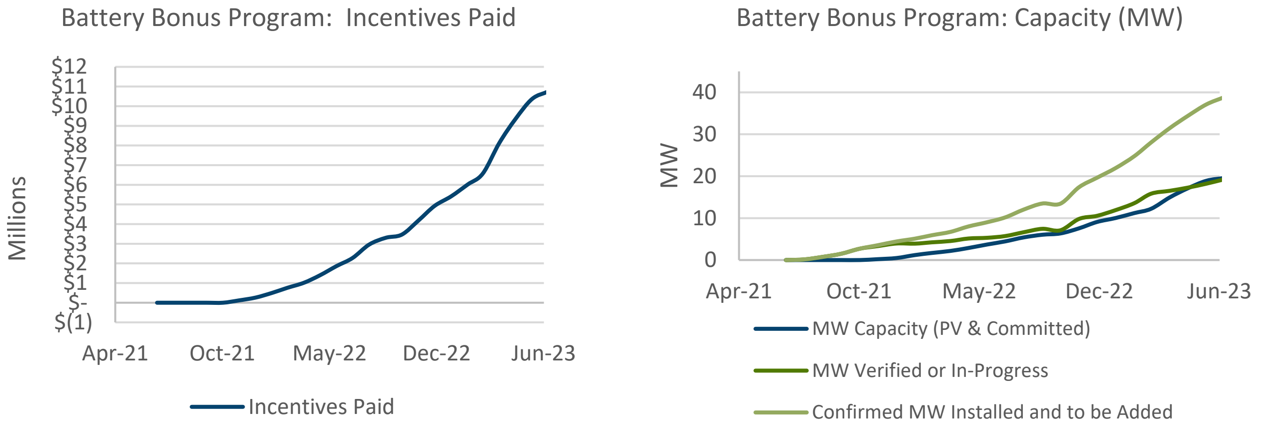

Figure 24 (Left) Cumulative Incentives Paid to Participants in the Battery Bonus Program Source: PUC Docket 2019-0323 Monthly SDP Report. (Right) Added Storage & PV Capacity from Residential Participation in the Battery Bonus Program Source: PUC Docket 2019-0323 Monthly Scheduled Dispatch Program (SDP) Report.

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[103] Hawaiʻi Public Utilities Commissions. DER Programs. (n.d.)

Table 8 Residential & Commercial Participation Sources: PUC HECO PUC KIUC HECO & KIUC, Form EIA-826 (2011) 2023-06

Customer-Sited Generation	Oʻahu County	Hawaiʻi County	Maui County	Kauaʻi County	Statewide
Customer-sited Generation as Percent of Total Generation (2022)	14%	16%	18%	13%	15%
Customer-sited Generation as a Percent of Overall Renewable Portfolio (2022)	50%	33%	50%	21%	44%
Total Number of DER Customers Connected (As of June 2023)	69,060	16,058	16,052	5,748	106,918
PV Capacity (MW) (As of June 2023)	905	159	151	34	1,249

**(Kauaʻi data Includes Schedule Q & NEM Only)*

Utility Generation

In addition to DER programs, swift development timelines for large scale renewable energy development are critical. The process of developing utility scale projects is rightfully a long and often arduous process. Many aspects of the process of development are in place to protect the resources valued by the community—including land, historical and cultural resources, plants and protected species, and other critical resources. Other aspects are in place to ensure safety, for example fire and electrical permits. However, certain approvals have been known to cause project delays.[104]

The observed development timelines (measured from PPA application submittal to declaration of commercial operations) exhibited by the most recent Hawaiian Electric procurements (Stage I and II), which experienced substantial delays, will not be adequate to meet interim targets. A statewide coordinated technical assistance program or function is necessary to appropriately reduce the timeline in which renewable energy projects are approved and implemented.

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[104] Hawaiʻi Public Utilities Commission, Docket 2021-0024. Order No. 37624 Opening Proceeding to Review Hawaiian Electric's Interconnection Process and Transition Plans for Retirement of Fossil Fuel Power Plants

Identification of Key Entities Responsible for the Electricity Sector

Entities responsible for this sector include the public utility companies (Hawaiian Electric and Kauaʻi Island Utility Cooperative), independent power producers (IPPs), major electricity users in the state including military facilities and installations, which are serviced by the utility grid,[105] state and county facilities, hotels, and all individual consumers (residents and businesses).

The primary regulatory agency responsible for the Electric Sector is the Hawaiʻi Public Utilities Commission (PUC). The third-party Public Benefits Fee Administrator, currently Hawaiʻi Energy, plays a key role in Energy Efficiency and Demand Side management. The State Consumer Advocate also protects the interests of Hawaiʻi's consumers of regulated public utilities and transportation services. HSEO provides policy guidance and promotion in support of and under the direction of the Governor.

Waste Incineration

A large portion, ~85%, of Honolulu's municipal solid waste (MSW), is incinerated at the H-POWER waste-to-energy (WtE) facility in Kapolei.[106] As shown in Figure 13, waste incineration accounted for 1.5% of non-biogenic CO_2 emissions in the energy sector in 2019. Emissions from waste incineration have shown an increasing trend since 2011 when reporting under the EPA's GHGRP began.

Biogenic emissions from waste incineration, which are not included in the State Inventory totals make up a substantial portion of the total emissions from the H-POWER facility. While biogenic emissions are not included in the statewide inventory totals, they are a substantial component of H-POWER's emissions. However, without incineration, the emissions from the MSW burned at H-POWER would likely otherwise be landfilled, and thus landfill emissions (Section 2.4 Waste) would increase without an incineration facility. Emissions from the wastewater treatment would also increase due to the wastewater solids incineration which occurs at H-Power.

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[105] Application of Hawaiian Electric Company, Inc. for Army Privatization Project; Docket No. 2019-0349 https://hpuc.my.site.com/cdms/s/puc-case/a2G8z0000007fApEAI/pc20924

[106] *Quinn, M.* (2021, January 6). Covanta's $60M ash processing contract in Honolulu signals next step in closing local landfill. Waste Dive

Table 9 Emissions from H-POWER Waste Incineration facility, including biogenic emissions which are not accounted for in the statewide totals. Data Source: EPA Greenhouse Gas Reporting Program[107] All data presented in units of metric tons of carbon dioxide equivalent using 100-year GWP from IPCC's AR4. Reported to EPA by facilities.

	Biogenic Emissions (MT CO_2e) *Not included	Non-biogenic Emissions MT CO_2e *Included	Total Emissions	Percent Biogenic
2011	325,108	200,505	525,613	61.9%
2012	348,809	213,346	562,155	62.0%
2013	421,574	271,001	692,575	60.9%
2014	348,603	289,828	638,431	54.6%
2015	397,736	269,210	666,946	59.6%
2016	380,855	268,496	649,351	58.7%
2017	395,406	225,554	620,960	63.7%
2018	433,127	264,922	698,049	62.0%
2019	440,238	284,526	724,764	60.7%
2020	467,068	279,160	746,228	62.6%
2021	415,365	296,714	712,079	58.3%

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[107] US EPA 2022, Greenhouse Gas Reporting Program (GHGRP) 2021 Data Summary Spreadsheets

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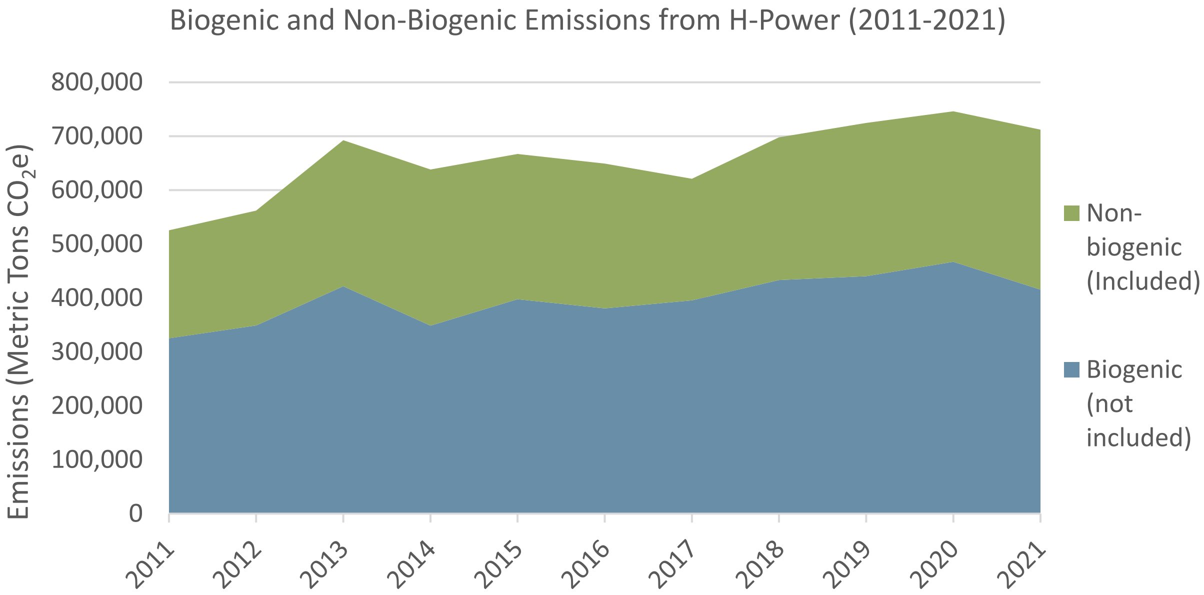

Figure 25 Biogenic and non-biogenic emissions from H-Power. Data from EPA GHGRP.

For more information on waste contributions refer to the waste sector analysis. Lower emitting alternatives to waste incineration (and landfilling) that generate energy (including fuels) include more modern technologies such as pyrolysis and gasification.[108] These technologies are being explored in Hawaiʻi and supporting their development should remain a priority.

Key Entities Responsible for Waste Incineration

Currently, the City and County of Honolulu (CCH), Department of Environmental Services (ENV) holds contract with Covanta. The power purchase agreement between the CH and Hawaiian Electric for the H-Power MSW disposal facility was approved in 2013 and remains in effect for a period of 20-years following COD of the expansion.[109] This means the PPA will be open for renegotiation in 2033. The Sand Island WWTP, also managed by ENV, sends sludge for burning.[110]

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[108] Dong, J., Tang, Y., Nzihou, A., Chi, Y., Weiss-Hortala, E., & Ni, M. (2018). Life cycle assessment of pyrolysis, gasification, and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants. *Science of the Total Environment*, *626*, 744-753.

[109] PUC Docket 2012-0129 For the approval of an Amended and Restated Power Purchase Agreement for Renewable Firm Energy and Capacity.

[110] City and County of Honolulu, Department of Environmental Services (ENV) Refuse Division (2022) H-POWER Facility

Petroleum Refining

Since 2018, emissions from refining activities have declined substantially due to the shutdown of the Island Energy Service Refinery. In August 2018, Island Energy Services (IES) announced it would cease refining operations and shift its focus to retail operations and logistics for petroleum products. Par Pacific Holdings, Inc. acquired the refining assets.[111] This switch is demonstrated in Figure 26, where 2018 emissions from IES declined to zero in 2019, with Par West acquiring IES assets. However, imports of refined fuel have made up for the island's petroleum demand. Values from refining activities were pulled from EPA's GHGRP data and are shown in Figure 26.[112]

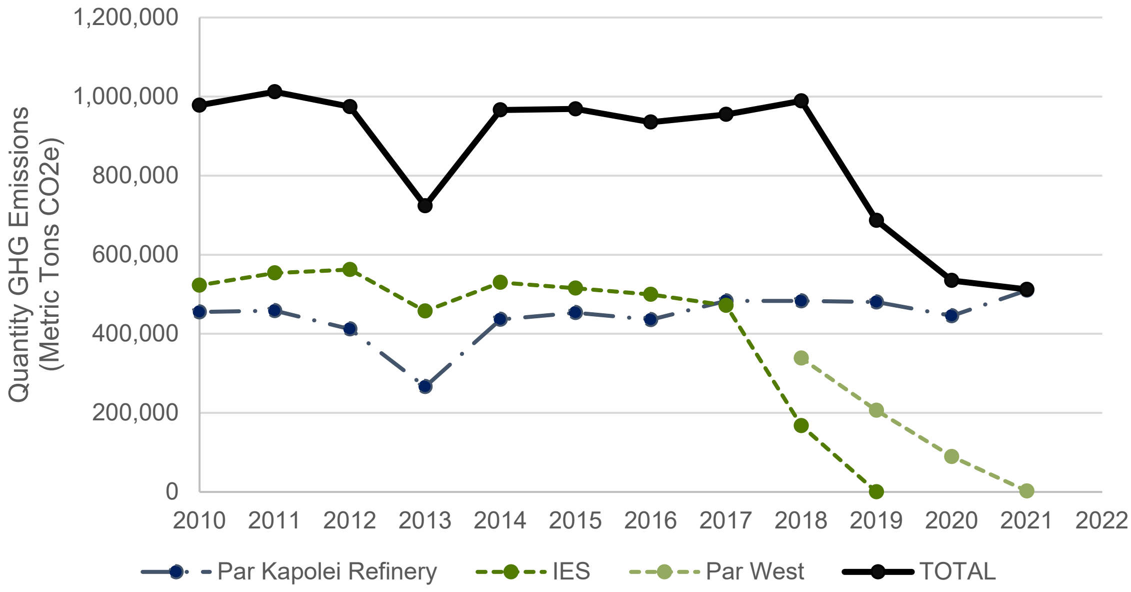

Figure 26 Emissions from state refineries from 2010-2021. Data was reported to EPA by facilities as of 08/12/2022. All emissions data is presented in units of MT CO_2e using GWPs from IPCC's AR4.

Fuels refined by Par Hawaiʻi are used in all sectors, including aviation (jet fuel), electricity combustion (distillate fuel oil, diesel, and waste/other fuel oils including crude, liquid butane, liquid propane, sludge oil, tar oil, etc.). Therefore, emissions from refining are separated from stationary combustion for this report.

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[111] Par Pacific Holdings, Inc., (2018). Par Pacific Successfully Closes Transaction with Island Energy Services News Release

[112] US EPA (2023). Emissions by Unit and Fuel Type 2022. File contains publicly available reported emissions data at the unit-level and fuel-level for facilities in the Electricity Generation (Subpart D), and General Stationary Fuel Combustion (Subpart C) source categories.

The total output of the Par Refinery is ~1.3 billion gallons of total fuel production annually, or 85,000 barrels per day.[113] The plant's operating capacity is ~94,000 barrels per day, with a storage capacity of ~5.4 million barrels. Most of the fuel currently refined at the Par Hawaiʻi facility is gasoline, ultra-low sulfur diesel, low sulfur fuel oil (LSFO), and residual fuel oil and approximately 20 thousand barrels per day of jet fuel is refined at the Par facility. The total state demand for jet fuel is approximately 50 thousand barrels per day; the state imports about 60% of its total jet fuel demand as refined products. The Par facility also produces asphalt.[114] Emissions from the production, refining, and transportation of these fuels to the islands are not accounted for in the state inventory, Chapter 5.

While emissions from refining have decreased in the past five years, refining emissions of imported fuels are not accounted for in the statewide inventory; tailpipe and storage emissions are accounted for in the end-use sector.

Natural Gas

The categories of current natural gas use in Hawaiʻi can be described as: 1) utility gas, and 2) non-utility gas. Utility gas is regulated by the PUC and defers from non-utility gas primarily in the way it is distributed to end-users. Utility gas service is only on Oʻahu, primarily in the urban core and is serviced by the synthetic natural gas (SNG) plant located next to the refinery in Kapolei. Hawaiʻi Gas, the only utility gas company in the state, produces their SNG from naphtha supplied by the PAR refinery. Hawaiʻi Gas also blends renewable natural gas (RNG) into its utility gas line derived from an advanced gas cleaning technology of municipal biogas at the Honouliuli Wastewater Treatment Plant (WWTP) in Kapolei.

Utility gas operations consist of the purchase, production, transmission, distribution, and sale of utility gas, which includes SNG (including 10-12% hydrogen (H_2) by volume, 50% of which is sourced from the Honouliuli WWTP), RNG, propane, and imported liquefied natural gas (LNG). Emissions from the SNG plant are relatively small and have been relatively consistent since 2011, averaging 24,711 metric tons (0.024 MMT) since 2011.

Imported natural gas was considered by Hawaiian Electric and Hawai ʻi Gas, primarily for replacing low sulfur fuel oil and diesel for electricity generation, until Gov. David Ige announced a policy shift in May of 2015. According to analysis by FACTS Global Energy (FGE), the use of natural gas under the import plan proposed by Hawai ʻi Gas if implemented from 2019 to 2022 would have lowered carbon dioxide emissions by 2.9 billion pounds annually, equivalent to removing more than 250,000 cars from Hawaii's roads. Cost savings during the same period would have been approximately $1 billion over the 4-year period if Hawaiʻi imported up to 1

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[113] Conversation with Eric Wright, August 25, 2023, President of Par Hawaiʻi

[114] Par Pacific (2022) Par Pacific 2022 Sustainability Report

million tons per annum (mpta) of LNG compared with prices that Hawaiian Electric paid for fuel oil and diesel for oil-fired electricity generation on Oʻahu during the same period.[115]

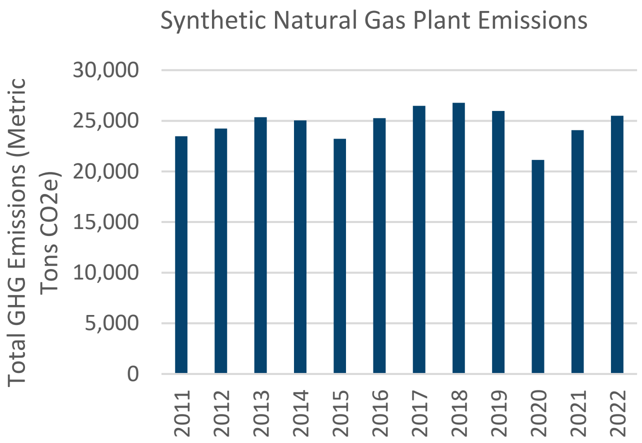

Figure 27 Emissions from the SNG Plant in Kapolei. Emissions are not inclusive of end-use and are only inclusive of SNG production, i.e. emissions from fuel burn of tiki torches in Waikiki would show in the commercial or buildings sector, emissions from residences utilizing gas stoves are not included. Emissions from the SNG production were obtained from EPA GHGRP.[116]

RNG, as a drop-in fuel for SNG, can be generated from various sources, including biogas obtained from waste water treatment plants and landfills (refer to Section 2.4 Waste), as well as gases produced from organic waste sourced from commercial, institutional, and industrial entities such as food manufacturers, wholesalers, supermarkets, restaurants, hospitals, and educational institutions. Additionally, biogas can be produced from lignocellulosic materials, such as woody biomass, dedicated energy crops, and crop residues, through various methods, including thermochemical conversions, co-digestion, and dry fermentation.

Hawaiʻi Gas currently blends RNG in its utility gas line (see Section 2.4: Waste) and is working to further expand this practice.[117] Hawaiʻi Gas is actively seeking lower carbon alternatives to SNG. In April 2023, Hawaiʻi Gas released an RFP for suppliers of Renewable Natural Gas and Renewable Hydrogen.[118] Proposals were due to Hawaiʻi Gas in September. The RFP is seeking 65,000 therms of RNG per day or 23.7 million therms per year. If successful at procuring this amount, RNG would

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[115] FGE compared the "all in" regasified LNG price offered by Engie of France under an integrated LNG Sales and Purchase Agreement for the supply of up to 1 million tons per annum (mtpa) of LNG for 15 years compared with prices that HECO paid for fuel oil and diesel for electricity generation on Oʻahu from 2019 to 2022.

[116] US EPA (2023). Emissions by Unit and Fuel Type 2022. The file contains publicly available reported emissions data at the unit level and fuel level for facilities in the Electricity Generation (Subpart D), and General Stationary Fuel Combustion (Subpart C) source categories.

[117] Hawaii Gas filing to the PUC, Re: Hawaii Revised Statutes (HRS) § 269-45, Gas Utility Companies Renewable Energy Report

[118] Hawaii Gas (2023) Hawaii Gas Request for Proposals, Supply of Renewable Natural Gas and Renewable Hydrogen.

make up a large portion of the natural gas flowing through the utility gas lines on Oʻahu – utility line customers consume about 24 million therms of SNG per year.[119]

Notably, one of the incentives for suppliers of RNG is the state's Renewable Fuels Production Tax Credit (RFPTC). Suppliers like the Honouliuli RNG plant did not meet the minimum threshold of 2.5 billion BTU per year, lowering this threshold can support smaller RNG producers if they meet lifecycle emissions requirements. Pursuant to HRS §269-45 Hawaiʻi Gas is required to report the percentage of feedstock comprised of petroleum feedstock and the percent comprised of non-petroleum feedstock. In 2022, around 1.3% of Hawaiʻi Gas's feedstock was from the Honouliuli WWTP.

2.3. Transportation

The transportation sector accounts for about half of the energy consumed in Hawaiʻi, mostly in the form of jet fuel and motor gasoline.[120] Emissions from the transportation sector (including aviation, marine, and ground transportation) were 10.68 MMT of CO_2e and accounted for ~55% of energy sector emissions and 48.5% of total GHG emissions (excluding sinks) in 2019, collectively making transportation the largest emitting category in Hawaiʻi (Figure 13).

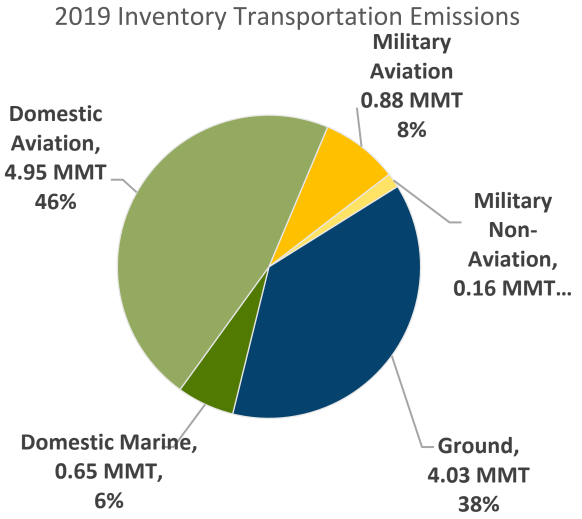

Figure 28 Emissions from the transportation sector, 2019. Proportions shown are not inclusive of international aviation or international marine travel.

Emissions from transportation can be broken into ground transportation, domestic aviation, marine transportation, military aviation, and military non-aviation. In general, the aviation sector accounts for the largest portion of transportation in emissions, followed by the ground transportation sector (Figure 28).

Emissions from transportation have shown an increasing trend since 2010. Emissions had a brief declining trend between 2007 and 2010, largely attributed to the economic crisis, but also

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[119] Hawaii Gas (2023), "Frequently Asked Questions "

[120] U.S. EIA, State Energy Data System, Table C1, Energy Consumption Estimates by End Use Sector, Ranked by State, 2021.

effective federal programs implemented by the Obama Administration, including such as the federal corporate average fuel economy (CAFE) standard and the cash-for-clunkers program.[121] The transportation sector, however, unlike the electric sector, does not have the same regulatory structure with enforceable mandates and therefore relies heavily on incentives and disincentives versus regulatory action. Without intervention, Business-as-Usual projections show little decline in emissions, Chapter 4.

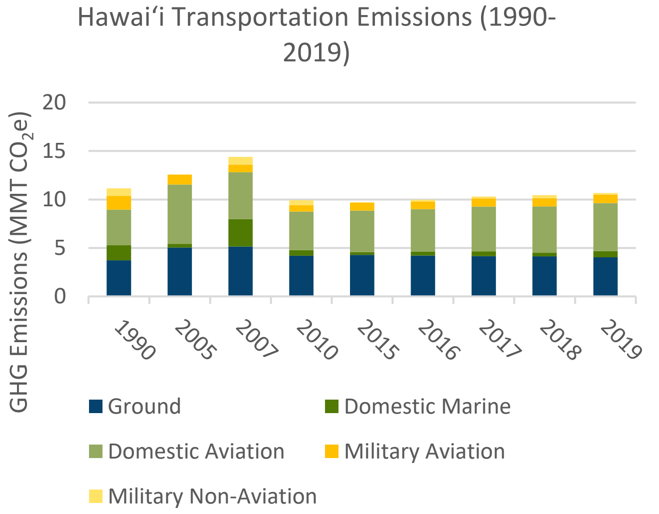

Figure 29 Hawaiʻi GHG Emissions by Transportation Category for 1990, 2005, 2007, 2010, and 2015-2019 (MMT CO_2 Eq.)

In 2023, the Hawaiʻi State Legislature passed Act 226 to be codified in HRS 225P-5, relating to GHG emissions from transportation. The act ultimately tasks the State DOT (responsible for 15 airports; 2,433 miles of paved state freeways, highways, and roadways; and 10 Harbors), in coordination with HSEO and the State Office of Planning and Sustainable Development (OPSD) with establishing long-term goals for zero emissions transportation and established two working groups: 1) Clean ground transportation working group, and the 2) Interisland clean transportation working group. Many of the recommendations set forth in this report can be appropriately carried through with these working groups, as the Act also authorizes both the Hawaiʻi DOT and HSEO to adopt rules pursuant to HRS Chapter 91.

The Hawaiʻi DOH estimated the GHG emissions of the transportation sector using aggregate fuel consumption data from EIA and subtracts international bunker fuels from aggregated totals to account for only domestic travel (consistent with IPCC methodology). Using the fuel consumption data obtained from EIA as the baseline,[122] DOH estimated CO_2e emissions from ground transportation using carbon content coefficients specific to each fuel type (i.e., mass of carbon per unit of energy in each fuel, C/btu). Then, the data was disaggregated by category (ground, marine, aviation) using fuel type data from EIA, as well as transportation data from DBEDT.[123] It was assumed diesel motor gasoline, propane, residual fuel, and natural gas used for the transportation sector were used in the ground and marine transportation categories, while

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[121] Li, S., Linn, J., & Spiller, E. (2013). Evaluating "Cash-for-Clunkers": Program effects on auto sales and the environment. *Journal of Environmental Economics and Management*, *65*(2), 175-193.

[122] US Energy Information Administration (EIA) State Energy Data System. Consumption & Expenditures. (2023)

[123] State of Hawaii, Department of Health. Greenhouse Gas Inventory (2023) Hawaiʻi Greenhouse Gas Emissions Report for 2005, 2018, and 2019

aviation gasoline and naphtha type jet fuel were assumed to be consumed for the aviation category. In the state GHG inventory, further disaggregation by vehicle type (i.e., on road/off-road, LDV/MDV, etc.) is not included.

Ground Transportation

The movement of people and commodities across land utilizing a variety of vehicles, such as cars, trucks, buses, and trains, but also movement via foot, bicycle, or alternative modes (walk, bike, and roll), is referred to as ground transportation. Ground transportation is essential for the functioning of everyone's day-to-day lives and the economy; however, it also significantly contributes to the production of GHG emissions primarily through vehicle combustion of petroleum-based fuels, like gasoline and diesel. While the primary focus when discussing transportation related GHG emissions is on CO_2 and other GHGs released during vehicle operation (i.e. tailpipe emissions), there are several other non-negligible emissions associated throughout the lifecycle of a vehicle, these emissions are further discussed in Chapter 5.

Ground transportation sector tailpipe emissions comprise 38% of all transportation emissions in Hawaiʻi (Figure 28). In 2019, ground transportation contributed 4.03 MMT CO_2e, making up 18.3% of the aggregated state gross total of 22.01 MMT CO_2e emissions.

Emissions from ground transportation can be further broken down by county. Honolulu's GHG emissions made up 62% of the ground transportation emissions, Hawaiʻi County made up 16%, Maui County 15%, and Kauaʻi County 7%. However, when looking at ground transportation emissions on a per capita basis (population based on de facto population), each county has similar contributions, with Hawaiʻi County having the highest per capita emissions (Figure 30) population is based on the de facto population obtained from DBEDT.[124]

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[124] DBEDT (2023). Data Warehouse Population and Vital Statistics, Population Total, De Facto Population

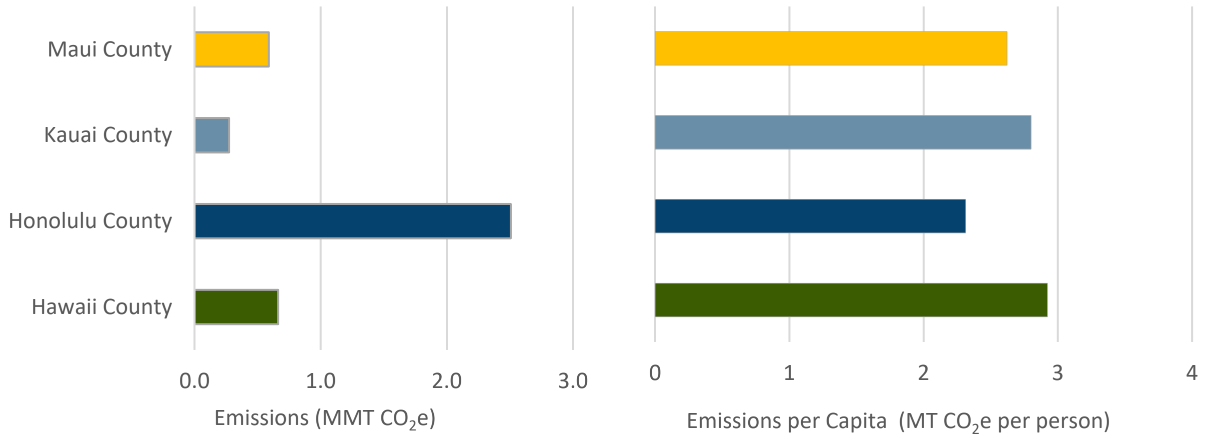

Figure 30 Emissions by County for Ground Transportation. Left represents total emissions, right represents emissions per capita (based on de facto population). While the City and County of Honolulu has the highest emissions, the emissions per capita are ultimately the lowest. This can be attributed to denser development and availability of alternative transportation options.

The amount and type of greenhouse gas emissions emitted by ground transportation in Hawaiʻi are largely dependent on the type of fuel used, fuel efficiency, total vehicle miles traveled (VMT), the number of vehicles, and vehicle weight.

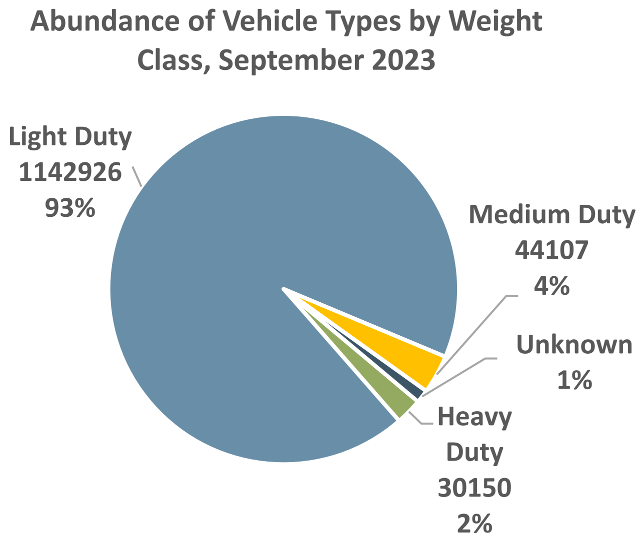

Figure 31 Registered vehicles by weight class. Data source Hawaiʻi State Energy Office, Data Portal 2023. Data aggregated based on data received from the Hawaiʻi Department of Transportation, City and County of Honolulu Dept of Information Technology, and US DOT National Highway Traffic Safety Administration.

Based on gross vehicle weight, vehicles can be subdivided into the following weight classes:

- Light-duty vehicles (LDVs) - defined as vehicles less than 8500 lbs. and include light duty trucks and SUVs.
- Medium-duty vehicles (MDVs) - defined as vehicles ranging from 8,501-10,000 lbs.; and
- Heavy-duty vehicles (HDVs) - defined as vehicles weighing more than 10,000 lbs.[125]

There are about 1.23 million registered vehicles in Hawaiʻi. From those

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[125] Title 10 Code of Federal Regulations part 490 Alternative Fuel Transportation Program

vehicles about 93%, 3.6% and 2% are LDVs, MDVs, and HDVs respectively (Figure 31). Unfortunately, the state inventory does not disaggregate GHG emissions by vehicle weight class. However, the DOH inventory does assume that all the gasoline for on-road usage in Hawaiʻi is used by LDVs and has calculated that LDVs are responsible for 85% of ground transportation emissions. The MDVs and HDVs are estimated to be mostly diesel powered, emitting more GHG per vehicle, but contributing less to the aggregated totals due to lower abundances/numbers of vehicles.

Considerable efforts, largely driven by federal CAFE standards, have been dedicated to enhancing the fuel efficiency of combustion engines, which has reduced the amount of needed fuel and associated emissions per vehicle mile. Although the number of miles an average vehicle travels has not increased the total number of vehicles in Hawaiʻi has been increasing; thus, the total vehicle miles travelled (VMT) has been increasing as well,[126] partially offsetting the GHG emission saved through improved fuel efficiency (Figure 32).

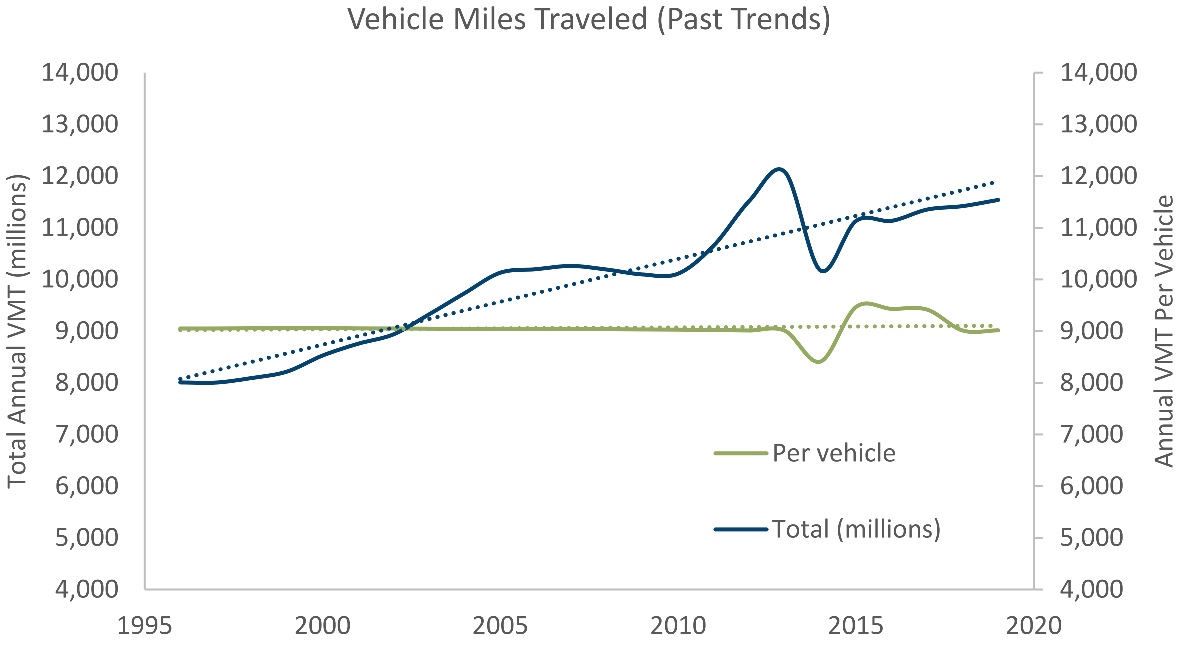

Figure 32 Total vehicle miles traveled versus vehicle miles traveled per vehicle. The relatively constant VMT per vehicle (green) indicates that the increase in total VMT (blue) is not due to increased travel, but rather by the increasing number of vehicles on Hawai'i's roads. Data source: State of Hawaiʻi, Department of Business, Economic Development, and Tourism. Data Book, Section 18.

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[126] DBEDT (2023) Data Book Section 18. *Based on motor vehicle total by county of inspection; includes both taxable and non-taxable vehicles, and all military non-resident exempt vehicles. Data include passenger cars, buses, trucks, and motorcycle, but excludes trailers and semi-trailers.*

Two major dips occur in total VMT in the last twenty years, one in 2014, which is generally attributed to high gas prices, and then again in 2020, when the pandemic "stay at home" orders were put in place (Figure 32).[127] While the pandemic temporarily lowered transportation emissions, the long-standing trend demonstrates failure to make a dent in transportation-related emissions, which have stayed relatively constant for the past 15 years.

With the completion of the Honolulu Skyline and associated transit-oriented development (TOD), the current rate of VMT growth is anticipated to slow down on Oʻahu.[128]

Actions to Reduce Emissions from Ground Transportation

Emission reduction in the ground transportation sector can generally be divided into two facets:

1. Reducing the amount of energy needed for ground transportation.
   a) Reducing the amount of travel needed: reduced number of trips (for example via telework and alternative work weeks), decreased single occupancy travel, as well as reducing the distance of the trips (via land use improvement such as transit-oriented development).
   b) Active Transportation: Enabling, through development choices, and encouraging walking, cycling, and other non-motorized means of transportation.
   c) Public Transportation: Expansion and improvement of public transit systems can reduce the number of individual vehicles on the road and VMT, thus reducing emissions.
   d) Improved Fuel Efficiency: stricter fuel efficiency standards, often implemented at the federal level, for conventional vehicles help reduce fuel consumption (and emissions) per mile traveled. Improved fuel efficiency also applies to electric vehicle, measured in mpg-equivalent (mpg_e)
   e) Driving Behavior Improvements: Widespread adoption of transportation best practices including carpooling and route planning, as well as increased awareness and adoption of energy efficient driving practices including proper tire maintenance, smooth acceleration, and braking, maintaining a steady speed, using air conditioning wisely, minimizing vehicle idling, etc.

2. Transitioning toward Zero Emission Vehicles

   a) Transition to Zero-Emission Vehicles (ZEVs): Promoting the transition to battery electric vehicles (BEVs) can significantly reduce emissions from vehicle operation.

      - While BEVs rely on the electric grid for charging, and thus may have emissions associated with charging, these are anticipated to decrease with time as the grid becomes cleaner. Further, emissions from charging can be reduced if charging occurs during the day when renewable generation is higher.

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[127] State of Hawaii, Department of Budget and Finance. Department of Transportation Budget FY2022-23

[128] Oʻahu Metropolitan Planning Organization (2023) 2045 Oʻahu Regional Transportation Plan

- BEVs also have substantially more efficient drive trains (Facet 1), a conventional gas internal combustion engine (ICE) with “good-fuel efficiency” may get ~30mpg. For BEVs, the mpg$_e$ of over 100mpg$_e$ is easily achieved, with the best EVs getting as much as 150 mpg$_e$ in the city, and 133 on the highway[129]

b) Alternative Fuels: The use of alternative fuels like biofuels, natural gas, and hydrogen can also help reduce the carbon footprint of transportation, particularly in vehicles that are harder to electrify such as medium and heavy-duty vehicles.

How these mechanisms can drive Decarbonization is further discussed in Chapter 4.

Hawaiʻi’s Ground Transportation and Regulatory Framework

The Hawaii Department of Health (DOH) collaborates with the U.S. Environmental Protection Agency and participates in the federal State Clean Diesel Program.[130] The DOH utilizes EPA Diesel Emissions Reduction Act (DERA) grants to reduce diesel emissions from existing older, air polluting diesel engines operating in the state. The Hawaii Green Infrastructure Authority (HGIA) provides a revolving credit line of up to $50,000,000 to state government entities for the purchase or lease of electric vehicles and the installation of electric vehicle supply equipment.[131]

Under the Clean Air Act, states in violation of National Ambient Air Quality Standards (NAAQS) under the Clean Air Act (CAA) are required to adopt enforceable plans to achieve and maintain air quality meeting the air quality standards. State plans also must control emissions that drift across state lines and harm air quality in downwind states. Those state plans, with Congestion Mitigation/Air Quality program incentives implemented at the state and county level have been extremely effective in reducing ground transportation emissions, with zero emissions vehicle (ZEV) and transportation control measures to reduce vehicle miles travelled (VMT) among them.

Because Hawaiʻi is not currently in violation of NAAQS, Hawaiʻi is restricted from enacting and imposing certain motor vehicle-related policies as a CAA compliance measure.

There is also a CAA federal preemption (*CAA §209, 42 U.S.C. §7543*) that prohibits states “to adopt or attempt to enforce its own standards for the control of emissions from new motor vehicles or new motor vehicle engines”, unless it “has adopted standards (other than crankcase emission standards) for the control of emissions from new motor vehicles or new motor vehicle engines prior to March 30, 1966”. Waivers may be granted for states proposing standards that are at least as strict as the federal standards. California is the only state to have been granted a waiver of the federal preemption under the CAA.

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[129] US Department of Energy and US Environmental Protection Agency (2023) FuelEconomy.gov.

[130] State of Hawaiʻi, Department of Health (2023) Clean Diesel Program – Disel Emissions Reductions Act (DERA)

[131] Hawaiʻi Green Infrastructure Authority (2023) Energy Efficiency Financing for State of Hawaiʻi Departments/Agencies

That waiver, except during the Trump Administration when the waiver was revoked, has permitted California to establish and manage a ZEV Standard as part of its Advanced Clean Cars program. Under that program, California requires 35% of new light-duty vehicles (passenger cars, SUVs and light-duty trucks) sold in California to be zero-emission starting in 2026, increasing to 68% in 2030 and 100% in 2035. This essentially bans the sale of *new* internal combustion engine light-duty vehicles in California from 2035. Several other states have adopted earlier versions of the California's ZEV standard.

Although no other state has yet been granted a waiver from EPA jurisdiction so that it can set its own motor vehicle standards, certain states are allowed to adopt and enforce California's standards. These states must have areas within their state that are not in attainment of NAAQS and have an EPA approved nonattainment plan provision (Clean Air Act § 177, 42 U.S.C. § 7507). It is worth repeating that Hawaiʻi is consistently in attainment with all NAAQS and therefore is ineligible to adopt CAA-like enforcement measures such as California's ZEV standard.

Hawaiʻi, nonetheless, continues to search for non-CAA measures to drive required changes to vehicle fuels and vehicles to support its robust GHG emissions target. Washington has a state-wide commitment to reduce GHG emissions by 95% by 2050. California is aiming to reduce GHG emissions throughout the state by 80% by 2050. It is important to keep in mind, however, that compared to California, Oregon, and Washington, Hawaiʻi does not implement as many alternative fuel programs and incentives to attract alternative fuel supply, largely due to small vehicular market size. Programs in Oregon, California, and Washington that Hawaiʻi may choose to emulate are briefly reviewed below.

Oregon, with the Small-Scale Local Energy Loan Program, offers low-interest loans for qualified programs for alternative fuel projects including feedstocks.132 Property used to produce biofuels, including ethanol and biodiesel, may be eligible for a property tax exemption if it is located in a designated Rural Renewable Energy Development Zone in Oregon.133

The California Energy Commission (CEC) administers the Clean Transportation Program to provide financial incentives with the goal of developing renewable fuels. The Program invests up to $100 million annually in a broad portfolio of transportation and fuel transportation projects throughout the state. California also has a multi-sector GHG cap-and-trade program.

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[132] Oregon Department of Energy (2021) Small Scale Local Energy Loan Program, Legislative Report

[133] For a summary of Oregon laws and incentives for alternative fuels, *see US Department of Energy Alternative Fuels Data Center, Oregon Laws and Incentives*

A cap-and-invest program has gone into effect in Washington during 2023, which sets a limit, or cap, on overall carbon emissions in the state and requires businesses to obtain allowances equal to their covered GHG emissions.[134]

Funds from a carbon dividend system, Section 1.4 could fund gaps in transit programs.

Aviation

Aviation is an essential part of Hawaiʻi's economy, connecting the islands to each other and to the rest of the world. Given Hawaiʻi's geographical isolation as one of the world's most remote island chains, residents and visitors rely heavily on aviation as the only practical form of transportation between Hawaiʻi and the continental U.S., and between Hawaiʻi and international destinations. The shortest aerial distance between Hawaiʻi and the continental U.S. covers approximately 2,500 miles, emphasizing the significance of air travel. Aviation is also relied on for travel between islands. Additionally, aviation serves as a critical component in the transport of cargo and mail, facilitating the flow of goods and communication.[135] However, it's important to acknowledge the extensive use of air travel also contributes substantially to GHG emissions, as documented in data provided by the DOH GHG report.

The DOH GHG inventory follows the IPCC Guidelines for National Greenhouse Gas Inventories,[136] which recommends that emissions resulting from the combustion of fuels used for international transport activities be excluded from emission totals and instead be reported separately. This is a standard implemented by IPCC to avoid possible double counting. Emissions from international travel are commonly referred to as international bunker fuels (IBF).

Domestic aviation includes only domestic flights originating in Hawaiʻi and departing to US states and territories – or flights from Hawaiʻi to US states and territories, or interisland trips.

Flight Miles Travelled by Destination

In 2019, Hawaiʻi interisland short-haul flights made up approximately 6% of total flight miles traveled from Hawaiʻi and 64% of total flight miles were to the U.S. continent, Alaska, and U.S. Territories. All these flights comprise domestic aviation, included in the state inventory. International flights departing from Hawaiʻi made up about 30% of the total flight miles in 2019 (Figure 33).[137] Since the pandemic, however, international travel has not fully recovered leading

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[134] State of Washington Department of Ecology (2023) Washington’s cap-and-invest program

[135] US Bureau of Transportation Statistics (2023) U.S. Airline Traffic by Airport

[136] Intergovernmental Panel on Climate Change (IPCC) 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[137] Bureau of Transportation Statistics (BTS), 2019. Form 41 BTS Filings All Carriers T-100 Segments

to lower international values in 2022. Domestic aviation, flights to the continent, have largely made up for the difference.

Figure 33 Total Flight Miles by destination category. International - represents flights destined for international locations outside the United States; Interisland - flights between the Hawaiian Islands; Domestic - represents flights within the United States excluding Hawaiian inter-island routes. The chart segments are proportionally sized based on the total flight miles attributed to each destination category, providing a visual insight into the distribution of flight distances departing from Hawaiʻi. Data from Bureau of Transportation Statistics (BTS), 2019 and 2022.

Jet Fuel Consumption

GHG emissions from the aviation sector are directly correlated with jet fuel consumption. The aviation sector in Hawaiʻi, used 17.8 million barrels of jet fuel in 2019 (Figure 34). Jet fuel consumption, is increasing by 4% per year on a global level and by about 2% in Hawaiʻi.[138]

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[138] Kahandawala, M. S., DeWitt, M. J., Corporan, E., & Sidhu, S. S. (2008). Ignition and emission characteristics of surrogate and practical jet fuels. *Energy & Fuels*, *22*(6), 3673-3679.

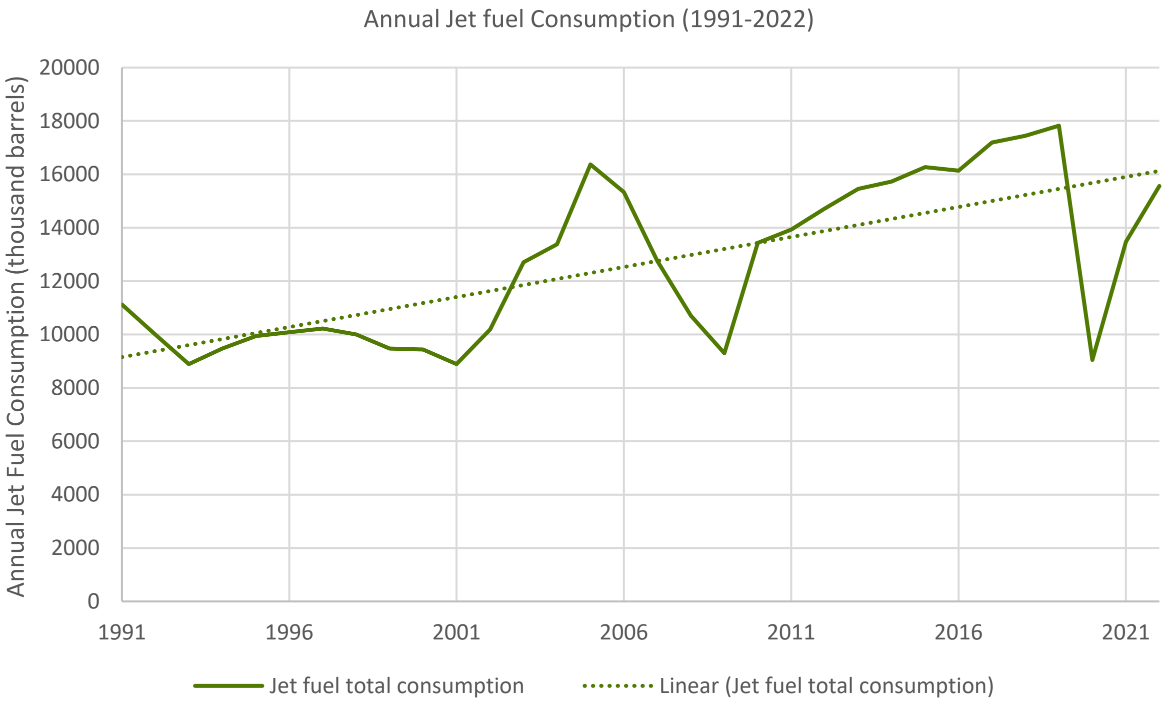

Figure 34 Hawai'i Jet Fuel Consumption, shown in thousands of barrels, since 1991. Data from EIA, State Energy Data System (SEDS).[139]

Aviation GHG Emissions

In 2019, domestic aviation alone contributed an estimated 4.95 MMT of CO_2e, making up 22.5% of the state's total 22.01 MMT of GHG emissions. Military aviation accounted for an additional 0.88 MMT, making up 4% of the state's total emissions of CO_2e in 2019 (Figure 13).

The total GHG emissions reported for the state does not include international flights (i.e., bunker fuel emissions), which were responsible for about 1.53 MMT Co_2e in 2019.[140] If emissions from outbound international flights were included in the state's total, the aviation sector would account for about 32% of Hawai'i's total GHG emissions. By not including international flights in Hawai'i's GHG totals, the aggregated totals do not account for about 21% of the aviation emissions (Figure 35).

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[139] EIA 2023, State Energy Data System. API Browser. Jet Fuel Consumption in the Transportation Sector, Hawaii.

[140] State of Hawai'i, Department of Health, 2023. Hawai'i Greenhouse Gas Emissions Report for 2005, 2018, and 2019: Final Report.

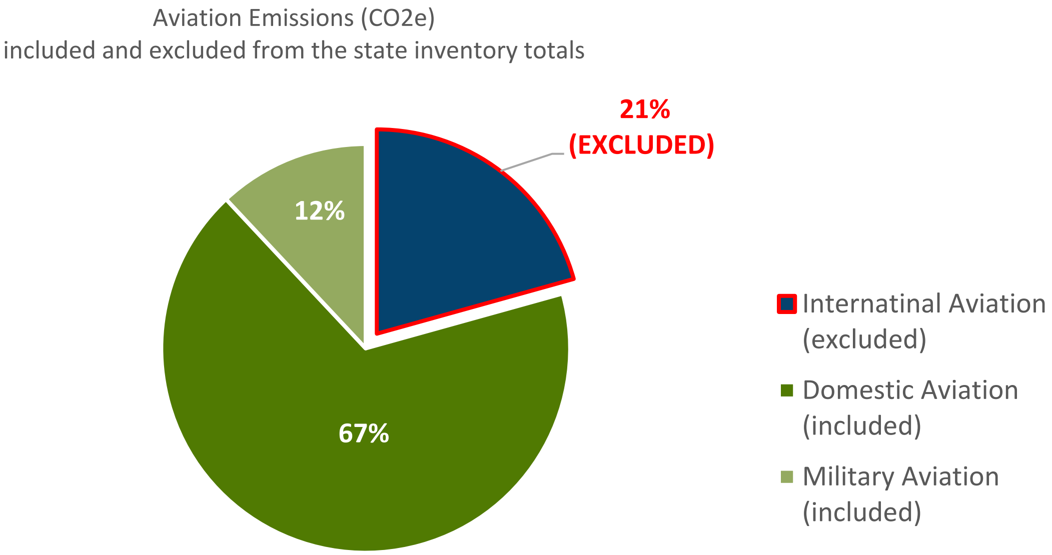

Figure 35 Aviation GHG emissions (CO_2e) broken down by sector. Red outline indicates the proportion of GHG emissions not included in the calculation of Hawai'i's total GHG emissions.

Non-CO_2 Aviation Emissions

Carbon dioxide represents the primary contributor to "climate forcing" associated with aviation, and its effects are now quantified and well-documented. However, there are other non-CO_2 aviation emissions that are not classified as greenhouse gases under the Kyoto Protocol and therefore are not included in the GHG inventory but have a significant indirect influence on the climate.[141]

It is noteworthy, that the impact of these emissions on climate change varies in intensity and longevity depending on the altitude at which the emissions are released.[142, 143] The aviation sector is unique compared to other sectors in that most of its emissions are released during aircraft cruising at altitudes ranging from 33,000 to 42,000 feet.

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[141] Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., ... & Zhou, B. (2021). Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change. *Clim. Change*, *3*, p. 31.

[142] Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C., Lim, L. L., ... & Sausen, R. (2009). Aviation and global climate change in the 21st century. *Atmospheric environment*, *43*(22-23), 3520-3537.

[143] Matthes, S., Lim, L., Burkhardt, U., Dahlmann, K., Dietmüller, S., Grewe, V., ... & Skowron, A. (2021). Mitigation of non-CO2 aviation's climate impact by changing cruise altitudes. *Aerospace*, *8*(2), 36.

The non-CO_2 aviation emissions and their climate effects resulting from burning jet fuel at high altitudes are:

- Water vapor and emission of soot particles which together can stimulate the formation of persistent linear contrails-cirrus (warming effect);[144]
- Emission of sulphate particles (cooling effect);
- NO_x emissions (net warming effect - resulting from the formation of short-term tropospheric ozone, a longer-term reduction in ambient methane (cooling effect), and a further longer-term small decrease in ozone (cooling effect)); and
- Aviation-induced cloudiness (potentially a warming effect).[145]

Globally, the sum of quantified non-CO_2 contributions accounts for about 66% of aviation radiative forcing. In other words, non-CO_2 emissions account for approximately two thirds of aviation induced warming.[142, 143]

Current Aviation Industry Efforts to Reduce Emissions

Over the past several decades aviation has made significant improvements in fuel efficiency, achieved via improved weight reduction, integration of more efficient engines, better wing design, and route optimization. However, these improvements have been largely diminished by the increased air travel demand.[146] Furthermore, incremental gains in fuel efficiency are becoming more difficult as technology has matured. The highest rate of fuel burn reduction for new aircraft is predicted to be no more than 1.37% each year, which is well below the 2% global annual average fuel efficiency improvement goal through 2050 set by the International Civil Aviation Organization (ICAO), one of the agencies responsible for accounting and suggesting options for managing emissions from international aviation.[147] The computed 1.37% per year long-term fuel efficiency includes the combined improvements associated with both technology and operations.

Aircraft design, which has remained largely the same over the past several decades, would have to radically change to achieve more significant fuel efficiency gains. However, these new transformations in aircraft design are not commercially available and if they were available, it would take at least a decade to penetrate fleets.[146] Efficiency gains will likely not be able to keep

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[144] Kärcher, B. (2018). Formation and radiative forcing of contrail cirrus. *Nature communications*, *9*(1), 1824.

[145] Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., ... & Wilcox, L. J. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric Environment*, *244*, 117834.

[146] Intergovernmental Panel on Climate Change. (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change: Chapter 10, Transportation (Section 10.5: Decarbonisation of Aviation)*. Cambridge University Press.

[147] Cumpsty, N. et al., 2019: *Independent expert integrated technology goals assessment and review for engines and aircraft*. International Civil Aviation Organization, Montréal, Canada, 225 pp.

up with increasing air travel demand globally estimated to be increasing far beyond efficiency improvement goals of 2% per year.

Another reason why the aviation sector is difficult to decarbonize is that it requires steady and transformational growth. Planes have a long operational lifespan, typically ranging from 20 to 30 years, or longer. This means that the technology of aircraft in use today will continue to affect emissions for decades to come unless drop-in low-carbon fuel alternatives can be developed and can meet the fuel demand.[148] Decarbonizing aviation often entails increased costs, especially in the early stages of adopting new technologies or alternative fuels. This can create economic challenges for airlines and passengers, impacting ticket prices and profitability.

Alternative Aviation and Alternative Fuel Technologies

Electric Aircraft

The concept of electrification in aviation has gained attention as a potential solution for reducing emissions; however, the technology is limited to smaller aircraft and short-haul flights. Electric propulsion systems application to larger aircraft and long-haul flights does not currently exist; therefore, most aircraft serving Hawaiʻi residents cannot be electrified. The primary obstacle hindering the adoption of electric propulsion in aircraft remains the weight of the batteries. The energy density of current batteries (i.e., energy per kilogram) falls short of the demands posed by most aircraft and the weight of the battery hinders the aircraft's ability to lift off the ground. Accordingly, in the conservative projection analysis presented in Chapters 4 and 5 it was assumed that battery technologies will not be developed in the timescale needed, by 2045, and can only displace emissions from short-haul (interisland) flights with fewer than twelve passengers.[149]

REGENT, a Boston-based company, has been combining boat and plane features to develop unique electric vehicles called *Seagliders*, which operate exclusively over water. This vehicle utilizes the wing-in-ground effect and uses aerodynamic forces to help it fly at very low altitude above the sea's surface. Apart from for takeoff and landing, it is not in direct contact with the water. Southern Airways, including Mokulele Airlines, and Hawaiian Airlines have invested in the development of these seagliders – both the 12 passenger Viceroy as well as the 50-100 passenger Monarch. Further development, including charging infrastructure assessments, rigorous safety testing certification processes, and feasibility analysis is still needed. Presently, REGENT has achieved a milestone by successfully conducting test flights using a quarter-scale proof-of-concept pilotless prototype. It will likely require several years before these vehicles undergo extensive testing and certification processes to guarantee adherence to maritime and potentially aviation regulations. Only after meeting these rigorous standards will seagliders become

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[148] Klöwer, M., Allen, M.R., Lee, D.S., Proud, S.R., Gallagher, L. and Skowron, A., 2021. Quantifying aviation's contribution to global warming. *Environmental Research Letters*, *16*(10), p.104027.

[149] Crownhart, C. (2022, August 17). *This is what's keeping electric planes from taking off | MIT Technology Review.* MIT Technology Review; MIT Technology Review.

commercially available. No boat or aircraft can enter commercial service until certification is completed, and that applies to REGENT seagliders as well. However, the process is expected to be much quicker for seagliders than for aircraft due to the maritime path vs the aviation path. Southern/Mokulele is planning to bring twelve-passenger seagliders to Hawaiʻi by the end of 2026 or early 2027. While ambitious, this may be more feasible than conventional electric aircraft because seagliders are not considered aircraft.

Alternative Aviation Fuels

The Royal Society, an independent scientific academy, recently published a policy briefing on *Net zero aviation fuels: resource requirements and environmental impacts.* The briefing summarizes different options to decarbonize the aviation sector, and rightfully points out that the selected solutions need to be globally accepted and the options available to date offer some carbon savings but are not ideal.[150]

The Royal Society Policy Brief states, *"it is important that the alternative fuels adopted are truly beneficial to the fight against the climate crisis and do not cause unacceptable collateral ecological damage."* HSEO echoes this statement and notes that the state must apply this precaution to all alternative fuels regardless of the end use sector.

Developing a sustainable supply chain for alternative aviation fuels, such as biofuels, hydrogen, or synthetic fuels is a complex task that involves issues related to feedstock availability, production scalability, distribution, and especially for the context of emissions reduction - a proper lifecycle analysis (inclusive of emissions analysis), discussed further in Chapter 5. The aviation industry also faces challenges in terms of public perception and acceptance of new technologies and changes in travel practices. Passengers and the broader public need to be willing to adopt and support low-carbon aviation options.

The four categories of alternative aviation fuels are broadly: 1) Biofuels, 2) Synthetic fuels, 3) Hydrogen, and 4) Ammonia, where biofuels and synthetic fuels can generally be referred to as Sustainable Aviation Fuel (SAF). These fuels are summarized in Table 10.

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[150] The Royal Society, 2023. Net zero aviation fuels – resource requirements and environmental impacts policy briefing. Issued February 2023.

Table 10 Types of Alternative Aviation fuels currently being evaluated by the aviation industry.

Fuel	Description	Substantial Infrastructure Upgrades at Airports?	New Airframe and Modified Aircraft Design?
Biofuels	Various pathways exist for producing biobased SAF. Feedstocks are generally comprised of plant and animal fats, oils, and greases such as tallow, cooking oil, camelina, and soybean oil; sugars from cane, sorghum, sugar beets, tubers, etc.; agricultural residues such as stover, grasses, forest residues and herbaceous energy crops, bio-derived hydrocarbons from algal oils, and gasified sources of carbon and hydrogen from forestry residues or MSW).	No - Considered a Drop-In Fuel	No - Considered a Drop-In Fuel
Synthetic Fuels	Produced from renewable energy sources through processes called Power-to-Liquid (PtL) synthetic fuel, or e-fuels, exhibits potential in reducing greenhouse gas emissions. In the PtL technique, renewable hydrogen combines with captured carbon (extracted from an industrial outlet or directly captured from the atmosphere) to produce methane. This methane can subsequently undergo conversion into a liquid fuel using gas-to-liquids technology. Power-to-liquids technology is still in its early stages and large-scale production feasibility and cost-effectiveness remain key concerns. The production of e-fuels requires substantial energy input.	No - Considered a Drop-In Fuel	No - Considered a Drop-In Fuel
Hydrogen	Hydrogen is an alternative fuel and is used in aircraft either as a hydrogen-electric fuel cell producing electricity to drive propellors or direct liquid hydrogen (LH2) burnt in combustion engines. Both liquid hydrogen and fuel cells have only been used in a few small experimental flights thus far. Hydrogen has specific storage and handling requirements that differ from conventional fuels, which necessitates major infrastructure upgrades and substantial workforce training given safety considerations. Although surpassing the energy density per mass of jet fuel, LH2 also has about four times less energy density by volume, taking up valuable space in the aircraft.	Yes - Adoption of hydrogen at scale requires substantial changes to infrastructure for hydrogen fuel production, as well as storage and distribution at the airports.	Yes – current R&D underway
Ammonia	Like LH2, ammonia (NH3) can be used as a fuel either in a fuel cell or through direct combustion. Compared to hydrogen, NH3 has a higher energy density per unit of volume - meaning it requires less space on the aircraft. Ammonia is a toxic gas and corrosive - safety precautions and substantial workforce training would be necessary.	Yes -Distribution and storage, no cryocooling.	Yes - current R&D underway

The environmental and GHG caveats associated with alternative fuels including biofuels, hydrogen, and ammonia are further discussed in Chapter 5.

Ammonia, hydrogen, and electric battery technologies to date are not anticipated to meet the long-range distances required by Hawaiʻi travelers. Concept aircraft, developed by Airbus, have maximum ranges of 2,000 nautical miles – precluding the Hawaiʻi market.[151] Further, the direction of the industry is largely toward SAF; therefore, these fuels were assumed in the analysis presented in Chapter 5, noting SAF also has substantial hurdles to overcome, including a substantial increases in local, national, and international production to meet demand needs.

Sustainable Aviation Fuels

In the quest for sustainable aviation, the aviation industry confronts a complex landscape of alternative fuels. While promising options like hydrogen and biofuels exist, challenges surrounding technological readiness, infrastructure, and the comprehensive assessment of emissions persist. In the near term, focusing on drop-in fuels, particularly biofuels and SAF, is pivotal as the industry endeavors to balance sustainability and operational viability. The advantage of these fuels is their compatibility with existing infrastructure and engines, avoiding the need for substantial modifications or technological overhauls. This characteristic facilitates a smoother transition toward alternatives. However, despite the promise of drop-in fuels, uncertainties linger regarding their full environmental impact. Assessing the net emissions of biofuels, for instance, involves considering the entire lifecycle, including feedstock cultivation, processing, and distribution.

The rise of SAF aimed at curbing aviation's carbon footprint is a growing field of exploration. ASTM International, formerly known as the American Society for Testing and Materials, responsible for aviation fuel standards, has certified seven types of SAFs from nine different pathways with blends currently limited to 50%.[152] The industry aims to reach 100% blending in the foreseeable future. Various types of feedstocks can be used including biofuels sourced from vegetable and animal fats, oils, and greases (FOG), dedicated, waste crops, or another biomass, or MSW. Alternatively, SAF can be produced via a chemical process that captures carbon directly from the air instead of getting from organic matter (synthetic fuels).

Feedstock availability and the high cost of bio-SAFs, around three to five times that of jet fuel, remain significant obstacles.

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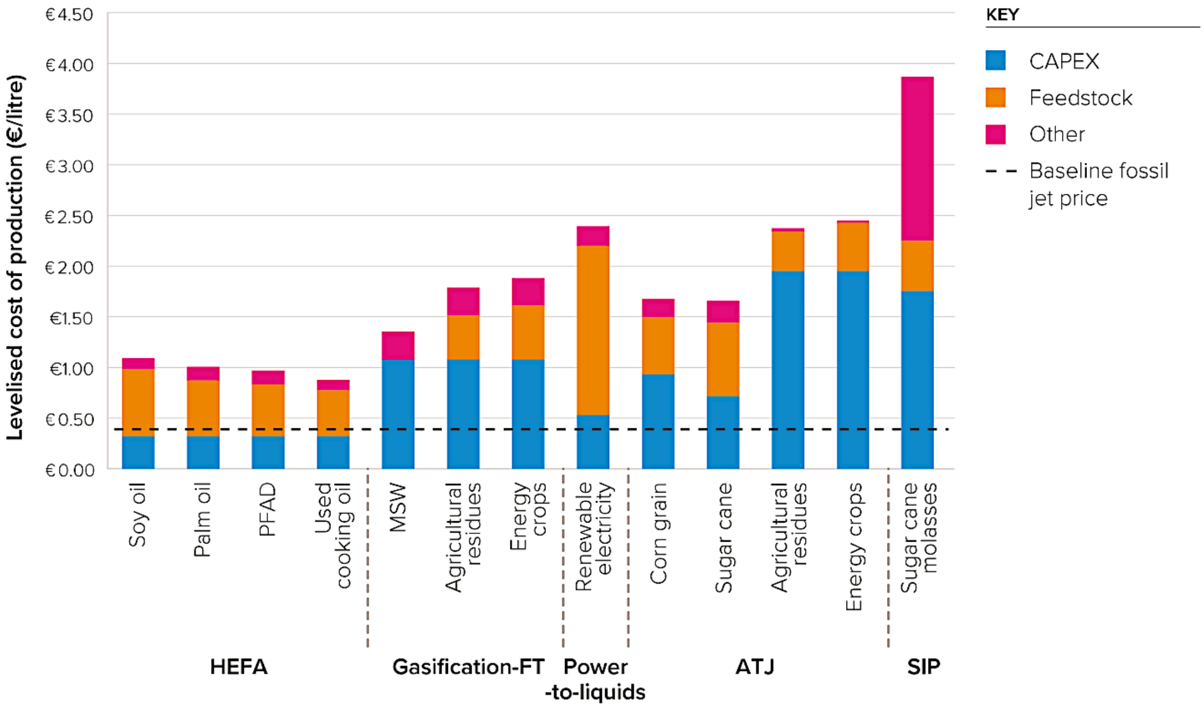
[151] Airbus ZEROe (2023) Towards the world’s first hydrogen-powered commercial aircraft

[152] US Department of Energy (2023) *Alternative Fuels Data Center: Sustainable Aviation Fuel*



Source: The International Council on Clean Transportation[48]

Figure 36 Estimated levelized costs of aviation fuels for various energy conversion pathways. Picture source: Royal Society Policy Briefing.[153]

Tackling aviation emissions at a state level presents substantial challenges, largely due to the cross-border nature of the issue. For instance, federal authorities establish emissions standards for aircraft, superseding any state-level regulations.[154] Overcoming these hurdles demands a collaborative approach involving governments, industry stakeholders, researchers, and the public. This collective effort is essential to drive the decarbonization of the aviation sector while safeguarding its economic sustainability and global connectivity.

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[153] The Royal Society, 2023. Net zero aviation fuels – resource requirements and environmental impacts policy briefing. Issued February 2023. https://royalsociety.org/-/media/policy/projects/net-zero-aviation/net-zero-aviation-fuels-policy-briefing.pdf *The text of this work is licensed under the terms of the Creative Commons Attribution License which permits unrestricted use, provided the original author and source are credited.*

[154] 42 U.S.C. § 7573 *("No State or political subdivision thereof may adopt or attempt to enforce any standard respecting emissions of any air pollutant from any aircraft or engine thereof unless such standard is identical to a standard applicable to such aircraft under this part.*"); 49 U.S.C §§ 40101, 41713.

Aircraft Emissions while Parked

Hawaiʻi has taken proactive steps to address air pollution and GHG emissions originating from aircrafts parked at airports within the state, while at the ramp HNL and other major airports with the exception of Kona and Hilo and encourages and provides the infrastructure for all wide-bodied aircraft to be powered by external electric power (i.e., ground power units (GPU)), when parked at the gate instead of using the aircraft's auxiliary power unit, or APU, which burns jet fuel to keep lights, avionics systems, air conditioning and other equipment on. Aircraft are also encouraged to use preconditioned air (PCA). The use of PCA and GPU has helped reduce air pollution and GHG emissions at Hawaiʻi's airports. Kona is hard standing (enplaning and deplaning by stairs), and Hilo has no transpacific flights so enplaning and deplaning is much quicker with interisland carriers, as the aircraft are smaller making external electric power more challenging.

While not accounted for in the aviation sector, the airports have also installed significant amounts of rooftop and solar canopies (elevated solar panels that provide shade over parking lots. These panels reduce the energy consumption at state airports. These initiatives have saved the state money on electricity bills and placed generation next to areas where there is significant demand.

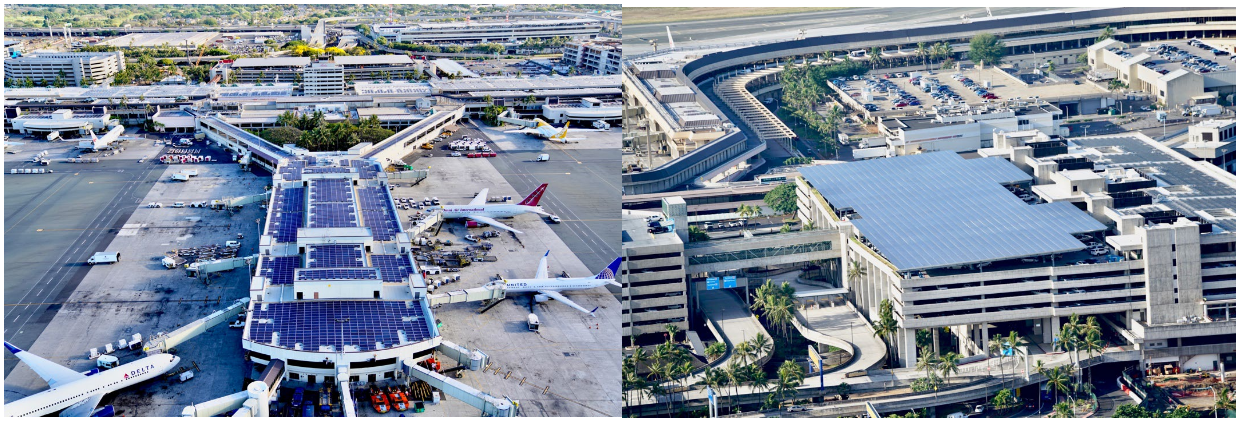

Figure 37 Solar photovoltaic panels at HNL. Image courtesy of HDOT. At the time of installation, these panels represented the single state Energy Savings Performance Contract in the nation. These panels reduce airports energy demand, but also allow for aircraft to plug-in when parked on the ramp to GPUs.

Marine Transportation

Marine transportation plays a distinctive role in the state's economy. While it may not be as essential for the movement of people, marine transportation holds immense significance[155] as a cornerstone for the import and transportation of cargo such as food, fuel, construction materials, and manufactured goods. Emissions from the marine transportation sector include only the emissions from burning marine bunker fuels when fueled in-state and departing to a domestic destination. It is feasible for some ships, particularly large tankers to make it to Hawaiʻi and back to another destination without refueling.[156] It is important to note, in-port land-based activities, such as heavy equipment operations are ultimately accounted for in the ground transportation sector (offroad vehicles).

The state's ports serve as a lifeline, ensuring the timely delivery of vital commodities to the islands. The state's largest commercial port, Honolulu Harbor, handles a wide range of cargo. Hawaiʻi also has nine (9) smaller ports that serve the outer islands; one of the Maui ports (Hana) is inactive. All cargo, whether it originates from foreign or domestic ports, initially arrives at one of the cargo handling terminals in Honolulu Harbor. For cargo destined for a neighboring island, it is subsequently transferred through Honolulu Harbor before reaching its ultimate destination. Honolulu Harbor also assembles export and outbound shipments from other islands. In fiscal year 2022, Honolulu Harbor moved about 10.3 million short tons of cargo.[157] Because the harbors are a lifeline for the state, it is important to acknowledge costs associated with decarbonization of ports, particularly if mandated and borne by the private sector, could have major repercussions to the costs of all essential goods in the state. Therefore, regulation in the marine transportation sector must be done mindfully so as not to inadvertently increase costs that get passed to the end user, particularly for essential goods. Another challenge facing Harbor tenants is adopting infrastructure improvements typically done through tenant improvements projects when the facilities they build-on are likely to be impacted by sea level rise. DOT-HAR is actively working on this challenge.

In addition to commercial shipping, Hawaiʻi is also a major hub for cruise tourism. The state's four cruise ports (Honolulu, Hilo, Kona, and Maui) host around 200,000 to 300,000 cruise visitors each year.[158]

As discussed in the aviation section, emissions from bunker fuels associated with international marine transportation are not incorporated into the state's greenhouse gas (GHG) inventory. The DOH inventory integrates only emissions arising from *domestic* marine transportation into the

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[155] A recent study showed that about 85% of everything we use in Hawaiʻi is imported and 91% of that comes through Hawai'i's Harbors System, The Value of Hawai'i's Commercial Harbor System, SMS 2021.

[156] American Petroleum Institute (2011) Fueling American Life

[157] Hawaiʻi Department of Transportation (April 2023) *Cargo Statistics Public Overview*

[158] DBEDT (2019) Hawaiʻi Tourism Authority *Annual Visitor Research Report.*

state’s GHG emissions inventory. Marine emissions stemming from international bunker fuel consumption are reported independently, in accordance with guidelines established by the IPCC (refer to Box 1 for details). Emissions arising from fuel use for the navigation of all vessels engaged in activities other than international transport, except for fishing vessels and military maritime, are integrated into the DOH’s GHG under the category of domestic Marine Travel.

According to DOH, in 2019 emissions from domestic marine transportation were 0.65 MMTs, which accounted for 6% of the overall emissions originating from the transportation sector in Hawaiʻi (Figure 28). However, it's important to note that the apparent lower portion of GHG emissions attributed to shipping may underestimate emissions from the marine sector in Hawaiʻi due to IPCC calculation standards. International shipping is the largest component of marine transportation, and it is not included in inventory calculations. Further, some ships servicing Hawaiʻi may not have to refuel in Hawaiʻi ports.

In 2019, ships worldwide transported approximately 11.08 billion tons of globally traded goods, which amounts to about 1.4 tons of transported good per capita.[159] Although accurate data regarding the worldwide transportation of goods is not available due to inadequate recording of statistics by numerous countries, it is estimated that about 80-90% of globally traded goods are transported via maritime shipping[160]. Globally, international shipping is responsible for more GHG emissions (~9% of transportation sector’s total) than international aviation (7% of the sector’s total). Alarmingly, “if the global maritime shipping industry were a nation, it would rank as the sixth-highest global emitter of GHGs, as indicated by the U.S. Department of Energy” (U.S. DOE). Shipping is currently experiencing significant growth, and its GHG emissions are projected to grow by 90-130% by 2050 from 2008 levels[161], underscoring the need to account for its substantial GHG contributions in comprehensive emissions assessments.

Like the aviation sector, many of the GHG reduction strategies for the maritime industry will require global acceptance. The International Maritime Organization (IMO), a United Nations agency responsible for safety, secure, and efficient shipping, formally adopted the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, outlines strategies to reduce emissions from shipping. Strategies recommended included a focus on carbon intensity standards to encourage adoption of low-emissions fuels (from a well to wake perspective); and the introduction of market-based measures to complement “control-and-command" policies – including carbon taxes or feebates. [162]

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[159] United Nations Conference on Trade and Development (UNCTAD) (2020). *Review of Maritime Transport 2020*

[160] UNCTAD (2022) *Review of Maritime Transport 2022.*

[161] International Marine Organization (IMO)(2021) Fourth IMO GHG Study 2020

[162] International Energy Industry (IEA) (2023). International shipping

The Jones Act and Maritime Emissions

Based on stakeholder outreach, there is considerable confusion and misunderstanding surrounding the Jones Act and its influence on Hawaiʻi and its economy. Some of the confusion may be arising from the erroneous attribution of other laws as part of the Jones Act—specifically, the Passenger Vessel Services Act of 1886 and various cabotage laws, which are often incorrectly referred to as the Jones Act.

The Jones Act, delineated as Section 27 within the Merchant Marine Act of 1920 (46 U.S.C § 55102), stands as a distinct federal law governing maritime commerce within U.S. waters and between U.S. ports. It is important to understand that it pertains exclusively to domestic maritime trade, encompassing exchanges between domestic ports.

Key provisions of the Jones Act mandate that vessels engaged in domestic trade:

a) Must be built in the United States;
b) Must be owned and controlled by U.S. citizens or companies with a minimum of 75% U.S. ownership;
c) Must operate under the U.S. flag; and,
d) Must be manned by U.S. citizens or lawful permanent residents (including the captain, officers, and a significant portion of the crew).

There is a common misconception that, due to the Jones Act, foreign vessels carrying foreign goods to Hawaiʻi must first journey to the U.S. mainland. This misconception implies unnecessary hikes in costs due to higher energy usage (and greater GHG emissions) because of the extra transportation required to bring those goods back across the Pacific Ocean to Hawaiʻi. However, this assertion is incorrect. Foreign ships transporting foreign goods from abroad are not subject to the Jones Act's regulations. They are allowed to, and often do, travel directly to Hawaiʻi to unload their foreign cargo without necessitating a visit to the U.S. mainland beforehand. Furthermore, these vessels can proceed to mainland U.S. ports to discharge additional foreign cargo. While in U.S. ports, they may even load American merchandise for export. Yet, they are prohibited by the Jones Act from selling U.S. merchandise within the USA. For instance, while they can potentially load Hawaiian pineapples while stopping in Hawaiʻi, these goods must be destined for export outside the U.S.; they cannot be taken by a foreign vessel to the mainland to be sold there.

Greenhouse Gas Emission Sources from the Marine Sector

The most prevalent fuel source for marine transportation is called residual fuel oil (RFO),[163] or heavy fuel oil (HFO). RFO is a thick and viscous liquid derived from the residue of crude oil distillation. For that reason, it is relatively cheap. Unfortunately, when burned RFO emits substantial quantities of CO_2 and contains high levels of sulfur, leading to the production of fine

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[163] US EIA State Energy Data System 2021 Consumption Technical Notes

particulate matter. Additionally, the combustion of RFO can generate black carbon, a potent absorber of solar energy, exacerbating climate effects.

The shipping industry has been pushed to start gradually using other fuels, such as distillate fuel oils (DFO), which are generally cleaner and emit less carbon dioxide and fewer particulate pollutants.[164, 165] International and regional regulations, such as the International Maritime Organization's (IMO) sulfur cap, have imposed stricter limits on the sulfur content of marine fuels. This has led to the increased use of lower-sulfur distillate fuels, especially within emission control areas (ECAs) and while ships are at berth in ports, to comply with these regulations and reduce emissions. Additionally, major companies operating in Hawaiʻi have adopted the use of exhaust emission cleaning systems, or scrubbers on their Hawaiʻi fleets.[166]

The industry is moving toward biofuels, natural gas-powered ships, ammonia, and methanol.[167]

Emissions while Docked in Port

GHGs stemming from domestic marine travel encompass not only emissions generated during voyages between ports, but also emissions resulting from the combustion of bunker fuels aboard vessels while they are docked in port. Ships require a continuous source of power, even when they are docked in port. This power is used for various functions, such as lighting, ventilation, air conditioning, refrigeration, and operating onboard equipment and systems. Instead of relying on shore-based electrical power, many ships continue to use their onboard generators, which are powered by bunker fuel.

Other onshore activities that use fuel may include cargo handling, ballast water management, waste treatment, and other services. Bunker fuel can be used to operate these auxiliary systems and auxiliary services. By keeping the ship's engines operational while in port, vessels can quickly disconnect from shore power and set sail without the need for extensive engine warm-up, facilitating a faster and more efficient departure.

Although using bunker fuel in ports provides convenience and flexibility to ships, the GHG emissions are significant. The emissions associated with in-port bunker fuel burning are explicitly measured in the GHG inventory and maybe excluded from the inventory entirely if the vessel is burning fuel sourced from outside of the state. Being able to quantify the amount of bunker fuel used in Hawaiʻi ports through mandatory reporting is essential for evaluating emissions and their

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[164] US EIA (2023) *Table A.3. Carbon Dioxide Uncontrolled Emission Factors.*

[165] US EPA (2023) Estimating Particulate Matter Emissions for eGRID. White Paper (2020)

[166] Matson (2023). LNG Conversions Next in Long-Term Climate Strategy.

[167] IEA (2023) Technology Collaboration Programme

associated effects and this capability is currently absent. Completing a port emissions inventory can improve current inventory accounting, given many of the accounting shortfalls.[168]

Given that most bunker fuels consist of RFOs, the burning of bunker fuels in ports not only adds to GHG emissions, but also poses significant environmental and health hazards because of the associated particulates affecting nearby communities.

This situation raises important questions of environmental justice in the context of ports and their impact on neighboring communities. As a result, there is a growing trend toward implementing shore power systems in ports, known as "cold ironing" or “shoreside power”, which allows ships to connect to cleaner and more environmentally friendly sources of electricity while at berth, reducing the need for onboard bunker fuel combustion in ports. However, the energy needs of these vessels are significant. Providing shoreside power to these vessels with electricity requires substantial upgrades to utility infrastructure at the ports. These vessels are “mini cities” from an energy perspective and could add substantial electrical demand to the utility grid, which the utility may not be able to accommodate. Further, if the industry moves to LNG-powered ships the tailpipe emissions associated with these vessels will be substantially lower, and the investment in substantially retrofitting the ports to accommodate shoreside power for large vessels may not be necessary. However, electrical infrastructure upgrades within the ports can allow for land-based emissions reductions by transitioning certain diesel-operated port equipment to electric.

A first step is understanding the need and determining if vessels that travel to Hawaiʻi ports can be powered with shoreside power.

2.4. Waste

Emissions from waste make up a small portion of the total in-state emissions, representing approximately 2% of total emissions statewide. However, emissions from the waste sector are predominantly methane (CH_4) and nitrous oxide (N_2O), both high global warming potential (GWP) greenhouse gases. When evaluating emissions from the waste sector, methane (CH_4) makes up 85% of the GHGs from the waste sector. This is particularly concerning given methane’s high global warming potential (GWP). The state inventory uses 100-year global warming potentials to calculate emissions, in accordance with IPCC guidelines; however, when evaluating or standardizing methane emissions over shorter time horizons, or using different GWPs to evaluate CH_4, the emissions would become more apparent (Table 11), underscoring the need to mitigate waste sector emissions. Methane for example is about 2.6 times more potent if evaluated over a 20-year time frame versus the 100-year time frame applied by inventories (Table 11). Further, waste management and waste utilization offer an opportunity to reduce emissions in other sectors (e.g. energy and agriculture) by moving toward a more circular economy and utilizing

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[168] US EPA (2023) *Port Emissions Inventory Guidance*

waste for energy or fuels through alternative processes such as pyrolysis or gasification[169], and/or by using the nutrients from green waste, as an alternative fertilizer far cleaner than fossil fuel-based fertilizers, a major source of greenhouse gases in the agriculture sector.

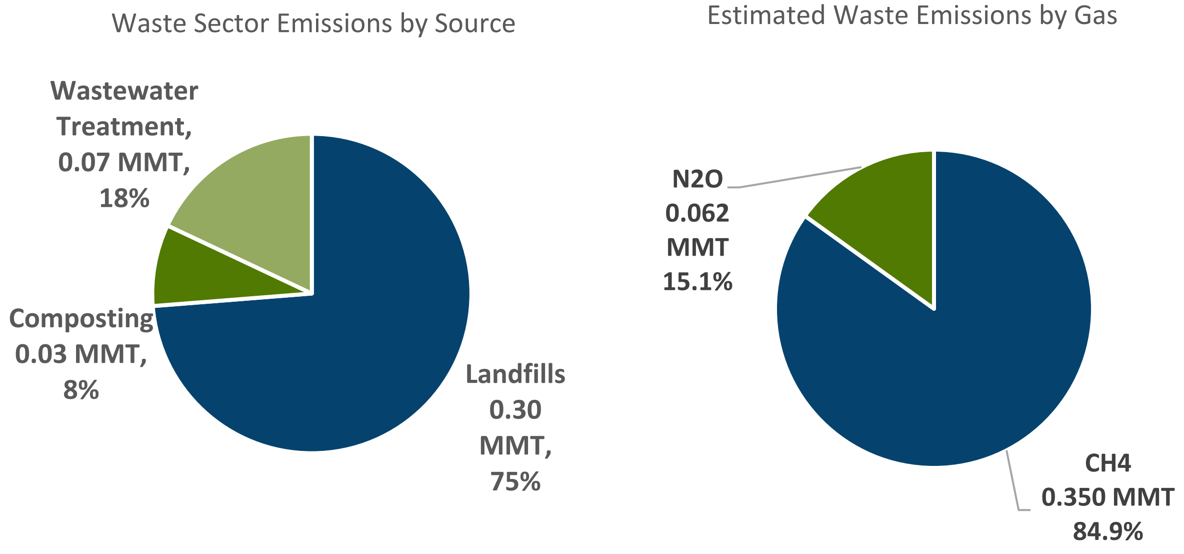

Figure 38 (Right) Estimated emissions from the waste sector by category or emissions source. (Left) Estimated emissions from waste by greenhouse gas. Data source, Hawai'i Department of Health, 2019 GHG Inventory, published April 2023. Emissions presented in CO_2e based on 100-year GWP.

An estimated 75% of emissions from the waste category are estimated to come from landfills, all of which is methane (CH_4). 17.5% of emissions are from wastewater treatment processes (microbial digestion) consisting of both nitrous oxide and methane. An estimated 7.5% of waste emissions come from composting with 58% and 42% of composting emissions coming from CH_4 and N_2O, respectively. Emissions in the waste category are not inclusive of waste that is incinerated, see Section 2.3 Waste Incineration.

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[169] Dong, et al., (2018). Life cycle assessment of pyrolysis, gasification, and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants. *Science of the Total Environment*, *626*, 744-753.

Table 11 Global warming potentials of GHGs in the waste sector over three different time horizons and GHG lifetime. Data Source United Nations IPCC Second Assessment Report: https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

GHG Species	Chemical formula	20 years	100 years*	500 years	Lifetime (years)
Carbon dioxide	CO_2	1	1	1	variable§
Methane**	CH_4	56	21	6.5	12 ± 3
Nitrous oxide	N_2O	280	310	170	120

The IPCC and the Hawaiʻi Inventory use 100-year Global Warming Potential (GWP) to calculate CO_2 equivalents. When the emphasis of the policy is limiting short-term non-linear climate responses, scientists have suggested that 20-year horizons are more applicable.[170]

*100-year global warming potentials from IPCC Second Assessment report to allow for comparison across time horizons. The 2019 inventory, published 2023, uses the fourth assessment values.
**Gases with higher 20-year GWPs than 100-year values. The short-term climate warming impact of these GHGs is underestimated by current inventory methodology.

Waste Sector Emissions by County

Honolulu, Hawaiʻi, and Maui County each represent about 1/3 of waste emissions, and Kauaʻi makes up a small portion of emissions. A large portion of Honolulu's municipal solid waste (MSW) goes to H-Power, if the waste was not incinerated, Honolulu's waste sector emissions would substantially increase.

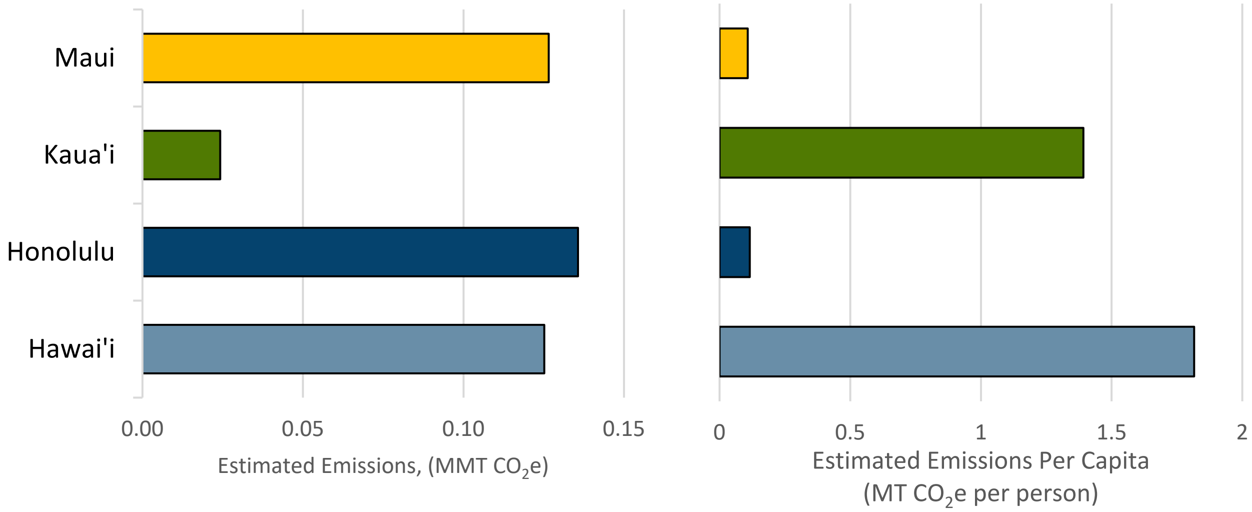

Figure 39 Waste sector emissions by County 2019. Data obtained from Hawaiʻi Department of Health, Greenhouse Gas Inventory, published April 2023. Oʻahu emissions per capita appear lower because most Honolulu MSW goes to H-POWER.

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[170] GTI Energy, Center for Methane Research. (2019). Implications of Using Different GWP Time Horizons.

Landfills

Landfills are the largest contributing category in the Waste Sector, representing an estimated 75% of Waste Sector Emissions. When MSW is deposited in a landfill, the organic material within MSW undergoes both anaerobic and aerobic digestion. During anaerobic digestion, methane (CH_4) is emitted when organic materials decompose in oxygen free environments. During aerobic digestion CO_2 is released; however, since the CO_2 released is biogenic, it is not included in inventory totals (thus methane is only accounted for), this is consistent with IPCC methodology; however, underscores the importance of diverting organic waste from solid waste landfills and minimizing non-organic waste.

Landfills are ultimately the responsibility of the Counties, or private entities that operate them. There are a total of 15 landfills in Hawaiʻi, with eight in operation and nine closed.

Landfills contribute most significantly to methane emissions. However, capturing and utilizing this methane as a clean energy source presents a viable solution to mitigate emissions while displacing the use of natural gas or oil. This approach can be advantageous from a climate perspective, offering a double benefit. The technology used to manage landfill methane is relatively simple; however, it is very costly, and often cost prohibitive particularly for established landfills unless the capture system is in place. Landfill gas (LFG) methane capture can achieve 85 percent efficiency or more in closed and engineered landfills; it is least effective in open dumps, where the collection efficiency is approximately 10 percent and capture is typically not seen as economically favorable.[171] As a waste treatment solution, landfill CH_4 capture is seen as a last resort and is preferred only to landfilling without methane capture. However, where landfills exist it is a solution for mitigating greenhouse gases.

The EPA administers the landfill methane outreach program (LMOP) and associated LMOP database, which tracks key data for municipal solid waste (MSW) landfills in the United States. The database also contains information on LFG energy projects in various stages.

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[171] Project Drawdown. (2020, February 6). Landfill Methane Capture | Project Drawdown.

Table 12 Landfills on Hawaii, including the year opened, the anticipated closure date, and if there is an LFG collection system in place. To date, no LFG WtE systems exist, and all LFG methane collected from the LFG collection system is flared.

Landfill Name	City	Landfill Owner Organization(s)	Year Open	Closure Year	Current Landfill Status	LFG Collection System in Place?	Current Project Status
Central Maui Landfill	Puʻunēnē	Maui County, HI	1987	2039	Open	Yes	Planned
Kekaha Landfills I & II	Kekaha	County of Kauai, HI	1953	2027	Open	Yes	Candidate
Waimanalo Gulch Landfill & Ash Monofill	Kapolei	City and County of Honolulu, HI	1989	2039	Open	Yes	Candidate
West Hawaiʻi Landfill/Puʻuanahulu	Waikoloa	Hawaiʻi County, HI	1993	2050	Open	Yes	Candidate
Hana Landfill	Hana	Maui County, HI	1969	2079	Open	No	Future Potential
Kaneohe Marine Corps Air Station Landfill	Kaneohe Bay	United States Marine Corps	1978	2024	Open	No	Unknown
Lānaʻi Landfill	Lānaʻi City	Maui County, HI	1969	2029	Open	No	Future Potential
Nāʻiwa Landfill	Kaunakakai	Maui County, HI	1993		Open	No	Future Potential
Closed Land Fills							
Kapaʻa and Kalaheo Sanitary Landfills	Kailua	City and County of Honolulu, HI	1970	1995	Closed	Yes	Shutdown
Palailai Landfill	Kapolei	Grace Pacific Company	1974	1988	Closed	Yes	Low Potential
Kapaʻa	Kailua	City and County of Honolulu, HI	1955	-	Closed	Unknown	Low Potential
Kailua Landfill	Kealakehe	Hawaiʻi County, HI	1975	1993	Closed	No	Low Potential
Kalamaula Landfill	Nāʻiwa	Maui County, HI	1970	1993	Closed	No	Low Potential
Olowalu Landfill	Lahaina	Maui County, HI	1967	1992	Closed	No	Low Potential
South Hilo Sanitary Landfill (SHSL)	Hilo	Hawaiʻi County, HI	1969	2019	Closed	No	Candidate

For landfills with and without capture systems, it is more cost-effective to both reduce total waste input and divert organic or green waste to composting facilities, Table 13. However, for landfills without these systems in place waste sorting programs and alternatives to landfills are crucial, especially given limited space throughout the islands for landfills and the limited life span of landfills. Other unique solutions, such as waste-to-fuels projects offer dual-benefit—reducing emissions from waste while producing necessary energy – either in the form of liquid fuels or gas products, such as sustainable aviation fuel[172] (SAF) or renewable natural gas. Taking advantage of chemical processes can have lower emissions than direct incineration, although full emissions benefits are dependent on feedstock type.[173] Local companies are currently working on developing this technology.

Composting

Composting plays an important role in combatting climate warming pollutants from reaching the atmosphere. While there are GHG emissions associated with composting, composting emissions are lower than methane emissions associated with organic waste being deposited in landfills per unit of waste produced. The US EPA publishes emissions factors for various waste products, based on the WARM model. The emissions associated with each disposal pathway are ultimately a function of the materials or input waste. Therefore, a one size fits all approach to waste management is typically not effective and there is a clear emission reduction value in waste sorting.

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[172] Schwartz, N. R., Paulsen, A. D., Blaise, M. J., Wagner, A. L., & Yelvington, P. E. (2020). Analysis of emissions from combusting pyrolysis products. *Fuel*, *274*, 117863.

[173] Environmental and Energy Study Institute (2017) Fact Sheet | Biogas: Converting Waste to Energy

Table 13 Emission factors for different waste materials and waste disposal methods. Source EPA GHG Emission Factor Hub.[174] *Emission factors from EPA's Waste Reduction Model (WARM). Higher value generally indicates higher emissions associated with the disposal method. Emission variation indicates the preferred disposal method is dependent on waste material.* [175]

	Metric Tons CO_2e / Short Ton Material			
Material	Recycled[A]	Landfilled[B]	Combusted[C]	Composted[D]
PLA - Biobased plastics	NA	0.02	0.01	0.17
Corrugated Containers	0.11	0.9	0.05	NA
Magazines/Third-class mail	0.02	0.42	0.05	NA
Newspaper	0.02	0.35	0.05	NA
Office Paper	0.02	1.25	0.05	NA
Phonebooks	0.04	0.35	0.05	NA
Textbooks	0.04	1.25	0.05	NA
Dimensional Lumber	0.09	0.17	0.05	NA
Medium-density Fiberboard	0.15	0.07	0.05	NA
Food Waste (non-meat)	NA	0.58	0.05	0.15
Food Waste (meat only)	NA	0.58	0.05	NA
Beef	NA	0.58	0.05	0.15
Poultry	NA	0.58	0.05	0.15
Grains	NA	0.58	0.05	0.15
Bread	NA	0.58	0.05	0.15
Fruits and Vegetables	NA	0.58	0.05	0.15
Dairy Products	NA	0.58	0.05	0.15
Yard Trimmings	NA	0.33	0.05	0.19
Grass	NA	0.26	0.05	0.19
Leaves	NA	0.26	0.05	0.19
Branches	NA	0.53	0.05	0.19
Mixed Paper (general)	0.07	0.8	0.05	NA
Mixed Paper (primarily residential)	0.07	0.77	0.05	NA
Mixed Paper (primarily from offices)	0.03	0.75	0.05	NA
Mixed Plastics	0.22	0.02	2.34	NA
Mixed Recyclables	0.09	0.68	0.11	NA
Food Waste	NA	0.58	0.05	0.15
Mixed Organics	NA	0.48	0.05	0.17
Mixed MSW	NA	0.52	0.43	NA
Carpet	NA	0.02	1.68	NA
Desktop CPUs	NA	0.02	0.4	NA

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[174] US Environmental Protection Agency (2023). EPA GHG Emission Factors Hub

[175] *These factors do not include any avoided emissions impact from any of the disposal methods. All the factors presented here include transportation emissions, which are optional in the Scope 3 Calculation Guidance, with an assumed average distance traveled to the processing facility. AR4 GWPs are used to convert all waste emission factors into* CO_2e.

Material	Metric Tons CO_2e / Short Ton Material			
	Recycled[A]	Landfilled[B]	Combusted[C]	Composted[D]
Portable Electronic Devices	NA	0.02	0.89	NA
Flat panel Displays	NA	0.02	0.74	NA
Electronic Peripherals	NA	0.02	2.23	NA
Hard-copy Devices	NA	0.02	1.92	NA
Mixed Electronics	NA	0.02	0.87	NA
Tires	0.1	0.02	2.21	NA
Fiberglass Insulation	0.05	0.02	NA	NA
Vinyl Flooring	NA	0.02	0.29	NA
Wood Flooring	NA	0.18	0.08	NA

A Recycling emissions include transport to recycling facility and sorting of recycled materials at material recovery facility.

B Landfilling emissions include transport to landfill, equipment use at landfill and fugitive landfill CH_4 emissions. Landfill CH_4 is based on typical landfill gas collection practices and average landfill moisture conditions.

C Combustion emissions include transport to combustion facility and combustion-related non-biogenic CO_2 and N_2O

D Composting emissions include transport to composting facility, equipment use at composting facility and CH_4 and N_2O emissions during composting.

For dark highlighted cells, composting represents a better alternative to landfilling, from an emission perspective. Composting can also reduce the need for imported fertilizers (fossil fuel based), exhibiting benefits in the AFOLU sector, by providing soil amendments for agriculture without relying on imported nitrogen-based fertilizers.

Wastewater Treatment Plants

Emissions from wastewater treatment plants come primarily from methane (CH_4) produced during the primary treatment of wastewater sludge. In 2019, emissions from wastewater treatment plants accounted for about 18% of waste sector emissions. Limiting the amount of wastewater, unlike other sectors, is challenging, therefore, emissions reduction for wastewater treatment plants is driven largely by technology.

A promising technology to capture and utilize these emissions is exemplified at the Honouliuli Wastewater Treatment Plant (WWTP), where methane that would otherwise be flared is captured and processed to create renewable natural gas in the form of biomethane. After the methane is captured, it is blended with utility gas and distributed as renewable natural gas (RNG), displacing synthetic natural gas (SNG) production, thus reducing emissions in both the waste as well as the gas sector.

2.5. Agriculture, Forestry, and Other Land Use - Natural Working Lands

The Agriculture, Forestry, and Other Land Use (AFOLU) sector is the only sector that acts both as a carbon sink as well as a carbon source (emitter). It is important to note that inventory accounting for this sector is the most challenging, particularly because national models have not been adapted to Hawaiʻi's unique environment. However, work has been done to refine carbon accounting in this sector[176, 177] and supporting this work into the future is critical, particularly if the state relies on AFOLU for its sink capacity to *offset*[178] hard-to-abate emissions. Incorporation of benchmarking work completed for Hawaiʻi's soils, climates, and ecosystems should be incorporated into future inventories, rather than depending on national models which are often limited in Hawaiʻi.[179]

The current GHG inventory estimates that AFOLU emissions sources come from:

1) Agricultural soil carbon which accounts for the "change in carbon stock in agricultural soils—either in cropland or grasslands—that have been converted from other land uses". Estimates assume that soils that are actively farmed are sources of carbon emissions due to soil disturbance; however, it is important to note that this may not be the case as soil conservation practices and climate smart practices can reduce agricultural soil carbon.
2) Agricultural soil management which accounts for nitrous oxide emissions from fertilizer application—inclusive of synthetic and organic fertilizers, crop residues, and manure all of which are used to increase the nitrogen in soil;
3) Enteric fermentation which estimates the methane released by livestock during their digestive processes based on livestock populations, inclusive of dairy cattle, beef cattle, and other livestock; and,

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[176] Crow, S. E., & Sierra, C. A. (2022). The climate benefit of sequestration in soils for warming mitigation. *Biogeochemistry*, *161*(1), 71-84.

[177] Crow, S.E., Rivera-Zayas, J., Tallamy-Glazer, E.V., Silva, J. (2021). Hawaiʻi Natural and Working Lands Baseline and Benchmarks. Final Report State of Hawaiʻi Office of Planning and Sustainable Development. Soil Ecology and Biogeochemistry Laboratory, Department of Natural Resources and Environmental Management, University of Hawaiʻi Mānoa. https://planning.hawaii.gov/wp-content/uploads/UH-CTAHR-Baselines-and-Benchmarks-Final-Report.pdf

[178] *Offsets in this context refer simply to the sink potential of NWL and the state's net-negative goals. NWL sink capacity should be prioritized regardless of whether it is negating a marginal emission. At present formalized offsets and carbon markets have faced major justifiable scrutiny and offsetting emissions without measures to substantially reduce emissions first is not appropriate. Offsets shall not replace measurable emission reduction across sectors. See Chapter 5.*

[179] Crow et al., 2021

4) Forest fires which are a growing concern throughout the islands given the dominance of pervasive invasive species and climate-exacerbated drought conditions.[180] This is a clear issue as fires are occurring in areas where it has not before, not only releasing substantial emissions but also devastating an area's natural resources particularly if the fires reach native rainforests.[181] Emissions sources estimates by category and gas are shown in Figure 40.

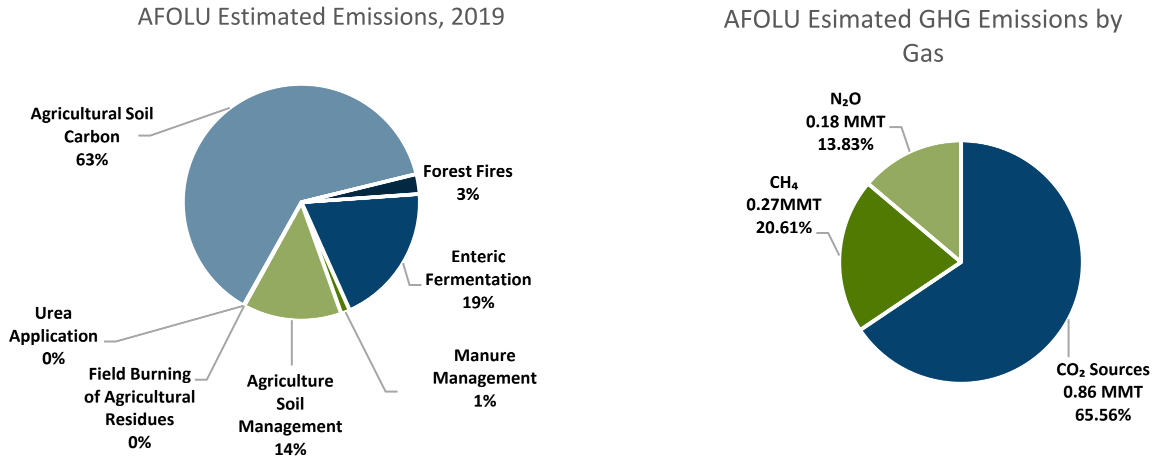

Figure 40 Estimated emissions from the AFOLU Sector by category (Left) and by gas (right). Emissions estimated from the DOH GHG Inventory.

AFOLU sinks in the GHG inventory included forest carbon, urban trees, and landfilled yard trimmings and food scraps (landfills are a significant source of CH_4 emissions, however, for this category it is assumed they are also a sink for carbon). The most substantial sink is forest carbon, followed by urban trees. The sink capacity in 2019 represented ~2.6 MMT or an estimated 11% of total state emissions. However, estimated uncertainty, for the sink category ranges from -2 MMT to -3.24 MMT.

As an alternative to measuring emissions as annual aggregations of sources and sinks, alternative metrics could be used to assess and track the amount of carbon that is fixed through photosynthesis, the amount of carbon sequestered, and the radiative forcing avoided because of actions taken at the plot scale or the system level. These metrics help us to understand the impact of direct actions.

Additional alternative metrics to track include:

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[180] https://pacificfireexchange.org/region/hawaii/

[181] The Associated Press. (2023, November 12). *Hawaii wildfire destroying irreplaceable rainforest on Oahu.* NBC News; NBC News.

1. Acreage of abandoned agricultural land – objective to reduce this acreage through time;
2. Number of farms or ranches and acreage adopting climate-smart agricultural practices – objective to increase this with time;
3. Soil health index and functional scores – objective to increase this with time.

With the use of alternative metrics, there must be meaningful measurability, which may not be fully encompassed in the inventory alone. It is critical in the NWL sector, and all sectors, that researchers, farmers, and ranchers are empowered to develop records and data that support positive climate impacts, and in turn, the data is utilized to inform policy.

Moving forward, it is recommended that when more accurate data or methodology (e.g. inventory models) is available they can be incorporated where appropriate. In the past, the use of certain tools became outdated, but they remain in place even when more appropriate tools and data become available. Locking in certain methodology because it is *the way it has always been done* is not appropriate, there must be a path to conversion when better data and toolsets become available. For example, the Climate Smart Commodities (CSC) project requires 5 years to collect data needed to develop an inventory model that appropriately fits Hawaiʻi, as this tool develops, the state must ensure a transition to using the updated model.

Actions in the AFOLU and NWL Sector to Reduce Emissions and Increase Sink Capacity

Many of the actions used in this sector to increase sink capacity also have benefits that go far beyond solely increasing sequestration capacity and reducing emissions.

Forests

Forests serve as the State's largest carbon sink and are highly threatened by fire, invasive species, and land use change. Land managers are increasingly being asked to consider how management can be expanded to also achieve carbon-related objectives, for example, protecting high carbon density areas or enhancing the amounts of carbon sequestered on stewarded lands. The required rapid and robust site characterization evaluating carbon sequestration potential requires accurate information on gross primary production (GPP), but also carbon stock attributes, and information on the type and condition of vegetation within a management unit.

Best practices for forest management to increase forest carbon and reduce emissions include:

1. Protection: Protecting existing forests is the most cost-efficient way to maintain and increase carbon sequestration.
2. Fencing: Protection fences against invasive species can allow for native forest regrowth without the need for replanting.

3. Invasive Species Control: Removing and creating boundaries to prevent encroachment of invasive plants and animals from forests and areas of potential encroachment. Preventing the establishment of new invasive species. These actions strengthen native ecosystems and make forests more resilient to shocks and stressors to maintain and increase carbon sinks.
4. Fire Risk Reduction: Minimizing fire risk through the removal of invasive species, building firebreaks, and outreach and education on fire safety. Note – solar developments allow for active management of large swaths of land, often abandoned and overrun with invasives, and can have this benefit.
5. Reforestation: Planting the appropriate trees for current and projected climate and ecosystem function to increase the carbon sequestration potential.
6. Preservation Purchasing additional land for forest protection or reforestation and long-term protection.

Urban Forests

Urban forests provide direct and indirect benefits to decarbonization. Each year mature street trees help create healthier communities by removing CO_2 and other air pollutants from urban air which exhibits higher pollutant concentration. Trees provide shade and cooling potentially reducing energy costs for cooling. Urban forests also provide socioeconomic co-benefits. Tree-lined commercial districts are better for business, and tree-filled neighborhoods reduce mental and physical stress, and encourage people to spend more time outdoors. A healthy urban forest reduces erosion and filters pollutants significantly reducing runoff and the destruction of our valuable reefs. Trees in Honolulu intercept more than 35 million gallons of stormwater per year, demonstrating a critical co-benefit.[182]

Best practices for urban forestry management to increase trees in our communities and reduce emissions include:

1. Streamlining Permitting and Ordinances: Getting a tree planted in neighborhoods or in urban areas can be a time-consuming process. Streamlining permitting and identifying public-private partnerships for tree planting and care can speed up the process of putting more trees in communities, consolidating disparate tree-related ordinances, and incorporating the use of trees and shrubs for stormwater management while providing for, maintaining, or improving existing tree canopy counties can have better coordination in tree planting and care.

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[182] Division of Forestry and Wildlife: Forestry Program | Why Trees Are Important (hawaii.gov)

2. Incentives for Trees: Develop a program to provide free or low-cost trees to homeowners. The program would provide education and financial incentives for growing trees on private properties. The program emphasizes citizens' participation as an important element of the program's success. Promote a reward program to publicize correct tree planting and maintenance. Much of the space that is available for trees in urban areas is on private lands. Incentives for homes that have green spaces and trees could encourage individuals to plant more trees and lower energy costs.

3. Identify and prioritize areas for tree planting: To maximize benefits from the resources invested criteria should be established for selecting sites and indicators to measure their success. These criteria and indicators can be based on specific objectives such as environmental protection, economic development, aesthetic identity, or social enhancement.

4. Plant the Right Tree in the Right Place: Tree species should be selected based on the nature of the site, the area available, the intended use, and the intensity of the use. Both the one-time costs of planting trees and the long-term maintenance costs should be considered while making such decisions.

5. Prioritize budget: An Urban Tree Canopy Program makes economic sense. With the increasing use of green infrastructure concepts, and recognizing the services provided by trees as described earlier, it is easier to view the investment in an urban tree program as comparable to any other infrastructure investment.

6. Establish Tree Minimums: Regulations should require a certain percentage of tree canopy for new developments or redevelopments, including transportation infrastructure. Rather than planting trees after infrastructure has been built, tree canopy should be planned early in the process for new and redeveloped areas, including transportation corridors.

7. Maintain existing urban trees: While trees can impose on urban infrastructure, for example; root damage, street and sidewalk displacement, utility interference, etc. proactive tree maintenance plays a critical role in minimizing the potential imposition of trees on critical infrastructure. Proper care and management can maximize the benefits of trees while reducing the risks. Further, it prevents future tree removal.

    - These best practices include regular pruning, root management, root barrier installation particularly on sidewalks and active transportation paths, and regular monitoring and assessment.

    - Collaboration between departments (e.g. state and city transit agencies working with arborists) is critical to ensure trees can co-exist with critical infrastructure.

Soils and Agriculture

Soils can play a key role in storing carbon. Studies have shown that two of the most dominant soil orders in Hawaiʻi (Histosols and Andisols, dominant on Hawaiʻi Island and Maui) have significant potential to store and sequester large amounts of carbon if appropriately conserved,[183] primarily in soil organic matter – which consists of decomposed plant and animal residues, microbial biomass, and other organic materials.

Best practices for soil management to increase soils carbon and reduce emissions include:

1. Cover Cropping: Planting cover crops during fallow periods helps in capturing carbon dioxide from the atmosphere and fixing it in the soil.
2. Reduced Tillage or No-Till Farming: Minimizing soil disturbance through reduced tillage or adopting no-till practices can prevent the release of carbon stored in the soil.
3. Crop Rotation: Diversifying crops in a rotation system improves soil health and carbon sequestration, as different crops have varied effects on soil organic matter.
4. Organic Amendments: Adding organic materials such as compost or manure to the soil enhances its carbon content and improves overall soil structure. Repurposing low-grade crops can be a great local compost source for farmers.
5. Biochar Application: Incorporating biochar, a stable form of organic carbon, into soils can enhance carbon sequestration and improve soil fertility.
    - Biochar is typically produced through the process of pyrolysis, which involves heating organic materials in the absence of oxygen. Biochar is a carbon-rich material produced from various organic sources, including wood, crop residues, and other biomass. Biochar production can also minimize emissions from the waste sector, Section 2.4 – thus exhibiting dual benefits.
6. Nutrient and Fertilizer Management: Optimizing fertilizer application based on soil nutrient requirements reduces the risk of over-fertilization and minimizes associated emissions.
7. Agroforestry: Integrating trees and shrubs into agricultural landscapes can sequester carbon in both aboveground and belowground biomass. If the wood products from agroforestry are harvested – keeping the products in their solid state, rather than combusting for energy can keep some of the carbon sequestered in the harvested material.
    - The carbon released from burning trees contributes to immediate emissions, impacting air quality and climate, whereas for wood products the carbon stored in wood products remains sequestered for the duration of the product's life. Longer-lived wood products,

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[183] Conservation International for the State of Hawaiʻi Office of Planning on behalf of the Greenhouse gas sequestration task force (2020). Reversing Climate Change: A study of pathways through Hawaiʻi's natural and working lands.

such as furniture or building materials, can retain carbon for an extended period, helping to reduce the emissions associated with their production.

8. Grassland Management: Proper management of grasslands, including rotational grazing, helps maintain soil health and prevent carbon loss. This also includes grassland varieties used for grazing and livestock feed which may not be indigenous to Hawaiʻi.
9. Water Management: Efficient water management practices, such as controlled irrigation, can prevent soil degradation and promote carbon sequestration. This is also an energy saving measure, as water pumping utilizes substantial energy.
10. Conservation Practices: Implementing conservation practices, like contour plowing and terracing can help prevent soil erosion and the loss of organic carbon.

It's important to note that the effectiveness of these practices varies across soil types; therefore, tailored approaches with regular field-scale measuring/soil sampling, monitoring, model benchmarking, verification, and tracking contribute to refining and adapting best practices.

Incentivizing Better Practices in Hawaiʻi's Agricultural Sector

Farming is a business: if farming is profitable our local farming industry will grow. A big way to support Hawaii's agricultural sector is to build capacity in terms of facilities and personnel (inspectors, labor, operators, etc.). While some food products may not be viable to produce locally, focus should be on methods to increase the replacement of imported produce and goods that can be produced in Hawaiʻi. Policies and resources are needed for Hawaiʻi farms to compete financially. Supporting the expansion of indigenous Native Hawaiian farming practices can help lead the decarbonization of Hawaiʻi's agricultural sector. In addition, some local farming operations are implementing new farming techniques that, if cost-effectively implemented, could increase local food production while reducing carbon-based inputs. Incentives to adopt the practices outlined above could include:

1. Support agricultural education programs in Hawaiʻi schools and universities.
    - Includes on-site education and workforce development programs.
2. Protect productive agricultural lands from development.
    - Existing state and county zoning laws offer certain protections for highly productive rated and important agricultural lands. Accurate methods of identifying and classifying good agricultural lands can facilitate their protection.
3. Make agricultural land more accessible to farmers and producers willing to adopt climate-smart practices.
    - For example, setting a leasing timeframe for land tenure that provides farmers with the capacity to practice long-term land conservation practices. This could involve increasing the lease term of the agricultural land to a minimum of 10 years with an extension option for farmers willing to commit to implementing appropriate climate-smart practices.

  - Rationale: Soil health regeneration takes up to 3 to 5 years, and many agricultural commodities take up to 8 years before reaching commercial production yields. An extension of land lease to 5, 10, or 20 years can be utilized as a tool to empower producers to invest in climate-smart practices implementation.
4. Incentivize or support composting and crop trials.
   - These techniques can encourage diversified agriculture, but often require up-front financial risks.
5. Incentivize and invest in infrastructure that facilitates climate smart implementation practices. Support could also include permit relief for limited low-impact agricultural activities. Examples include:
   - Lease programs for producers interested in producing locally sourced soil fertility and amendments that support climate-smart practices such as compost, biochar, mulch, fish/bone meal, etc.
   - Assistance for producers to access specialized machinery that facilitates the implementation of climate-smart practices. Examples, but not limited to crimpers, compost spreaders, tractors, etc. While questions have been raised concerning the ability of electrified heavy equipment to endure the all-day rigors and start-stop-start needs, the electrification of heavy equipment is rapidly growing thanks largely to the widespread manufacture and use of smaller electrified vehicles.[184] The Oak Ridge National Laboratory's November 2021 report, "Summary Report for the Virtual Summit on Decarbonizing the Agricultural Sector," discusses the key barriers and solutions to decarbonize the agricultural sector.[185]
   - Encourage or fund the development of on-island slaughterhouses and other food processing and packaging and discourage the export of live feedstock. Work to meet economies of scale to keep more food on island.
   - Incentivize or support energy efficiency equipment for Hawaiʻi farming operations; e.g., rebates for refrigeration units similar to current rebate programs for residential and commercial refrigeration units.
   - Incentivize community-based cooperative facilities and operations.
   - Incentivize or support dual use of agricultural land for energy production and agriculture (agrivoltaics).
   - Incentivize or support electrification of farming equipment.

2.6. Industrial Processes and Product Use

The Industrial Processes and Product Use (IPPU) sector in Hawaiʻi is small in comparison to many other states in the continental US, this is because Hawaiʻi has very little industry contributions.

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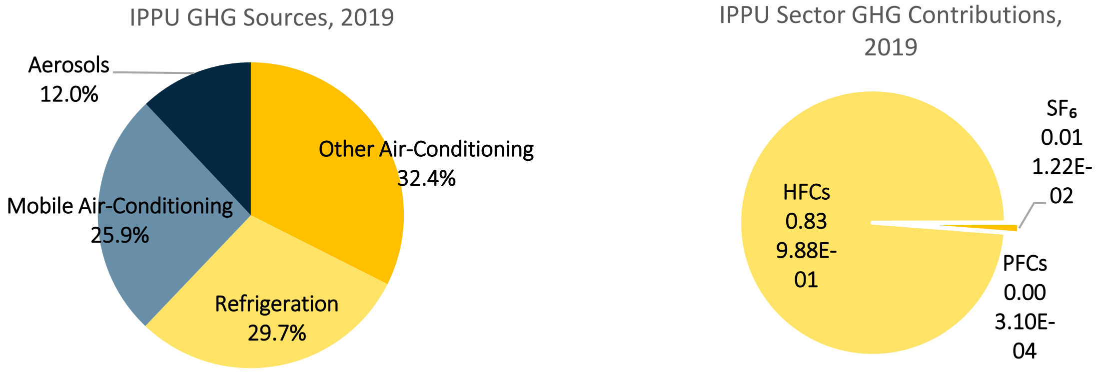
[184] The Beachhead Strategy: A Theory of Change for Medium- and Heavy-Duty Clean Commercial Transportation | April 1, 2022 - CALSTART

[185] Microsoft Word - Virtual AgDeCarbonization September2021 summit report_Final_12-10-21[3].docx (ornl.gov)

For many other states, two substantial contributors to the IPPU category include the chemical industry (inclusive of petrochemical production and ammonia production – predominately used for fertilizers) and the mineral industry (with emissions dominated by cement production and lime production).[186] However, because Hawaiʻi imports all the cement and its synthetic fertilizers, the emissions are not accounted for in Hawaiʻi's inventory, Chapter 5. Accordingly, most of Hawaiʻi's in-state IPPU emissions come from the use of refrigerants, or hydrofluorocarbons (HFCs), which are a substitute refrigerant used to replace prior refrigerants which were ozone depleting substances. The GHG sources for the various refrigerants are shown in Figure 41.


IPPU GHG Sources, 2019

IPPU Sector GHG Contributions, 2019

Figure 41 IPPU GHG emissions sources by activity (left) and by gas (right). Estimates obtained from the 2019 GHG Inventory, published 2023. Metric ton CO2e values based on 100-year GWPs from the IPCC 4th assessment report.

Notably, these refrigerants exhibit high global warming potential and exhibit far greater climate warming potential, as exhibited by their high GWPs, if evaluated over a shorter time horizon (Figure 14).

Table 14 Global warming potentials of applicable GHGs in the IPPU sector over three different time horizons and GHG lifetime. Data Source United Nations IPCC Second Assessment Report:

GHG Species	Chemical formula	20 years	100 years*	500 years	Lifetime (years)
Carbon dioxide	CO_2	1	1	1	variable§
HFC-32**	CH_2F_2	2,100	650	200	5.6
HFC-125**	C_2HF_5	4,600	2,800	920	32.6

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[186] US EPA 2023. Inventory of U.S. Greenhouse Gas Emissions and Sinks and the new Inventory of U.S. Greenhouse Gas Emissions and Sinks by State, *1990-2021.* Sector - Industrial processes and product use.

HFC-134a**	CH_2FCF_3	3,400	1,300	420	14.6
HFC-143a**	$C2H_3F_3$	5,000	3,800	1,400	48.3
Sulphur hexafluoride	SF_6	16,300	23,900	34,900	3,200

The IPCC and the Hawaiʻi Inventory use 100-year Global Warming Potential (GWP) to calculate CO2 equivalents. When the emphasis of the policy is limiting short-term non-linear climate responses, scientists have suggested that 20-year horizons are more applicable.[187]

*100-year global warming potentials from IPCC Second Assessment report to allow for comparison across time horizons. Source: IPCC Second Assessment Report.[188] The 2019 inventory, published 2023 uses the fourth assessment values.
**Gases with higher 20-year GWPs than 100-year values. The short-term climate warming impact of these GHGs is underestimated by current inventory methodology. HFCs applicable to IPPU category.

In 2023, HB 197 and companion SB503, was introduced to address refrigerant management. This bill established a refrigerant management program, administered by the DOH to "reduce emissions of high global warming potential refrigerants and any refrigerant that is an ozone depleting substance from stationary, commercial, and industrial refrigeration systems and air conditioning systems and adopt rules for the regulation of the use of such refrigerants."[189] This type of program is critical to understand the refrigerant inventory (the current inventory uses national estimates applied to Hawaiʻi population) and manage refrigerant usage in the state.

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[187] GTI Energy, Center for Methane Research (2019). *Implications of Using Different GWP Time Horizons.*

[188] *Global Warming Potentials (IPCC Second Assessment Report*. (n.d.). United Nations Climate Change; Intergovernmental Panel on Climate Change. Retrieved December 5, 2023, from

[189] Hawaiʻi State Legislature, 2023 Archives HB197 HD1SD1

Chapter 3. Decarbonization Projections Methodology and Scenario Design

3.1. Scenario Design Overview

This study evaluates different pathways for achieving net negative economywide emissions and examines the range of outcomes in a future where the state achieves the emissions targets under Act 15, as codified in HRS §225P-5. To meet these objectives, the team examined four scenarios of future energy demand and emissions, including the Reference Scenario and three mitigation scenarios (S1-S3). The Reference Scenario represents a business-as-usual case that includes current state and federal policies, as well as current trends driving energy demands and emissions. The Reference Scenario serves as a comparison point that shows the current emissions trajectory without further mitigation action. Emissions reductions in the Reference Scenario are mainly driven by the RPS target in the electric sector, as well as the adoption of electric light duty vehicles.

The mitigation scenarios represent distinct pathways to achieving Hawai‘i's net-negative goal. As described further in Section 3.2, the mitigation scenarios are not meant to represent the "optimal" or "likeliest" pathways to achieving the state's 2045 GHG target but were designed to explore key tradeoffs among different mitigation measures.

In designing the mitigation scenarios, careful consideration was given to the values outlined in the ‘Āina Aloha Assessment Tool to ensure a Hawai‘i-centric perspective, as described in greater detail in Chapter 1. Relevant values from the ‘Āina Aloha Assessment Tool were adapted to create scenario development criteria to be evaluated through the modeled scenarios. These criteria were refined based on stakeholder engagements over the course of the modeling exercise. The list of scenario development criteria is shown below in Table 15.

Table 15 Scenario development criteria adapted from ʻĀina Aloha values discussed in Chapter 1.

Scenario Development Criteria	Additional Details
Minimize land impacts of energy infrastructure	• Protect and restore the integrity of Hawaiʻi environments. • Improves Hawaiʻi's long-term food security and builds and sustains local food production
Reliance on in-state energy (energy independence)	• Limit overseas fuel imports
Limit Reliance on Negative Emissions Technology	• Focus on improving soil and forest health to bolster natural carbon sequestration potential. • Improve future accounting for natural systems and base accounting on local data and knowledge • Aim for the greatest possible direct emissions reductions
Minimize total costs of energy transition	• Focus on the most cost-effective emissions reduction measures to positively impact community well-being and equity
Ease of implementation	• Understand large-scale changes needed for each scenario to be plausible. • Focus on strategies that are technically feasible

The three mitigation scenarios were designed with a goal of exploring tradeoffs related to the scenario development criteria above. While all scenarios assumed far-reaching measures across all sectors of the economy, the key differences among the scenarios were selected specifically to address measures that would likely have large impacts on the scenario development criteria listed in Table 15. The three main differentiators among the scenarios were:

1. **Level of energy efficiency and conservation in buildings and transportation:** energy efficiency and conservation play a significant role in reducing the cost, environmental impact, and the total amount of electricity generation, fossil fuels and decarbonized fuels that are needed in Hawaii.
2. **Size of land-based carbon sink:** given that one of the development criteria is related to improving the fertility and integrity of the environment, the scenarios explore two distinctly different trajectories for the natural carbon sink, reflecting activities to reduce emissions through various natural and working land measures.
3. **Level of additional "gap closing" measures:** demand reductions and land-based mitigations are two categories of mitigation measures that have great potential to reduce emissions. However, these measures are not sufficient on their own to meet the state's

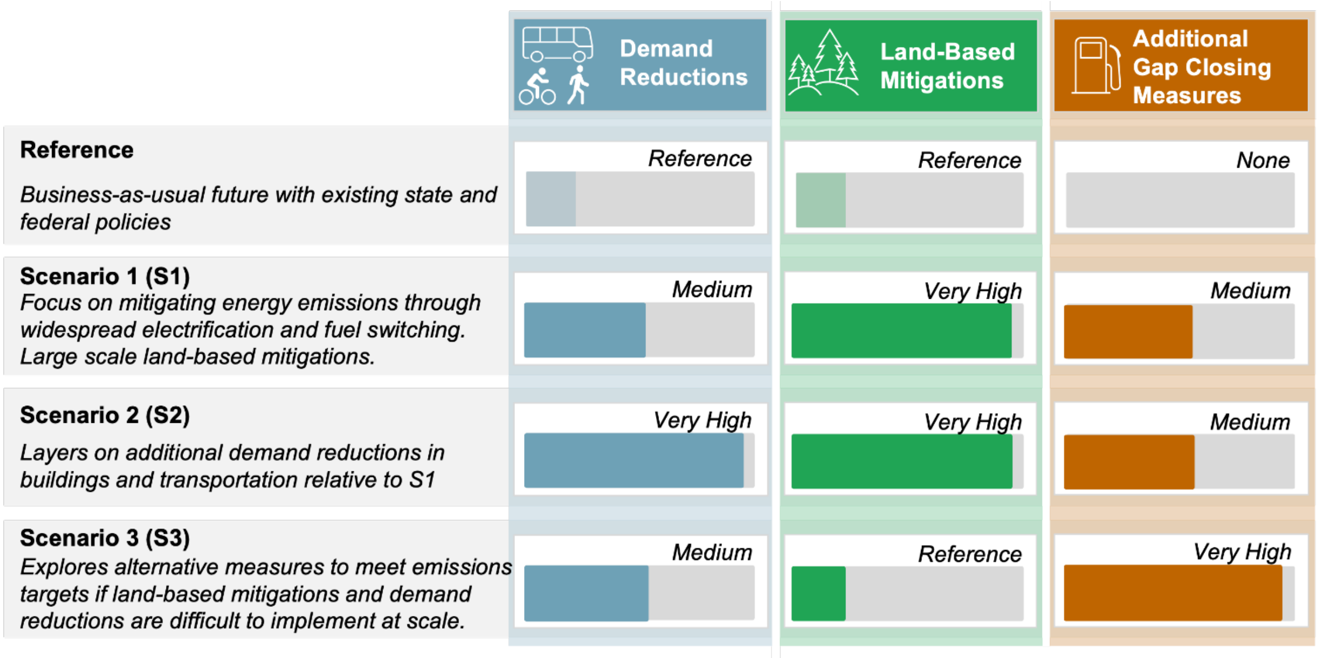
climate goals and may be challenging to implement at the scale modeled in these scenarios. “Gap closing” measures are emission reduction strategies modeled to help meet the state’s climate goals. Additional energy-based gap closing measures such as early retirements of internal combustion engine vehicles, additional blending of low carbon fuels, and negative emissions technologies (NETs) are explored to provide insights into additional pathways to reduce emissions. NETs are explored in a Hawai’i context further in Appendix E.

The scenarios are described at a high level in Table 16. Mitigation scenarios are named Scenario 1, Scenario 2, and Scenario 3 (shortened to S1, S2, and S3).

Table 16 Qualitative description of core scenario elements

Scenario	Description of core scenario elements
Reference	• Business-as-usual future of energy demand and emissions, including all current state and federal policies. • Does not meet the 2030 or 2045 emissions targets
Scenario 1 (S1)	• Widespread electrification of the transportation and buildings sectors, dramatically reducing fuel combustion • Substantial fuel-switching to low-carbon fuels • Large focus on active land management and agricultural practices to increase the size of the natural carbon sink
Scenario 2 (S2)	• Explores policy options that focus on energy efficiency and conservation and have the potential to limit land use impacts from energy infrastructure. • Carries forward all mitigation strategies from S1, but layers on substantial additional energy efficiency and conservation in buildings and transportation
Scenario 3 (S3)	• Explores alternative measures to achieve the 2030 and 2045 targets if energy demand reductions and land-based carbon sequestration are difficult to implement at the scale modeled in S1 and S2 • Energy demand reductions consistent with S1 and land-management/agricultural strategies consistent with Reference scenario • Light-duty internal combustion engine vehicle buy-backs are applied from 2025-2030 to achieve the 2030 target. • Additional sustainable aviation fuel and negative emissions technologies are deployed to meet the 2045 target

The key differences among the scenarios are illustrated in Figure 42.



	Demand Reductions	Land-Based Mitigations	Additional Gap Closing Measures
Reference *Business-as-usual future with existing state and federal policies*	*Reference*	*Reference*	*None*
Scenario 1 (S1) *Focus on mitigating energy emissions through widespread electrification and fuel switching. Large scale land-based mitigations.*	*Medium*	*Very High*	*Medium*
Scenario 2 (S2) *Layers on additional demand reductions in buildings and transportation relative to S1*	*Very High*	*Very High*	*Medium*
Scenario 3 (S3) *Explores alternative measures to meet emissions targets if land-based mitigations and demand reductions are difficult to implement at scale.*	*Medium*	*Reference*	*Very High*

Figure 42 Visualization of core scenario differences

All three mitigation scenarios employ far-reaching decarbonization measures across all sectors of the economy to achieve the net-negative by 2045 goal. A summary of the scenario measures is shown in Table 17, with narrative detail provided in the subsequent sections.

Table 17 Summary of scenario assumptions (bold text indicates a change relative to the neighboring scenario to the left)

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Transportation On-road	Light-duty vehicles: 52% zero-emission vehicle sales by 2030, 95% by 2045. Medium- and heavy-duty vehicles: 50% zero-emission vehicle sales by 2030, 61% by 2045. Follows the moderate scenario from a recent report by the International Council on Clean Transportation (ICCT) that includes impacts of the Inflation Reduction Act.[190] Sales shares were projected out to 2045 for this study.	**Light-duty vehicles: 100% zero-emission vehicle sales by 2035** **Medium and heavy-duty vehicles: 100% zero-emission vehicle sales by 2045** **100% decarbonized diesel and gasoline by 2045**	Light-duty vehicles: 100% zero-emission vehicle sales by 2035 Medium and heavy-duty vehicles: 100% zero-emission vehicle sales by 2045 100% decarbonized diesel and gasoline by 2045	Light-duty vehicles: 100% zero-emission vehicle sales by 2035, **with buybacks for older ICE vehicles. Assumes that 30% of ICE vehicles on the road in 2024 are replaced with EVs from 2025-2030.** Medium and heavy-duty vehicles: 100% zero-emission vehicle sales by 2045 100% decarbonized diesel and gasoline by 2045

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[190] International Council on Clean Transportation (January 2023) Analyzing the impact of the Inflation Reduction Ace on Electric Vehicle Uptake in the United States.

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Vehicle Miles Traveled (VMT) Reductions for On-Road Vehicles	Business-as-usual with a 5% reduction in VMT per vehicle on O‘ahu (based on the 2045 O‘ahu Regional Transportation Plan)[191]	*Same as Reference*	**~20% statewide reduction in total VMT based on SSTI Policy Scenario.**[192]	*Same as Reference*
Aviation: **Efficiency and Visitor Arrivals**	10% fleetwide efficiency improvements by 2045 (assumption based on 50% of the projected aviation efficiency improvements from EIA Annual Energy Outlook (AEO) (2023)[193] Underlying visitor arrival forecast from DBEDT[194]	*Same as Reference*	**20% fleetwide efficiency improvements by 2045 (assumption based on 100% of the projected aviation efficiency improvements from EIA AEO 2023)** Underlying visitor arrival forecast from DBEDT. **Increase the average length of stay to reduce flight miles while maintaining tourist activity (10% reduction in flight miles by 2030.)**	*Same as Reference*

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[191] O‘ahu Metropolitan Planning Organization (2023) 2045 O‘ahu Regional Transportation Plan

[192] McCahill, C., Sundquist, E., Osborne, B., State Smart Transportation Initiative (SSTI) and Smart Growth America (2019) Estimating policy effects on reduced vehicle travel in Hawaii, Prepared for Transcending Oil: Hawaii’s Path to a Clean Energy Economy Commissioned by Elemental Excelerator

[193] US EIA (2023) Annual Energy Outlook

[194] DBEDT (2023) Daily Passenger Counts Data Dashboard

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Aviation: Fuel blending and electrification	Business-as-usual	**10% SAF blend by 2030 (based on Hawaiian Airlines target)**[195] **Gap closing measure: 70% SAF blend by 2045 was selected to meet the 2045 emissions target.** **Some electrification of inter-island aviation, roughly aligned with the aviation demand for Mokulele Airlines. ~15 GWh by 2045**	10% SAF blend by 2030 (based on Hawaiian Airlines target) **Gap closing measure: 64% SAF blend by 2045 was selected to meet the 2045 emissions target.** Some electrification of inter-island aviation, roughly aligned with the aviation demand for Mokulele Airlines. ~15 GWh by 2045	10% SAF blend by 2030 (based on Hawaiian Airlines target) **Gap closing measure: 100% SAF blend by 2045 was selected to meet the 2045 emissions target.** Some electrification of inter-island aviation, roughly aligned with the aviation demand for Mokulele Airlines. ~15 GWh by 2045
Transportation Other Off-road	Business-as-usual	**100% decarbonized diesel and residual fuel oil by 2045**	100% decarbonized diesel and residual fuel oil by 2045	100% decarbonized diesel and residual fuel oil by 2045

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[195] Hawaiian Airlines, Newsroom (March 2023) Hawaiian Airlines Commits to New Milestones on Path to Net-Zero Carbon Emissions

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Residential Buildings	Energy Efficiency: “Achievable Potential -- BAU” levels from Hawai‘i PUC market potential study[196] Solar water heating for all new residential buildings	**Energy Efficiency: “Achievable Potential -- High” levels from Hawai‘i PUC market potential study** **100% sales of electric devices for all end uses by 2035.** Solar water heating for all new residential buildings	**Energy Efficiency: “Economic Potential” levels from Hawai‘i PUC market potential study** 100% sales of electrified devices for all end uses by 2035. Solar water heating for all new residential buildings	**Energy Efficiency: “Achievable Potential -- High” levels from Hawai‘i PUC market potential study** 100% sales of electric devices for all end uses by 2035. Solar water heating for all new residential buildings (aligned with S1)
Commercial Buildings	Energy Efficiency: “Achievable Potential -- BAU” levels from Hawai‘i PUC market potential study	**Energy Efficiency: “Achievable Potential -- High” levels from Hawai‘i PUC market potential study** **100% sales of electric devices for all end uses by 2040**	**Energy Efficiency: “Economic Potential” levels from Hawai‘i PUC market potential study** 100% sales of electrified devices for all end uses by 2040	**Energy Efficiency: “Achievable Potential -- High” levels from Hawai‘i PUC market potential study** 100% sales of electrified devices for all end uses by 2040. (aligned with S1)

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[196] Applied Energy Group (AEG) (2020) State of Hawai‘i Market Potential Study. Prepared for the Hawai‘i Public Utilities Commission.

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Gas Pipeline/ Propane Blend	Business-as-usual	**100% decarbonized natural gas and propane by 2045**	100% decarbonized natural gas and propane by 2045	100% decarbonized natural gas and propane by 2045
Refinery	5% of operations converted to renewable fuel production by 2025 based on planned conversion.[197]	**Transformation to 100% renewable fuel production by 2045 starting in 2025.**	Transformation to 100% renewable fuel production by 2045 starting in 2025.	Transformation to 100% renewable fuel production by 2045 starting in 2025.
Waste (non-combustion)	Business-as-usual	**Max abatement available below \$200/MTCO$_2$e from EPA Non-CO$_2$ report** [198]	Max abatement available below \$200/MTCO2e from EPA Non-CO$_2$ report	Max abatement available below \$200/MTCO2e from EPA Non-CO$_2$ report
Refrigerants	In line with Kigali amendment (HFC phasedown projection from the 2023 Department of Health Greenhouse Gas Inventory)	**SNAP program for refrigerant management**	SNAP program for refrigerant management	SNAP program for refrigerant management

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[197] Par Pacific (April 2023) Par Pacific Announces Significant Investment in Hawaii Renewable Fuels Production

[198] US EPA (2023) U.S. State-Level Non-CO2 GHG Mitigation Report.

Sector/Category	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Agriculture, Forestry, and Other Land Uses (AFOLU)	Agriculture aligned with EPA non-CO_2 report BAU. Net emissions from land use aligned with USGS report.[199]	**Agriculture: max abatement available below \$200/tCO_2e from EPA non-CO_2 report.** **Increase in net land sink based on "High Sequestration" projection from White House 2021 Biennial Report**[200]	Agriculture: max abatement available below \$200/tCO_2e from EPA non-CO_2 report. Increase in net land sink based on "High Sequestration" projection from White House 2021 Biennial Report	*Same as Reference*
Negative Emissions Technologies	None	None	None	**Gap closing measure: 0.5 MMT/year of carbon dioxide removal by 2045 to meet the 2045 emissions target**

Underlying Assumptions for All Scenarios

Forecasted changes to underlying drivers of energy demand are included in the model and are common across all scenarios. These drivers include population growth, baseline aviation travel demand, growth of commercial building square footage, and energy demand for industry. These were aligned with Hawaiʻi-specific data sources where possible, supplemented by national data from the EIA Annual Energy outlook where Hawaiʻi-specific data were not available. This study also modeled underlying assumptions for end-use efficiency improvements across all scenarios.

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[199] Giardina, C. P. (2017). United States Geological Survey, Professional Paper 1834 Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawaiʻi.

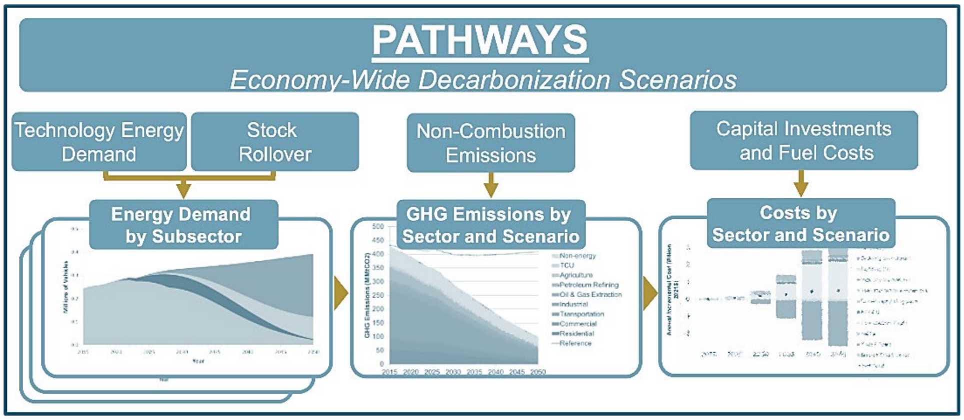
[200] US 7th National Communication. (2021) White House.gov A review of sustained climate action through 2020

The modeling aligned building efficiency trajectories with results from the State of Hawaiʻi Market Potential Study.[201]

3.2. PATHWAYS Model Overview

E3 created the PATHWAYS model to help policymakers, businesses, and other stakeholders analyze trajectories to achieving deep decarbonization of the economy. The model has been used in projects analyzing decarbonization at the utility service territory, state, and national level; recent examples include work with Hawaiian Electric, the California Energy Commission, the New York State Energy Research and Development Authority, and the Colorado Energy Office.

E3 used the PATHWAYS model to analyze decarbonization pathways for Hawaiʻi. The PATHWAYS model is an economywide representation of infrastructure, energy use, and emissions within a specified geography. The model allows comparison of user-defined scenarios of future energy demand and emissions to answer “what if” questions related to decarbonization. PATHWAYS can be used as a tool to explore the impacts and implications of potential climate and energy policies specified by the user, including energy, non-energy emissions and technology costs. Figure 43 provides an illustration of the E3 PATHWAYS model. E3 built bottom-up island-level PATHWAYS models for Oʻahu, Hawaiʻi island, Kaua’i, Maui, Molokaʻi, and Lānaʻi, where each island was modeled individually.



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[201] Applied Energy Group (AEG) (2020) State of Hawaiʻi Market Potential Study. Prepared for the Hawaiʻi Public Utilities Commission.

Figure 43: Illustration of E3's Pathways Model

A key feature of PATHWAYS is the characterization of stock rollover in major equipment categories, specifically in buildings[202] and transportation fleets. The stock rollover approach tracks the retirement of vehicles and end-use equipment in buildings and their replacement with newer equipment that may have improved performance or may be powered by different fuels. This captures the time lag between changes in annual sales of new equipment and changes in the overall stock of equipment, and resulting energy demand, in the economy over time. This is important as different technologies will have different lifetimes; some technologies, such as lightbulbs, might have lifetimes of just a few years, while others, such as building shells, can have lifetimes in the order of decades. By accounting for this dynamic, a PATHWAYS scenario can determine the pace of technology deployment necessary to achieve economywide greenhouse gas emissions goals or policy targets.

Benchmarking

The process of calibrating PATHWAYS model inputs so that base year outputs align with historical data is referred to as benchmarking. Base year model outputs were benchmarked to the 2023 Department of Health Greenhouse Gas Inventory (referred to as the inventory) and historical energy consumption from the EIA State Energy Data System at the state level. [203] [204] For this study, 2019 was used as the base year given that 2019 is the most recent year in the inventory. Note that while 2019 was used as the base year for benchmarking, emissions reductions are shown relative to 2005 baseline emissions consistent with the written statewide emissions targets. Additional detail on the sources and assumptions used in developing PATHWAYS model inputs can be found in Appendix B-1.

As described in further detail in Chapter 5, Hawaiʻi uses a production-based emissions inventory (PBEI). In PBEI, the emissions associated with goods and services produced within a geographic boundary (in this case, the state of Hawaiʻi) are counted, and emissions associated with producing products made elsewhere are not. This accounting framework leaves various "seams", where some emissions are not accounted for within the inventory. One example is in transportation emissions, where the inventory only accounts for emissions from intra-state transportation and domestic transportation that originates from within the state. This means that emissions from international marine transportation and international aviation are not counted. Another example lies in emissions from fuel production. The inventory quantifies

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[202] *Herein, "buildings" largely refers to the stationary combustion sector of the inventory as buildings are the largest end-use of electricity produced by stationary combustion.*

[203] State of Hawaii, Department of Health. Greenhouse Gas Inventory (2023) Hawaiʻi Greenhouse Gas Emissions Report for 2005, 2018, and 2019

[204] US EIA State Energy Data System (2023). State energy consumption

emissions associated with the combustion of fuels within the state. However, it does not account for the total lifecycle emissions of imported fuels, given that emissions associated with the production of imported fuels did not occur within the state. While this accounting approach is a common convention for state GHG inventories, it does neglect certain emission contributions, such as those discussed above. These shortcomings are discussed in detail in Chapter 5. For consistency, the present modeling analysis has been structured to align with the accounting approach in the official state inventory, consistent with HRS §342B-71. Adjusting the models to account for sector specific emission contributions not included in the inventory was outside the scope of this analysis.

Scenario Costing in PATHWAYS

Annual and total costs and benefits were calculated for each scenario. This includes costs for the electric sector as well as costs for other sectors of the economy. Direct costs include capital investments in new clean infrastructure, such as renewable generation and electrification technologies, operation and maintenance costs, and fuel expenditures. The benefits of decarbonization include the climate benefits associated with reduced GHG emissions based on the social cost of GHGs. To quantify the benefits and costs of additional actions needed to reach net zero, all cost estimates are calculated relative to the Reference scenario.

For this study, incremental costs for each scenario were calculated relative to the Reference scenario. Costs are analyzed from a total cost perspective, meaning that internal cost transfers within the state of Hawaiʻi are not directly modeled. Measures that cost money relative to the Reference scenario are positive costs, and measures that save money relative to the Reference are negative costs (i.e., cost savings).

A summary of cost categories modeled in each sector can be found in Table 18. Some mitigation measures will affect multiple cost categories. For example, an increased share of electric vehicles will affect upfront transportation investments, device operations and maintenance (O&M) costs, electricity costs, and fuel costs.

Table 18 Cost category descriptions and sources

Category Name	Description	Source(s)
Electricity	Total electric sector costs from NREL Engage Energy Modeling Tool. Note that NREL electric sector cost outputs do not include costs for necessary distribution upgrades.	NREL Electric Sector Modeling (described in Section 3.4)
Buildings Investment	Includes all capital costs for building appliances (e.g., water heaters, clothes washers, dish washers, etc.)	EIA (2023)[205], E3 (2019)[206], TRC Solutions (2016)[207]
Building Energy Efficiency	Includes costs for energy efficiency programs in buildings	Energy efficiency supply curves developed for the Hawaiian Electric IGP.[208] Supply curves were based on the scenarios from the Hawai'i PUC market potential study.[209]
Industry Investment	Includes all capital costs for refinery conversion and equipment that allows for electrification of agriculture and construction	Refinery conversion costs from Par Pacific (2023)[210] E3 assumption for electric equipment
Transportation Investment	Includes all capital costs for transportation equipment (e.g., electric vehicles)	ICCT (2022),[211] ANL (2021),[212] E3 assumption for electric aircraft cost
Low Carbon Fuels	Includes the feedstock and conversion costs for biofuels and the capital costs for hydrogen production	E3 Biofuels Optimization Tool (see Appendix B-1 for details on fuel cost assumptions)

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[205] U.S. Energy Information Association. (2023). Updated Buildings Sector Appliance and Equipment Costs and Efficiencies.

[206] Energy & Environmental Economics. (2019). Residential Building Electrification in California, Consumer economics, greenhouse gases, and grid impacts.

[207] TRC Solutions. (2016). Palo Alto Electrification Final Report.

[208] Hawaiian Electric (2022) IGP Key Stakeholder Documents Integrated Grid Inputs and Assumptions Workbooks.

[209] Applied Energy Group (AEG) (2020) State of Hawai'i Market Potential Study. Prepared for the Hawai'i Public Utilities Commission.

[210] Par Pacific (April 2023) Par Pacific Announces Significant Investment in Hawaii Renewable Fuels Production

[211] International Council on Clean Transportation (2022) Assessment Of Light-duty Electric Vehicle Costs And Consumer Benefits In The United States In The 2022–2035 Time Frame

[212] Argonne National Laboratory, 2021, Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains

Category Name	Description	Source(s)
Agriculture, Forestry, and Other Land Uses (AFOLU)	Includes the costs of emissions reductions from changes to agricultural practices and other land management	EPA Non-CO_2 Report (2023)[213]
Non-Energy Mitigation	Includes the costs of mitigating emissions from waste and refrigerants	EPA Non-CO_2 Report (2023)
Negative Emissions Technologies (NETs)	Includes all capital costs for capturing and sequestering CO2 with negative emissions technologies	Fasihi et. Al (2019)[214], McQueen et al. (2021)[215], National Academies of Sciences, Engineering, and Medicine (2019)[216]
Device O&M	Includes the operations and maintenance costs for end-use devices in buildings and transportation	ICCT (2022),[217] CARB ACT, EIA (2023), E3 (2019), TRC Solutions (2016), E3 (2019)[218], EIA (2023) [219], TRC Solutions (2016)[220]
Fossil Fuels	Includes annual spending on fossil fuels using AEO 2023 price projections scaled based on Hawai'i fuel prices	EIA AEO (2023)[221], EIA SEDS (2021)[222]

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[213] US EPA (2023) U.S. State-Level Non-CO2 GHG Mitigation Report.

[214] Fasihi, M., Efimova, O., & Breyer, C. (2019). Techno-economic assessment of CO2 direct air capture plants. *Journal of cleaner production*, *224*, 957-980.

[215] Board, O. S., & National Academies of Sciences, Engineering, and Medicine. (2019). Negative emissions technologies and reliable sequestration: a research agenda.

[216] McQueen, N., Gomes, K. V., McCormick, C., Blumanthal, K., Pisciotta, M., & Wilcox, J. (2021). A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. *Progress in Energy*, *3*(3), 032001.

[217] International Council on Clean Transportation (2022) Assessment Of Light-duty Electric Vehicle Costs And Consumer Benefits In The United States In The 2022–2035 Time Frame

[218] Energy & Environmental Economics. (2019). Residential Building Electrification in California, Consumer economics, greenhouse gases, and grid impacts.

[219] US EIA (March 2023) Updated Buildings Sector Appliance and Equipment Costs and Efficiencies

[220] TRC Solutions. (2016). Palo Alto Electrification Final Report

[221] US EIA (2023) Annual Energy Outlook

[222] US EIA State Energy Data System (2023). State energy consumption

Category Name	Description	Source(s)
Social Cost of GHGs	Includes the social benefits of GHG reduction using social GHG cost values from the EPA Draft "Report on the Social Cost of Greenhouse Gases".	EPA Draft "Report on the Social Cost of Greenhouse Gases" (2022)[223]
Non-Costed Measures	*VMT reductions and flight mile reductions are unable to be quantified in this cost analysis.*	*N/A*

3.3. Electric Sector Modeling

For this report, electric sector modeling was completed by the National Renewable Energy Laboratory (NREL). NREL's electric sector analysis does not replicate modeling completed by Hawaiian Electric in the Integrated Grid Plan (IGP), a regulated proceeding with several iterations of formal review and comment that began in 2018. However, the inputs and assumptions from the IGP were used in the Engage, capacity expansion model, as described below. For this analysis, E3 developed economywide energy and greenhouse gas emissions scenarios for all main Hawaiian Islands, as described in Sections 3.1 and 3.2. E3 and NREL also integrated costs into the PATHWAYS model that reflects each scenario and incorporated cost considerations from state and federal policy into the final analysis.

The decarbonization scenario analysis included a three-step modeling toolchain, depicted in Figure 44.

Step 1: PATHWAYS was used to develop economywide scenarios, as previously described. Oʻahu, Hawaiʻi Island, Maui, Kauaʻi, Molokaʻi, and Lānaʻi were all modeled individually. Outputs from the PATHWAYS model include annual GHG emissions, electric demand, energy use by fuel, stocks of end-use equipment (e.g., EVs and heat pump water heaters), and costs. All outputs can be further refined by sector, subsector, and end use.

Step 2: NREL used the annual PATHWAYS electric demand projections to analyze decarbonization scenario impacts on each island's electric sector. To perform this analysis, NREL used the Engage capacity expansion modeling tool to estimate the most cost-effective mix of generation and storage technologies needed to meet future electricity demands, described below. The model also produces direct costs and emissions associated with building and operating the system, which E3 incorporated into their economywide analysis.

Step 3: Technology mix results from Engage were run through the Probabilistic Resource Adequacy Simulator (PRAS) to assess the system reliability across different weather years and

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[223] US EPA (2022) Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review

with thermal generator outages. The resource adequacy model identified additional generation and storage technologies and capacities needed to improve the system.

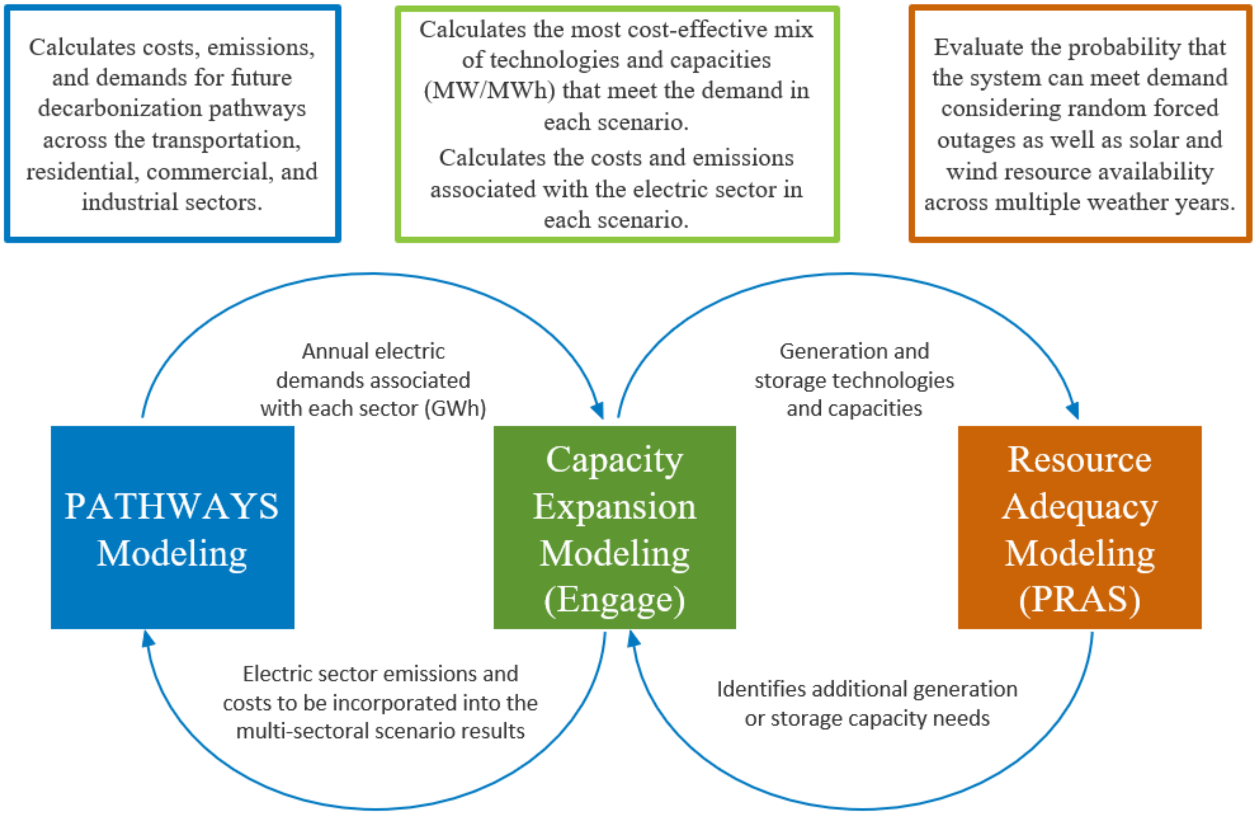

Figure 44 Depiction of PATHWAYS and Engage modeling feedback loop.

3.4. Electric Sector Models Overview (Engage and PRAS)

The electric sector modeling effort identified the most cost-effective portfolios of generation and storage, which meet the PATHWAYS projected electric demand for each scenario as well as the RPS constraints and 2045 emissions constraints. To perform this analysis, NREL used both the Engage[224] capacity expansion modeling tool and PRAS[225] . The modeling tools, inputs, and assumptions used in the electric sector analysis are described in Appendix C.

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[224] National Renewable Energy Laboratory (NREL). (2023). Engage – Open access energy system planning

[225] NREL (2023) PRAS: Probabilistic Resource Adequacy Suite

Capacity Expansion Modeling Overview

Engage is a free, publicly available modeling tool built around Calliope,[226] an open-source modeling framework for cross-sectoral energy system modeling and planning. Engage is a least-cost optimization model, meaning the model assesses the most cost-effective way to meet demand in each year based on assumptions about future electricity demand, fuel prices, technology costs and performance, and policy and regulation. In this study, NREL used Engage to develop energy system models for O‘ahu, Hawai‘i Island, Kaua‘i, Maui, Moloka‘i, and Lāna‘i.

Inputs and assumptions for each island's capacity expansion model

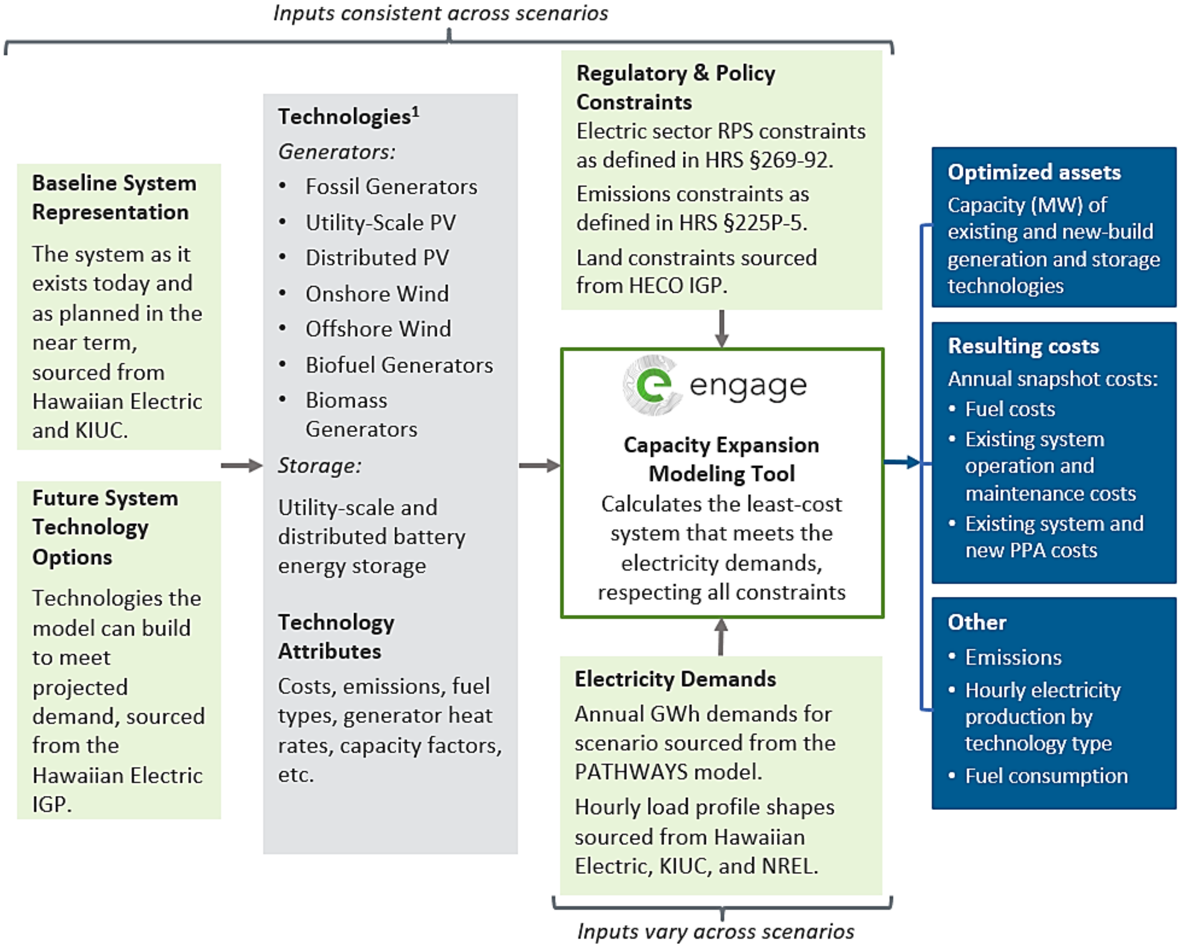

Figure 45 Inputs and assumptions applied to electric sector capacity expansion model (Engage) as well as outputs of the Capacity Expansion Model.

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[226] Calliope (2023)

As illustrated in Figure 45, Engage used four principal categories of inputs to assess the most cost-effective mix of generation and storage technologies: baseline system representation, future system technology options, electricity demand projections, and regulatory and policy constraints.

The capacity expansion modeling effort began with representing the baseline system technology options. The baseline energy system representation included: 1) the energy system assets currently in operation (generation, storage, transmission), 2) energy system assets planned to be installed in the near term, and 3) planned retirement dates of existing generation facilities. This analysis explored the high-level impacts of each decarbonization scenario on the electric sector for each island. No existing system transmission constraints were modeled for this analysis.

In addition to this baseline system, future system technology options were also represented in the model. Engage chose which technology options and the capacity of each option (MW/MWh) to build to meet future system needs and constraints. The future system needs driving the model to build new technology capacities includes meeting the electricity demand, replacing retired generation, lowering operating costs in place of more expensive generation, and adhering to regulatory constraints such as RPS requirements. The model follows the retirement dates for existing generation set forth in the Hawaiian Electric IGP.

Both the baseline and future system technologies were defined by their operating characteristics (hourly resource availability, MW/MWh capacity, efficiency, heat rate, etc.) and associated current and projected costs (operation and maintenance, fuel, and capital costs). In this study, the baseline and future system technology attributes and costs for each island were held constant across all scenarios. In other words, no scenarios were designed to reflect faster or slower cost declines for any of the modeled technologies.

The final two key inputs to the capacity expansion model were the regulatory constraints and electricity demands. The regulatory constraints enforced in each island model were aligned with the RPS requirements outlined in HRS §269-92 and the 2045 emissions requirements outlined in HRS §225P-5. The interim 2030 emissions targets were not a constraint in the model. Noted regulatory constraints did not vary across scenarios. Different from the other inputs described thus far, the electricity demand inputs varied by scenario. Using the cross-sectoral electricity demand results from PATHWAYS, NREL translated the annual demands into hourly demand profiles for each scenario, sector, and island.

For each island and scenario, Engage ran a snapshot year analysis every 5 years from 2030 to 2045. A 5-year modeling cadence was chosen to reduce model run times while still capturing the incremental generation needs of the changing electric demands and RPS requirements. Starting in 2030, the model searched for the least-cost combination of existing and new generation and storage that could be dispatched to meet the demand each hour.

Engage added the new technologies built in 2030 to the baseline system, allowing the results of the 2030 run to become the baseline inputs to the subsequent year run (2035). The model then repeated this process for each snapshot year through 2045.

After completion, the Engage model results for each island, scenario, and year were sent to the PRAS modeling tool for a resource adequacy assessment. Engage was paired with a resource adequacy modeling analysis to strengthen the capacity expansion analysis result for several reasons. First, Engage does not represent forecast uncertainty for solar and wind, and uncertainty in solar and wind resource availability are particularly impactful for 100% renewable systems. Second, although Engage builds a system to meet the demand in every hour of the year, Engage does not currently include reserve margins which provide additional capacity for operational and contingency situations. Third, Engage does not perform a probabilistic assessment of capacity requirements to compensate for generator outages. By pairing this Engage analysis with a resource adequacy analysis, NREL produced more robust results with adequate resource availability in each hour considering different weather year resource forecasts and probabilistic generator outages.

Resource Adequacy Modeling Overview

Resource adequacy (RA) studies evaluate whether a system's resources (generation and storage fleet) combined with demand-side and interchange contributions will be able to meet the instantaneous load and reserve requirements across a range of specified expected conditions and to an expected standard, such as a defined loss of load expectation (LOLE). RA studies have been used to support various regional resource assessment efforts.

Specifically, for each expansion scenario and year, PRAS simulated 10,000 Monte Carlo forced outage samples for generation components with historical forced outage rate data. The forced outage samples were then used to calculate the likelihood that sufficient generation and storage capacity are available to meet projected electricity demands during every hour of the year. In addition, the RA calculations account for the availability of wind and PV resources based on the production profiles for utility-scale solar, distributed solar, land-based wind, and offshore wind.

PRAS is a probabilistic model based on samples of pseudo-random forced (fossil-fuel-fired) generation outages and renewable energy availability.[227] The sensitivity of wind and PV resources to weather year was analyzed using 2014 and 2018 weather year wind and PV profiles which represented years with low land-based wind and solar resource potential. This multi-year analysis did not model climactic events or meteorological tails. A deterministic (predetermined) planned outage profile was also used in the PRAS analysis to analyze the effects of planned generation fleet outages on resource adequacy.

In addition to evaluating the standard RA metrics of each expansion year and scenario, NREL used a sensitivity analysis to identify additional firm capacity requirements needed to achieve industry-accepted levels of reliability. For each expansion scenario and year, NREL analysts incrementally added 2 MW of firm capacity, which is always available (zero forced outage rate), until the LOLE was reduced to below 2.4 event-hours/year. This analysis used 2.4 event-

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[227] NREL (2023) PRAS: Probabilistic Resource Adequacy Suite

hours/year due to the high historical forced outage rates of the Hawai‘i generation fleets.[228] The total additional firm capacity required to achieve this level of reliability was added in the form of biodiesel generation.

Resource adequacy is only one of multiple aspects of a system reliability assessment. Full reliability assessments are complex and consider the physical flow of electricity, irrespective of contracts or economics, for a single point in time (e.g., less than 5 seconds) when subject to a contingency event. As NREL only analyzed the decarbonization scenarios with copperplate models, this study did not perform a full system reliability assessment, which can make high-penetration renewable energy systems analysis much more complex. Ultimately, stability and contingency planning may reveal the need to make transmission, distribution, and grid services improvements, the costs of which are not included in this analysis.

Translating PATHWAYS Demand Into Hourly Profiles

The PATHWAYS model generated gigawatt-hour demands for each sector and each year through 2045. To translate these annual demands into hourly demand profiles, NREL sourced sector- and subsector-specific load shapes from several different sources, outlined in Table 19. The sector and subsector hourly load shapes were then scaled to align with the annual PATHWAYS demand results.

Table 19. Sector and subsector demand profile shape data sources.

Sector	Subsector	Source
Buildings	Residential, Commercial, and Industrial	Hawaiian Electric IGP (2023),[229] KIUC Production Cost Model[230]
Transportation	Light-duty EVs	Hawaiian Electric IGP (2023)
Transportation	Medium-duty, heavy-duty, and off-road EVs	NREL & Argonne National Laboratory, ongoing work
Transportation	Electric Bus	Hawaiian Electric IGP (2023)
Transportation	Aviation	Developed for this study based on inputs from Mokulele Airlines and Regent Seagliders analysis (2023)[231]

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[228] Stephen, G., Tindemans, S. H., Fazio, J., Dent, C., Acevedo, A. F., Bagen, B., ... & Burke, D. (2022, June). Clarifying the Interpretation and Use of the LOLE Resource Adequacy Metric. In *2022 17th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)* (pp. 1-4). IEEE.

[229] Hawaiian Electric. (2023). Integrated Grid Plan (full report).

[230] Data provided courtesy of KIUC.

[231] Data provided courtesy of Mokulele Airlines and REGENT Craft and the Hawai'i Seagliders Initiative.

Hawaiian Electric[232] and KIUC[233] both developed hourly demand profiles that represent each island's current and projected underlying demands, which predominantly represent residential, commercial, and industrial end-use loads. Hawaiian Electric also published energy efficiency profiles that account for projected hourly energy efficiency saving impacts on the underlying demand shape. These energy efficiency load reduction profiles were added to the underlying system hourly demands. NREL scaled these hourly utility profiles to align with the summed annual PATHWAYS electricity demand outputs from the residential, commercial, and industrial sectors.

Electrification of certain subsectors, such as the electrification of hot water heaters, has the potential to change the current utility load shape, but the load shape impacts of electrifying these subsectors are not explored in this study. Further analysis on the impact of water heating and load shifting potential is likely to be explored in the next iteration of the Market Potential Study. Hawaiian Electric and KIUC's underlying load profiles for each island exclude the projected impacts of EV charging, distributed PV adoption, and electrification of aviation on the load shape.[234]

To incorporate the impacts of LDV charging on the hourly demand profiles, NREL developed a light-duty EV charging profile. The charging profile generated for this study transitions from a lightly managed profile in 2030 to a highly managed charging profile by 2045, under the assumption that Hawaiʻi utilities will implement progressively more widespread and aggressive time of use (TOU) rates that incentivize daytime EV charging.[235, 236] NREL developed the profile using a mix of the Hawaiian Electric IGP unmanaged EV charging profiles[237] and a new, highly managed EV charging profile.

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[232] The Hawaiian Electric hourly demand profiles used in this study are provided in excel workbooks. IGP Inputs and Assumptions. *For Oʻahu, Hawaiʻi island, Maui, Molokaʻi, and Lānaʻi, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "March 31, 2022 – Hawaiian Electric Response to Order No. 38253 Approving Inputs and Assumptions with Modifications (PDF)." The underlying load profiles and associated energy efficiency load reduction profiles are sourced from the workbooks associated with each island entitled "Workbook 3." Hawaiian Electric Provides more information on the development of these underlying profiles in Appendix B, Section 1.1 of the 2023 Integrated Grid Plan*

[233] Data courtesy of KIUC.

[234] *The KIUC underlying demand profile includes the impacts of behind the meter distributed PV and storage on the Kauai hourly load shape. As a result, the load shape for the residential, commercial, and industrial sectors is likely under-representing daylight hour demands in the electric sector models. Future work should assess the impacts of behind the meter solar and storage on this underlying load shape.*

[235] Hawaiian Electric (2023). Shift and save

[236] Hawaiian Electric (2023). Shift and save

[237] Hawaiian Electric (2022) Approved IGP Inputs and Assumptions *The Hawaiian Electric hourly demand profiles used in this study are provided in excel workbooks.* For Oʻahu, Hawaiʻi Island, Maui, Molokaʻi, and Lānaʻi, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "*March 31, 2022 – Hawaiian Electric*

The 2045, highly managed charging profile (Figure 46) assumes 70% of charging occurs from 9 a.m. to 5 p.m., 10% of charging occurs from 5 to 11 p.m., and 20% of charging occurs between 11 p.m. and 8 a.m. The shape of the 2045 light-duty vehicle EV charging profile in this study represents a more managed charging shape with a greater degree of daytime charging than the 2045 Hawaiian Electric IGP managed charging shape.[238] Figure 46 also shows the 2030 normalized lightly managed charging shape compared to the 2045 normalized highly managed charging shape. No prior unmanaged EV charging forecasts existed for Kauaʻi, so the Kauaʻi model uses the unmanaged charging shape from the Hawaiian Electric IGP Maui profile.

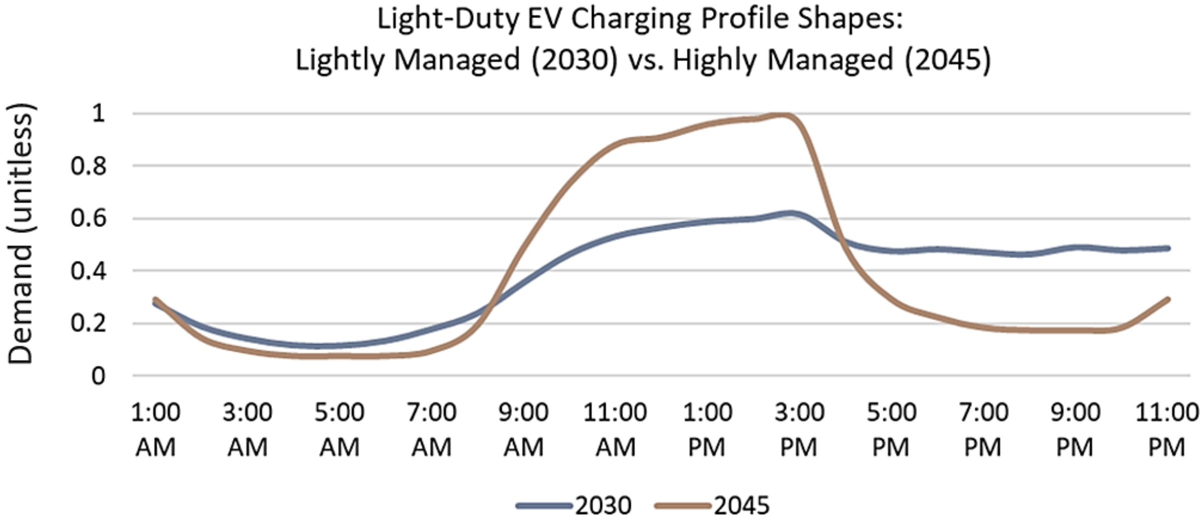

Figure 46 Normalized light-duty lightly managed (2030) and highly managed (2045) EV charging profile shapes.

Profile shapes for medium- and heavy-duty vehicles were sourced from representative day charging shapes developed in ongoing work by NREL and Argonne National Laboratory, simulating local vehicle charging behaviors with the POLARIS transportation system simulation tool.[239] These normalized representative day shapes are shown in Figure 47. The representative day shape for medium- and heavy-duty EV charging is duplicated across each day of the year to

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Response to Order No. 38253 Approving Inputs and Assumptions with Modifications (PDF)." The unmanaged EV charging profiles are sourced from the workbooks associated with each island entitled "Workbook 3." Hawaiian Electric Provides more information on the development of these underlying profiles in Appendix B, Section 1.1 of the 2023 IGP.

[238] For Oʻahu, Hawaiʻi island, Maui, Molokaʻi, and Lānaʻi, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "March 31, 2022 – Hawaiian Electric Response to Order No. 38253 Approving Inputs and Assumptions with Modifications" The Hawaiian Electric IGP managed EV charging profiles can be found in the workbooks associated with each island entitled "Workbook 3."

[239] Argonne National Laboratory (2023) POLARIS Transportation Simulation Tool

create a full annual hourly profile. The off-road vehicle subsector used the same profile shape as the medium-duty vehicles. Further analysis on medium- and heavy-duty vehicle demand should be performed to tailor these profile shapes to the Hawaiʻi context and represent temporal demand variations.

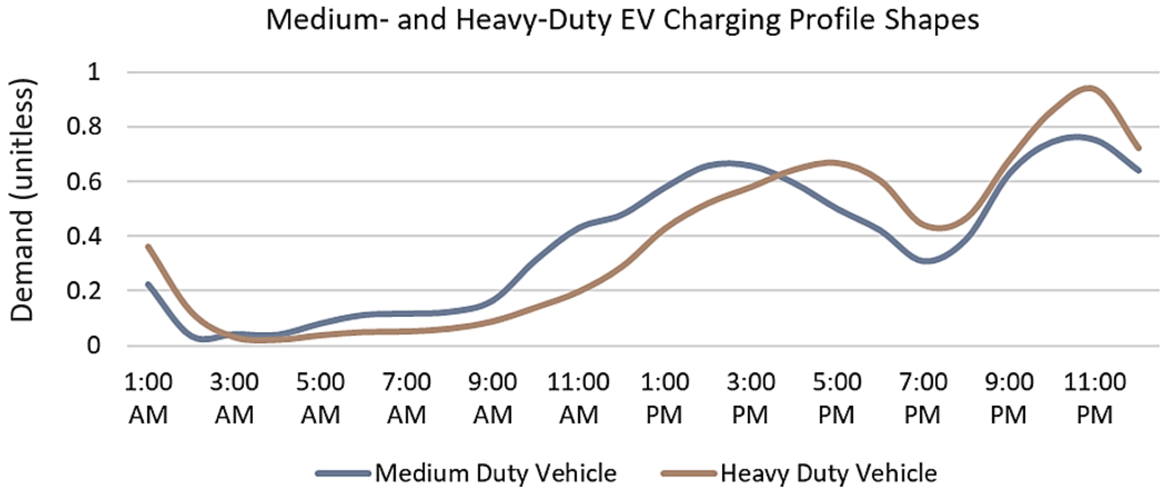

Figure 47. Normalized medium- and heavy-duty EV charging profile shapes.

Electric bus charging profiles were sourced from the Hawaiian Electric IGP (2023).[240] Only Oʻahu, Hawaiʻi, and Maui Island IGP inputs contained electric bus profiles. No electric bus profiles existed for Moloka'i, Lāna'i, or Kaua'i, so the Maui electric bus profile shapes were used in the models for these islands. The electric bus profile shapes were scaled to align with the PATHWAYS annual gigawatt-hour electric bus demands for each year, island, and scenario.

The electric aviation charging profiles were developed based on the current Mokulele Airlines flight schedule as well as a study completed by Regent Craft,[241] a seaglider manufacturer developing crafts that Mokulele plans to use to replace a portion of their inter-island flights. The aviation subsection of the Transportation section in Chapter 2 (Section 2.3) discusses the electrification of inter-island flight and technologies in greater detail. The aviation profiles developed assumed a weekly charging shape that varies by day (see average normalized day shape in Figure 48) and reduces charging in non-daylight hours. This charging shape was used across all islands on which Mokulele Airlines operates and was scaled by the island aviation

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[240] The Hawaiian Electric hourly demand profiles used in this study are provided in excel workbooks. For Oʻahu, Hawaiʻi island, Maui, Molokaʻi, and Lānaʻl, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "March 31, 2022 – Hawaiian Electric Response to Order No. 38253 Approving Inputs and Assumptions with Modifications"

The electric bus, or ebus, charging profiles are sourced from the workbooks associated with each island entitled "Workbook 3." Hawaiian Electric Provides more information on the development of these profiles in Appendix B, Section 1.1 of the 2023 Integrated Grid Plan.

[241] REGENT Craft (2023) Seagliders

demand breakdown derived from BTS data presented in Chapter 2 (aviation demand breakdowns are documented in the Electric Sector Modeling Inputs and Assumptions Appendix C). Future electrification of inter-island aviation should develop more detailed charging profiles and explore the impacts of electrifying inter-island flight on a sub-hourly level.

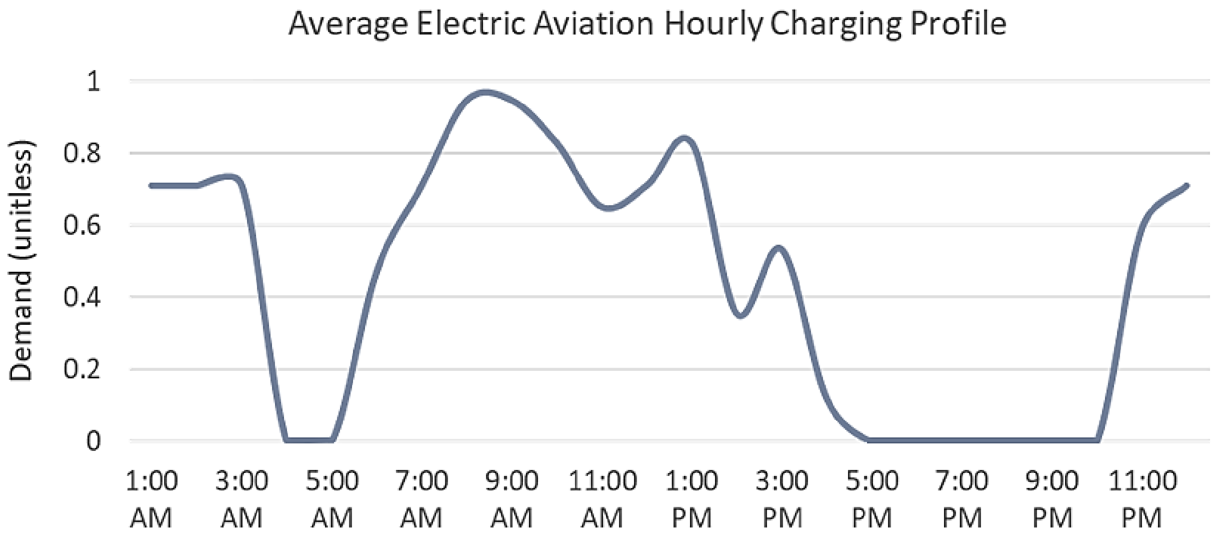

Figure 48. Normalized electric aviation average charging profile.

Generation and Storage Cost and Operating Characteristics

Existing, Planned, and Targeted Generation and Storage Baseline Systems

The electric sector analysis began in 2030 to analyze the midterm (2030) and long-term (2045) Hawaiʻi decarbonization goals. All existing, planned, and targeted generation anticipated to be built by 2030 was represented as a fixed, baseline input to the electric sector models. Planned and targeted generation and storage included Hawaiian Electric's planned and targeted stage two and three RFPs, phase two Tranche 1 and LMI Community-Based Renewable Energy (CBRE) selected projects, and Kauaʻi's West Kauaʻi Energy Project.[242,243] Most CBRE and all stage three RFPs were modeled as planned capacity procurements without project- or site-specific costs and characteristics. Retirement schedules, post-2030 utility-targeted generation, were also represented as fixed inputs that were removed or added to the system in alignment with the Hawaiian Electric IGP Base Resource Plan[244] and KIUC[245] targets.

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[242] Hawaiian Electric (2023) Integrated Grid Plan Appendix C Data Tables

[243] KIUC (2022) West Kauaʻi Energy Project

[244] https://hawaiipowered.com/igpreport/06_IGP-AppendixC_DataTables.pdf

[245] Data provided courtesy of KIUC.

The cost and operating characteristics for existing, targeted, and planned system generation and storage were sourced from the 2023 Hawaiian Electric IGP [246] capacity expansion model inputs and 2023 KIUC production cost model.[247] No minimum operating capacities or minimum up and down times were represented in the energy system models. Additionally, average heat rates for each thermal plant were calculated based on the Hawaiian Electric IGP capacity expansion model results.[248] These modeling configurations result in a simplified thermal generation representation as compared to the 2023 Hawaiian Electric IGP capacity expansion model.

Planned solar and storage projects on Molokaʻi align with energy roadmap items two and three, as described in the Community Energy Resilience Action Plan (CERAP). Roadmap item two plans to fast-track CBRE projects at Pālāʻau (2.2 MW PV + 10.1 MWh storage) and Kualapuʻu (0.25 MW PV + 1 MWh storage). Roadmap item three plans for community-scale solar in West Molokaʻi (2.2 MW PV + 8.8 MWh storage). Additionally, different from the 2023 Hawaiian Electric IGP, all Pālāʻau generators are programmed to retire by 2045, due to the generators' advanced age and HSEO input. The Molokaʻi CERAP contains a total of 10 energy roadmap objectives. Not all energy roadmap objectives are represented in the Molokaʻi model due to model configuration challenges and time constraints. This Molokaʻi energy system analysis should be a reference to how Molokaʻi emissions will contribute to statewide decarbonization goals and should not be seen as a proposed procurement plan.

Distributed Solar and Storage Adoption Forecasts

Distributed solar and storage forecasted adoption was also a fixed electric sector modeling input. Each island model used the distributed solar and storage adoption assumptions in the 2023 Hawaiian Electric IGP Base scenario model input assumptions.[249] No projected distributed solar and storage adoption projections were available for Kauaʻi, so the Kauaʻi model applied the same annual percent growth in distributed solar and storage capacity as the Oʻahu forecast.[250] See Appendix C for the distributed solar and storage adoption projections used in the electric sector models.

In addition to this forecasted distributed generation adoption, distributed solar and storage were also modeled as capacity expansion technology options, described in the next subsection.

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[246] Hawaiian Electric (2023) Integrated Grid Plan Appendix C Data Tables. *Section 1.2 Existing Resource Portfolios contains a list of all existing and planned generation and storage resources through stage 2 RFPs*

[247] Data provided courtesy of Hawaiian Electric and KIUC.

[248] Data provided courtesy of Hawaiian Electric.

[249] Data provided courtesy of Hawaiian Electric. Distributed solar and storage adoption forecasts are described in Hawaiian Electric (2023) IGP Appendix B, Section 1.2 DER Forecasts

[250] The 2023 distributed solar and storage capacities were provided courtesy of KIUC.

Capacity Expansion Generation and Storage

The capacity expansion technology options included in this study were sourced from the model inputs to the 2023 Hawaiian Electric IGP Base scenario.[251] Hawaiian Electric describes the cost and forecast assumptions used to generate these costs in the IGP report.[252] Figure 49 shows the technology-level levelized cost of electricity (LCOE) and levelized cost of storage (LOCS) averaged across islands. The LCOE and LCOS can be used to compare the cost of a kilowatt-hour of electricity generated from each technology. LCOE and LCOSs consider the capital and operational costs, fuel costs, other developer costs, as well as the quantity of electricity the technology can produce throughout the year. The costs modeled in the 2023 Hawaiian Electric IGP use underlying NREL cost forecasts from the 2021 ATB as well as pre-IRA Investment Tax Credit (ITC) incentives. Future electric sector analysis should update the underlying cost inputs for these technologies with updated ATB data and the impacts of IRA ITC incentives. Future analysis could also consider modeling the impacts of different scenarios that consider a wider variety of future technologies and technology costs.

Different from the IGP, this analysis costed all new solar and storage capacity options with the 2023 Hawaiian Electric IGP costs for paired solar and storage. Paired solar and storage costs were used, as these costs are the most representative of recent RFP and planned future procurements. Additionally, all new storage technologies procured by the model were allowed to charge from the grid, as the IRA no longer requires storage technologies to be paired with an exclusively renewable source to qualify for ITC incentives.[253]

This study also modeled the transmission costs required to interconnect new generation capacity in areas of Oʻahu, Maui, and Hawaiʻi islands without the necessary transmission infrastructure. These developable areas and associated transmission needs are described in the Hawaiian Electric Transmission Renewable Energy Zone (REZ) Study.[254]

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[251] Data courtesy of Hawaiian Electric.

[252] Hawaiian Electric. (2023). Integrated Grid Plan (full report).

[253] Utility Dive. (2022, November 7). *IRA sets the stage for US energy storage to thrive.*

[254] Hawaiian Electric (2022) Renewable Energy Zones Study

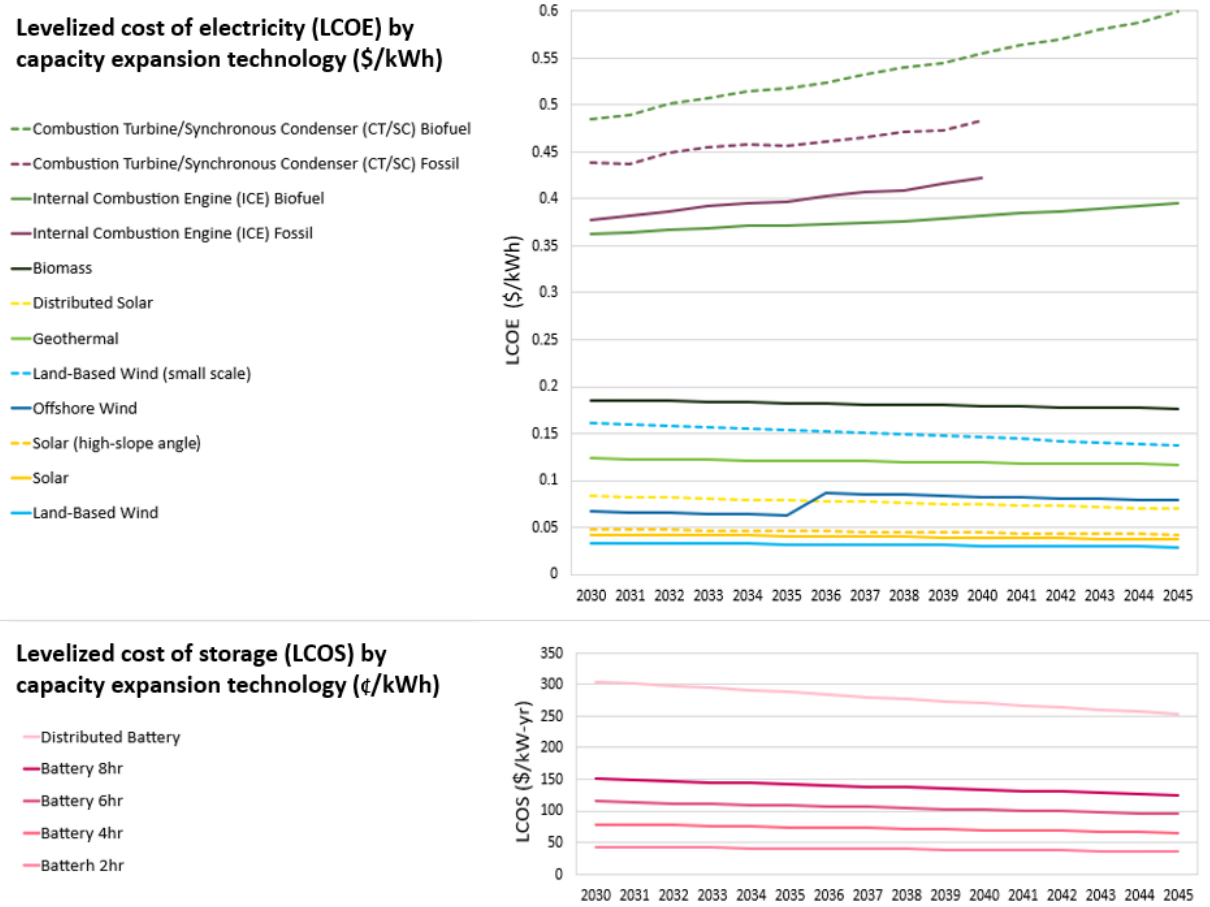

Figure 49. Levelized Cost of Electricity and Storage by Capacity Expansion Technology from 2030 to 2045, averaged across islands. Solar and battery storage costs represent the costs of paired solar and storage technologies. The offshore wind LCOE increases in 2036 due to offshore wind incentives phasing out.

Fuel price forecasts

Figure 49 shows the fuel cost projections for thermal generators averaged across all islands. Fuel cost projections for Kauaʻi were sourced from KIUC production cost model inputs.[255] Fuel cost projections for all other islands were sourced from the Hawaiian Electric IGP inputs.[256]

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[255] Data provided courtesy of KIUC

[256] Hawaiian Electric (2023), Integrated Grid Plan, Appendix C, Section 1.1 Fuel price forecast.

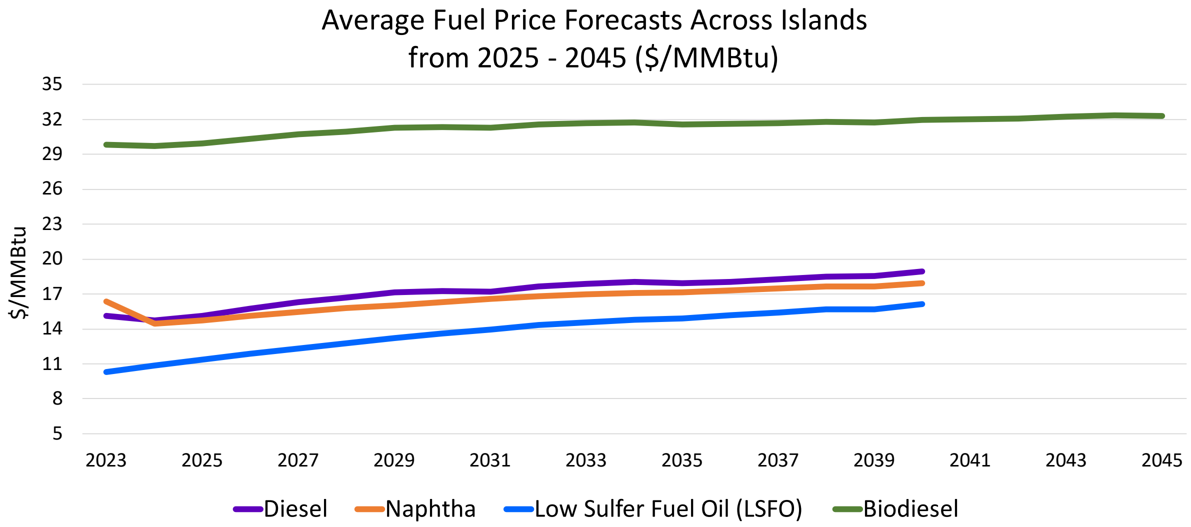

Figure 50. Fuel price forecasts averaged across all islands from 2023 to 2045. The model did not represent fossil fuels in 2045, thus the last year with fossil fuel generation was 2040.

Solar and Wind Technical Potential

For Oʻahu, Hawaiʻi Island, Maui, Molokaʻi, and Lānaʻi, solar and wind resource technical potential and available capacity were sourced from 2023 Hawaiian Electric IGP Base scenario assumptions. The 2023 Hawaiian Electric IGP Base scenario uses state-specific land exclusion datasets as described in the 2021 update of the NREL technical potential report Alt-1 scenario.[257,258] A solar resource technical potential study has not been performed for Kauai, so the System Advisor Model (SAM)[259] was used to generate solar resource technical potential profiles.

The RA multi-weather year analysis was performed with weather year data from 2014 and 2018.[260] The 2014 weather year represented a year with low solar and offshore wind resource, and the 2018 weather year represented a year with low land-based wind resource from the available weather year data (2000–2019). Solar and wind weather year-specific resource data were sourced from the Alt-1 scenario in the 2021 NREL technical potential report. For Kauai, 2014 and 2018 solar weather year data were generated using the same approach used to generate

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[257] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[258] The solar and wind technical potential profiles used in the capacity expansion analysis are provided in excel workbooks. For Oʻahu, Hawaiʻi island, Maui, Molokaʻi, and Lānaʻi, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "March 31, 2022 – Hawaiian Electric Response to Order No. 38253 Approving Inputs and Assumptions with Modifications." The solar and wind technical potential profiles are sourced from the workbooks associated with each island entitled "Workbook 2."

[259] National Renewable Energy Laboratory. (2022) System Advisor Model Version 2022.11.29 (SAM 2022.11.21).

[260] This resource adequacy modeling effort only represented two recent weather years and did not model climactic events or meteorological tails.

technical potential profiles for new-build solar. Distributed solar 2014 and 2018 technical potential data were also generated with SAM, using data from the area on each island with the largest population and assuming a rooftop-mounted panel with a 20-degree tilt. See Appendix C for more information on technical potential inputs.

Emissions

Engage performed the emissions accounting for the electric sector. Emissions for each fuel type modeled were sourced from the EPA Mandatory Reporting of Greenhouse Gases Final Rule Table C-1.[261] As Engage represents thermal generation with simplified operational constraints (average heat rates and no unit commitment), the emissions accounting from Engage does not represent a high-resolution emissions accounting. A modeling approach that considers a more detailed thermal generation unit dispatch is needed for more accurate electric sector emissions accounting and is recommended for future studies.

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[261] EPA (2009) Mandatory GHG Reporting Rules

Chapter 4. Scenario Analysis Results

4.1. Synopsis

Based on the modeling results discussed in this Chapter, HSEO has identified and prioritized near-, mid-, and long-term decarbonization opportunities. With a renewed focus on workforce development and community engagement, the commercialization of clean and efficient technologies can be the centerpiece of cost-effective decarbonization in Hawaiʻi.

Near-Term Decarbonization Opportunities (2020's)

1. Energy efficiency in all buildings, including "net zero ready" building design for new buildings and retrofit programs for existing buildings.
2. Energy efficient transportation infrastructure design and development planning.
3. Utility-scale renewable energy expansion with grid-forming inverters and storage.
4. Agrivoltaics research and development for utility scale solar farms.
5. Fossil fuel power plant efficiency improvements.
6. Replacement of LSFO and diesel with lower carbon and lower cost alternatives.
7. Geothermal resource evaluation in community preferred areas.
8. Protections, incentives, and enhancements for natural working lands as carbon sinks and climate smart agriculture adoption.

Mid-Term Decarbonization Opportunities (2030's)

1. Full prosumer market development for distributed renewable resources, grid-connected appliances, and time-based EV charging incentives.
2. Early retirement of internal combustion engine vehicles.
3. Full decarbonization of the electricity sector.
4. Minimized thermal generation and conversion to synchronous condensers.
5. Transition to lower carbon intensity fuel imports, including hydrogen and SAF blending.
6. Geothermal resource development.
7. Widespread adoption of Climate-Smart Agriculture.

Long-Term Decarbonization Opportunities (2040's)

1. Retrofits of early 21st century building stock.
2. Full decarbonization of public transit and agricultural equipment.
3. Repowering of early 21st century renewable projects with contemporary technology.
4. Carbon capture and sequestration.
5. Fuel imports fully decarbonized.
6. Local clean hydrogen production at scale.

4.2. Economywide Overview

Summary metrics for each modeled scenario are shown in Table 20. While all three mitigation scenarios achieve the 2030 and 2045 GHG emissions targets, they face different practical challenges. For instance, S2 is the lowest cost mitigation scenario and has the greatest emissions reductions on the 2030 timeframe, but it would also require the natural carbon sink to grow by 0.4 MMT relative to 2019, as well as economywide energy demand to shrink by 56% relative to 2019. Conversely, S3 does not rely on these aggressive land-based mitigations or sweeping demand reductions in buildings and transportation, but it is more costly because of the alternative measures employed to meet the targets (e.g. stock buybacks and additional procurement of decarbonized fuels).

Table 20 Summary metrics for modeled scenarios

Summary Metric	Year	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Emissions Reductions	**2030** **2045**	**-45%** **-54%**	**-54%** **-100%**	**-58%** **-100%**	**-52%** **-100%**
Electricity Load growth relative to 2019 (GWh)	**2030** **2045**	**-490 GWh** **675 GWh**	**-230 GWh** **3638 GWh**	**-1545 GWh** **1155 GWh**	**192 GWh** **3684 GWh**
Absolute change in net land sink relative to 2019 levels (MMT CO_2e)	**2030** **2045**	**-0.4 MMT** **-0.7 MMT**	**0.4 MMT** **1.0 MMT**	**0.4 MMT** **1.0 MMT**	**-0.4 MMT** **-0.7 MMT**
Percent change in total annual economywide energy demand relative to 2019	**2030** **2045**	**-10%** **-16%**	**-12%** **-26%**	**-19%** **-37%**	**-15%** **-25%**
Reliance on decarbonized fuels (low carbon fuel demand, excluding electric sector, Tbtu)	**2045**	**2 Tbtu**	**84 Tbtu**	**68 Tbtu**	**109 Tbtu**
Reliance on negative emissions technologies (MMT CO_2 sequestered)	**2045**	**0 MMT**	**0 MMT**	**0 MMT**	**0.5 MMT**

Summary Metric	Year	Reference	Scenario 1 (S1)	Scenario 2 (S2)	Scenario 3 (S3)
Cost of energy transition (2019-2045 NPV of direct costs relative to Reference Scenario, Billion 2021$)	**NPV 2019-2045**	**-**	**$3.4B**	**($3.4B)**	**$5.8**

Color Key
Orange = higher level of challenge compared to other GHG mitigation scenarios
Green = lower level of challenge compared to other GHG mitigation scenarios

Figure 51 shows net emissions (GHG emission sources net of carbon sinks) over time for all three mitigation scenarios alongside the Reference scenario from the base year of 2019 through 2045. After a historic steep drop and then a rebound in GHGs due to the impacts of the COVID-19 pandemic, future economywide net GHG emissions are projected to decline. Net emissions decline to 54% below 2005 levels by 2045 in the Reference scenario, while emissions reach net-negative levels by 2045 in all three mitigation scenarios (S1, S2, and S3). Economywide emissions reductions relative to 2005 levels are reported in Table 21 . Although the three mitigation scenarios have similar emissions trajectories, they vary considerably in their demands for electricity and decarbonized fuels as well as costs due to the different approaches they take towards decarbonization. This will be discussed further in the subsequent sections focused on energy demands and costs.

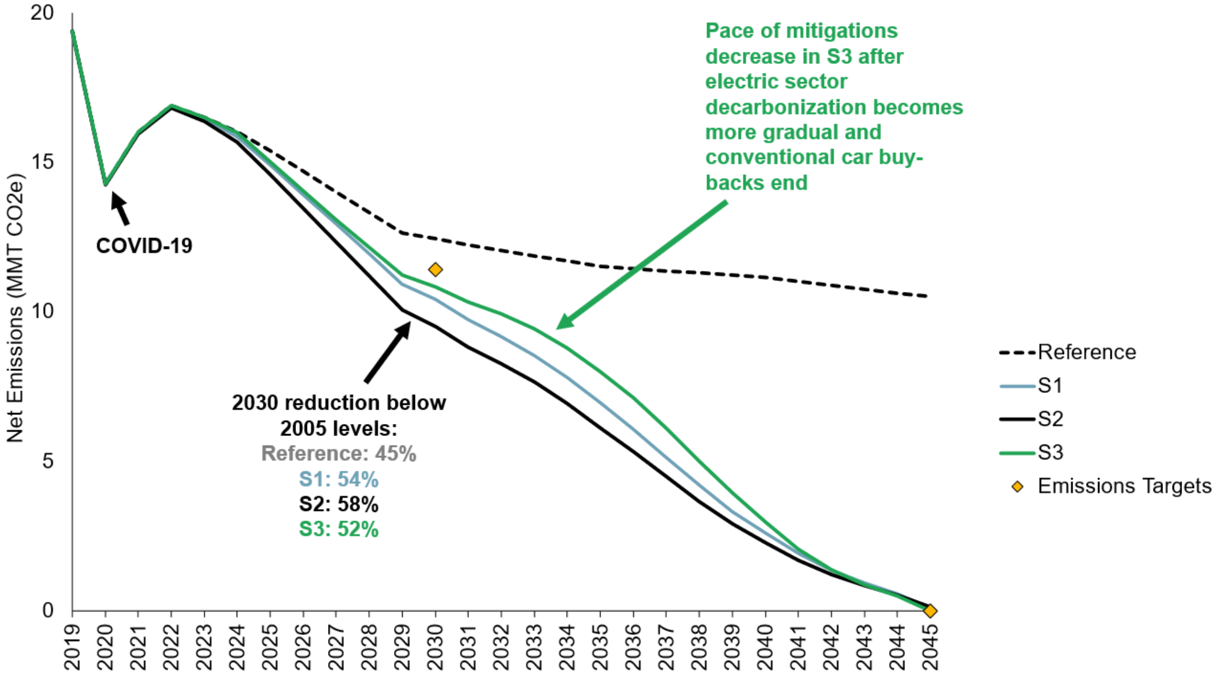

Figure 51 Economywide emissions for each scenario

Table 21 Economywide GHG emissions reductions relative to 2005 levels in key years

Scenario	2030 % GHG Reduction Below 2005 Levels	2045 % GHG Reduction Below 2005 Levels
Reference	45%	54%
S1	54%	100%
S2	58%	100%
S3	52%	100%

Figure 52 shows changes in GHG emissions by sector in each scenario in three key years: 2019, 2030, and 2045. The figure shows gross emissions as areas above the x-axis, negative emissions as areas below the x-axis, and net total emissions as a black diamond. In the Reference scenario, the bulk of emissions reductions come from RPS achievement leading to decarbonization of the electric power sector (shown in dark blue) and reductions in on-road transportation emissions due to electrification of light-duty vehicles (shown in yellow). Sectoral emissions are reported in Table 22.

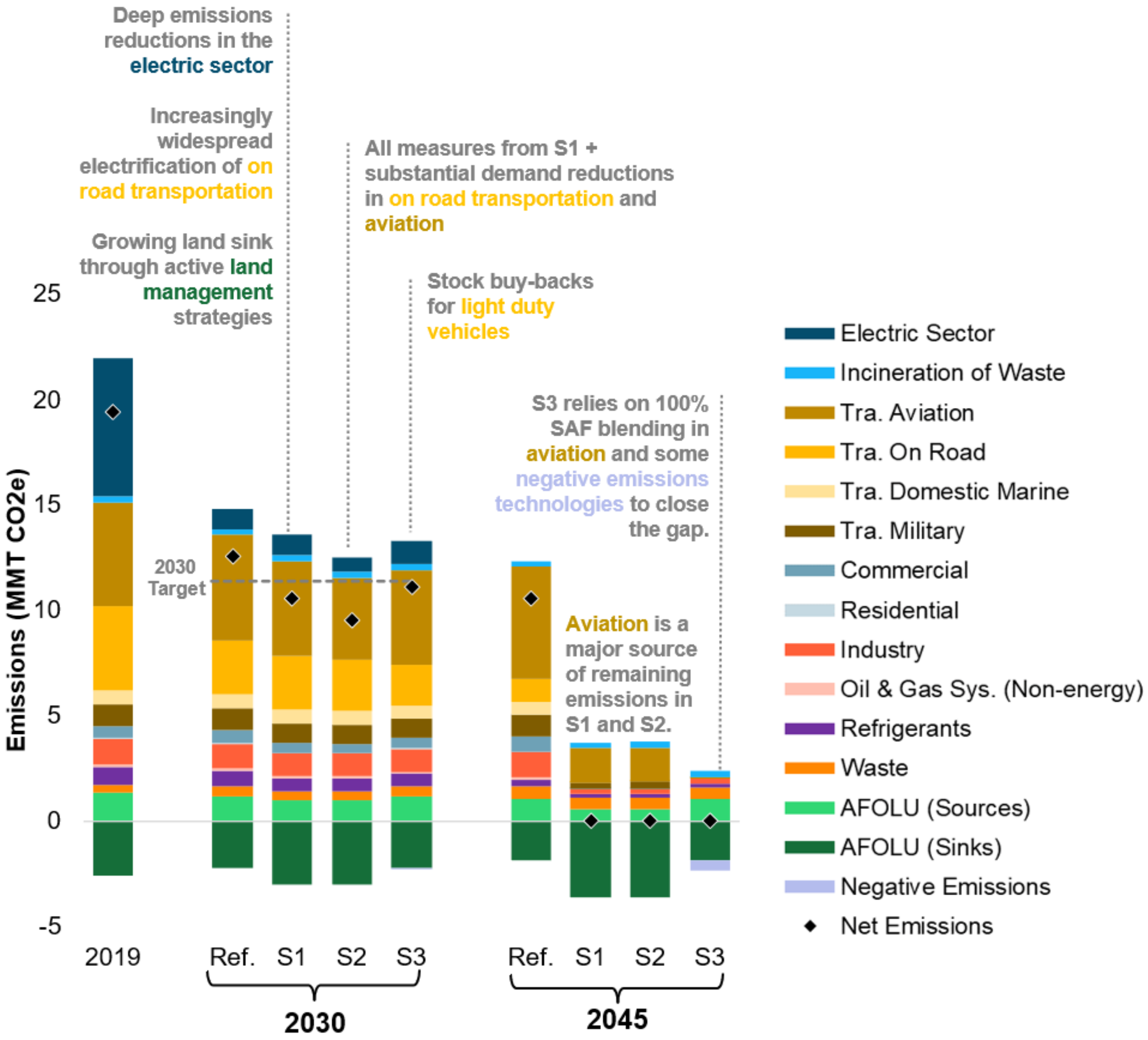

Figure 52 Economywide emissions snapshots in 2019, 2030, and 2045

In 2030, all three mitigation scenarios exceed the target of a 50% reduction in net GHG emissions relative to 2005 levels. In S1, the most significant reductions on the 2030 timeframe come from rapid decarbonization of the electric sector, widespread electrification of on-road vehicles, and the growing natural land sink. In S2, the additional demand reductions lead to even greater emissions reductions on the 2030 timeframe relative to S1. By contrast, S3 does not assume demand reductions, and the natural land sink has shrunk by the year 2030 relative to the base year (consistent with the Reference scenario assumptions). The light duty vehicle stock buybacks allow this scenario to meet the 2030 target. Note that without the stock buy-back measure, S3 would fall just short of the target. However, with the stock buybacks as modeled, S3 achieves a 52% reduction by 2030 relative to 2005. Table 22 shows the percent change in sectoral emissions in 2030 relative to 2005 levels.

Table 22 Sectoral emissions in 2019, 2030, and 2045 (MMT CO_2e)

Sector	2019	2030				2045			
		Ref.	S1	S2	S3	Ref.	S1	S2	S3
Electric Sector	6.6	0.8	0.8	0.7	0.9	0.0	0.0	0.0	0.0
Incineration of Waste	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Tra. Aviation	4.9	5.0	4.5	3.9	4.5	5.3	1.6	1.6	0.0
Tra. On Road	4.0	2.6	2.5	2.4	1.9	1.1	0.0	0.0	0.0
Tra. Domestic Marine	0.6	0.6	0.6	0.6	0.6	0.6	0.0	0.0	0.0
Tra. Military	1.0	1.0	0.9	0.9	0.9	1.0	0.3	0.3	0.0
Commercial	0.6	0.6	0.5	0.4	0.5	0.7	0.0	0.0	0.0
Residential	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Industry	1.2	1.2	1.1	1.1	1.1	1.2	0.2	0.2	0.2
Oil & Gas Sys. (Non-energy)	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Refrigerants	0.8	0.7	0.6	0.6	0.6	0.4	0.2	0.2	0.2
Waste	0.4	0.5	0.4	0.4	0.4	0.6	0.5	0.5	0.5
AFOLU (Sources)	1.3	1.2	1.0	1.0	1.2	1.1	0.6	0.6	1.1
AFOLU (Sinks)	(2.6)	(2.2)	(3.0)	(3.0)	(2.2)	(1.8)	(3.6)	(3.6)	(1.8)
Negative Emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	(0.5)
Net Emissions	19.4	12.4	10.4	9.5	10.8	10.5	0.0	0.0	0.0

By 2045, all three mitigation scenarios reach net negative GHG emissions. In S1 and S2, there are significant remaining gross emissions in 2045 from the combustion of fossil jet fuel in aviation, amongst other sources of gross emissions including non-combustion emissions that are difficult to abate. 2045 gross emissions are offset by the natural land sink in S1 and S2. By contrast, S3 assumes a smaller natural sink and thus must rely on reductions in other sectors to achieve the net-negative goal. S3 assumes 100% blending of sustainable aviation fuel by 2045 and requires additional emissions reductions from negative emissions technologies to achieve the 2045 target.

Table 23 Percent change in 2030 sectoral emissions relative to 2005 levels

Sector	Reference	S1	S2	S3
Buildings	50%	17%	-2%	17%
Industry	-8%	-16%	-16%	-16%
Transportation	-27%	-32%	-37%	-37%
Electric Sector	-90%	-89%	-91%	-89%
Refrigerants	40%	18%	18%	18%
Oil & Gas Systems (Non-energy)	-70%	-74%	-74%	-74%
Waste	-29%	-32%	-32%	-32%
AFOLU Sources	-3%	-20%	-20%	-3%
AFOLU Sinks	-13%	18%	18%	-13%

Figure 53 shows the statewide electricity demands in the key snapshot years of 2019, 2030, and 2045. Future electricity demands are driven by the scenario assumptions across energy-consuming sectors. All scenarios show significant load growth in transportation largely due to the electrification of on-road vehicles. Note that while there is some electric aviation in the mitigation scenarios, the application was restricted to only a small subset of inter-island flights given the limitations of electric aviation with regards to the number of passengers that electric planes might be able to carry. Therefore, the electricity demands for aviation are very minor relative to other demands and are barely visible in Figure 53.

The three mitigation scenarios rely heavily on energy efficiency in buildings to reduce electricity demands. This is most pronounced in S2, which assumes the highest levels of energy efficiency. Total economywide load growth relative to 2019 is reported in Table 23. By 2030, total annual load shrinks relative to 2019 load in all scenarios except for S3, mainly because of the high levels of energy efficiency assumed in buildings. By 2045, however, all scenarios show load growth relative to 2019 loads.

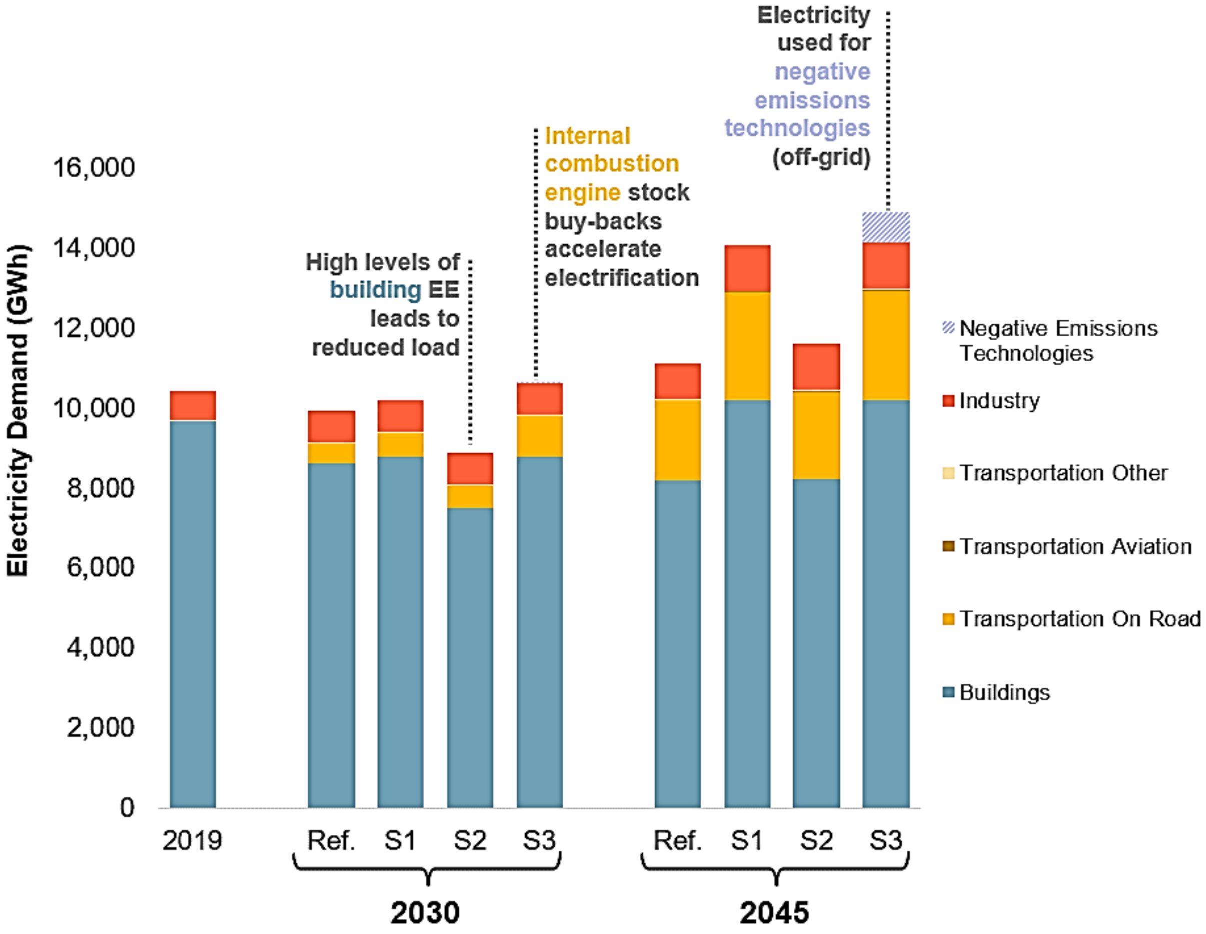

Figure 53 Statewide electricity demands by sector in key snapshot years.

Table 24 Total economywide load growth relative to 2019

Scenario	2030 Load Growth Relative to 2019	2045 Load Growth Relative to 2019
Reference	-5%	6%
S1	-2%	35%
S2	-15%	11%
S3	2%	43%

Figure 54 shows the economywide energy demands across fuel types throughout the modeled time horizon, including electricity. Note that fuels consumed for electricity generation are not shown.

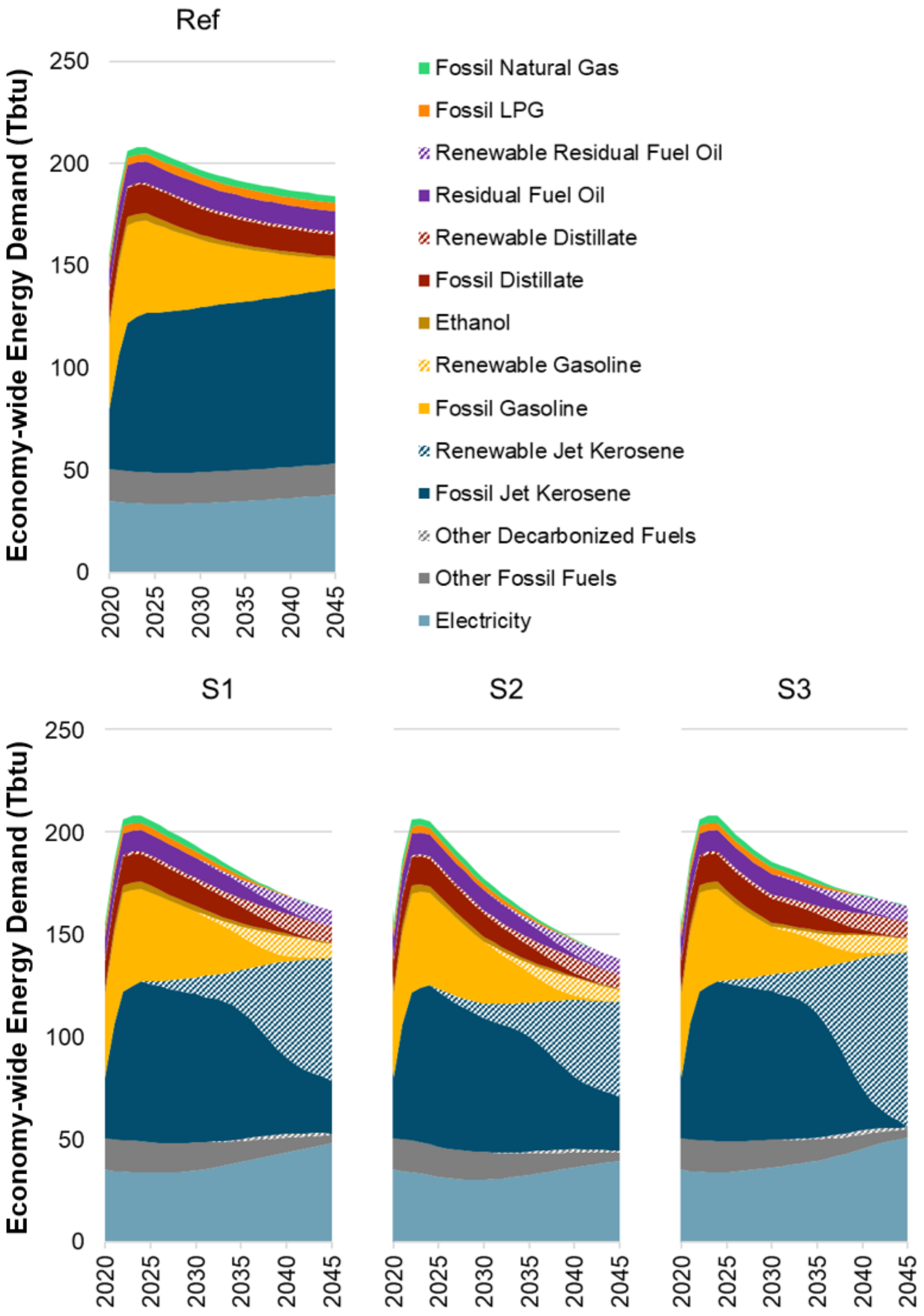

Figure 54 Economywide energy demand from 2020 through 2045 (excludes fuels combusted for electricity generation)

Total energy declines over time in all scenarios due to a combination of energy efficiency, electrification, and demand reductions. Despite widespread electrification across end-uses in the mitigation scenarios, there is still a large demand for fuels through 2045. This is driven mostly by transportation fuels, especially for aviation. 2045 demands for decarbonized fuels and fossil fuels are reported alongside 2019 historical fossil fuel demands in Table 25.

Table 25 2045 economywide estimated demands for decarbonized fuels and fossil fuels alongside historical 2019 fossil fuel demand (excluding fuels consumed for electricity generation)

	2019 Fuel Demand	2045 Fossil Fuel Demand				2045 Decarbonized Fuel Demand			
Fuel Type	**Historical**	**Ref**	**S1**	**S2**	**S3**	**Ref**	**S1**	**S2**	**S3**
Jet Kerosene (Tbtu)	80	86	26	26	0	0	60	46	86
Gasoline, Diesel, & Residual Fuel Oil (Tbtu)	81	35	0	0	0	2	23	21	23
Natural Gas & LPG (Tbtu)	7	8	0	0	0	0	1	1	1
Total Fuel Demand (Tbtu)	219	144	30	30	4	2	84	68	109
Total % of 2019	100%	66%	14%	14%	2%	1%	38%	31%	50%

4.3. Transportation

The transportation sector, particularly the marine and aviation sub sectors will require significant volumes of decarbonized fuels. Figure 48 shows energy demand across fuel types for the transportation sector. Fossil fuels are shown with solid bars, while decarbonized fuels are shown in hashes.

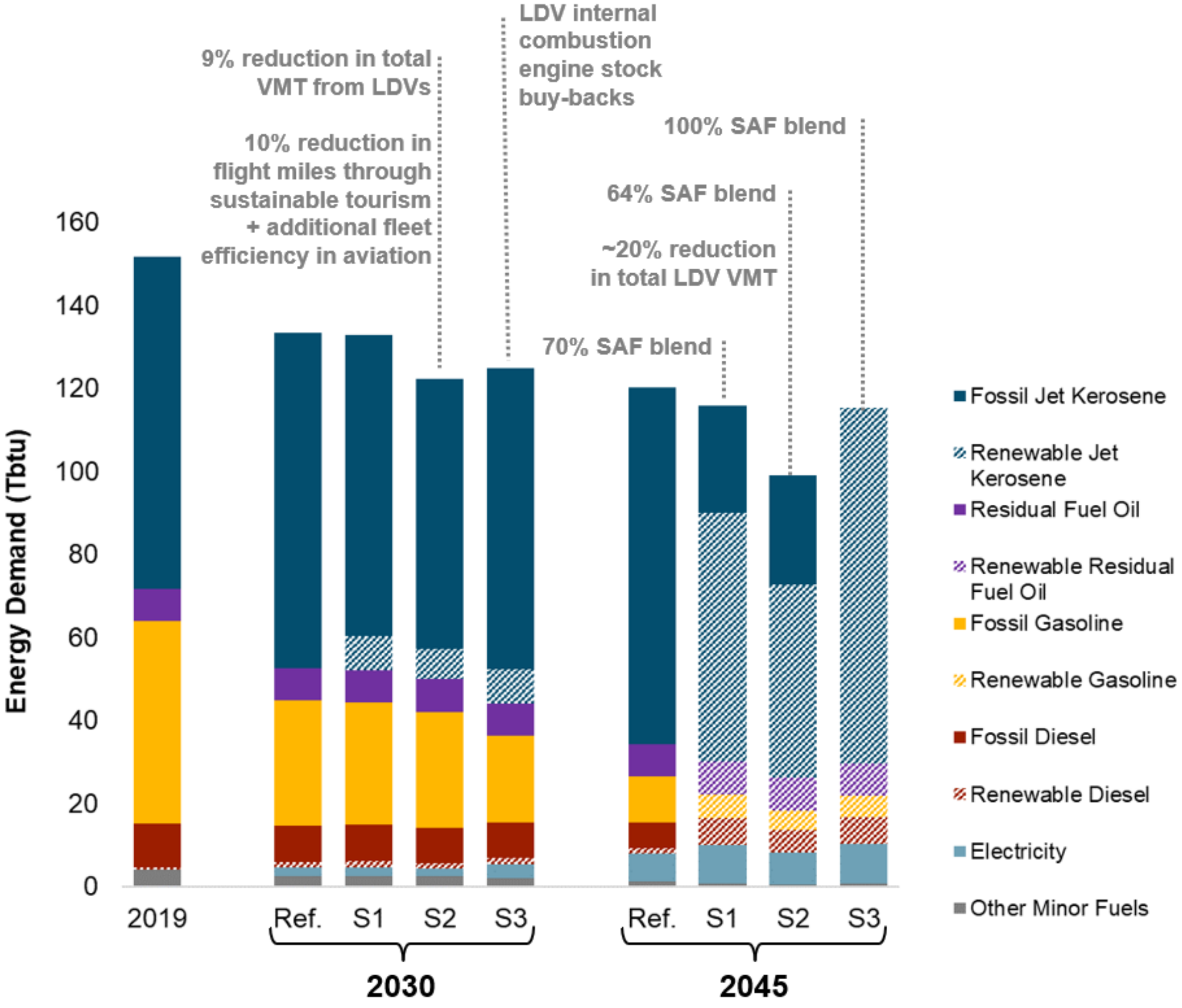

Figure 55 Transportation energy demand snapshots in 2019, 2030, and 2045

There are dramatic reductions in the demand for gasoline across all scenarios because of widespread vehicle electrification in on-road transportation. The demand for electricity increases accordingly. Total energy demand declines, largely efficiency gains in electric on-road vehicles relative to internal combustion engine vehicles. In S2, there are also demand reductions in the form of reduced vehicle miles traveled and reduced flight miles that contribute to further reductions in total transportation energy demand.

Despite widespread electrification of on-road vehicles, there is still significant demand for liquid transportation fuels in 2045. The largest driver of fuel demand is aviation both in 2019 and in the later years. In all mitigation scenarios, decarbonized diesel, residual fuel oil, and gasoline are all set to make up 100% of their respective fuel demands by 2045. These transitions follow S-curves that begin in 2030 for diesel, residual fuel oil, and gasoline. Sustainable aviation fuel was modeled as renewable jet kerosene. The level of sustainable aviation fuel (SAF) blending in each scenario was used as a slack variable to achieve the 2045 economywide target in the mitigation scenarios, ranging from 64-100% in 2045.

Light-duty Vehicles Sales and Stocks

Figure 56 shows the sales shares and resulting stock shares for light-duty vehicles in each scenario.

Figure 56 Light-duty vehicle (LDV) sales shares and stock shares

The Reference scenario assumes light-duty zero-emission vehicle (ZEV) sales aligned with a 2023 report by the International Council on Clean Transportation (ICCT)[262]. Sales are assumed to follow the moderate scenario for non-ACC II[263] states, which includes impacts of the Inflation Reduction Act (IRA). Light-duty vehicles reach 46% of zero-emissions vehicle sales by 2035. Since the ICCT report only projected sales through 2035, an S-curve adoption trajectory was applied to extend the sales projections through 2045. Light-duty vehicles reach 95% of zero-emission vehicle sales

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[262] International Council on Clean Transportation (January 2023) Analyzing the impact of the Inflation Reduction Ace on Electric Vehicle Uptake in the United States.

[263] Advanced Clean Cars II, known as ACC II, is a regulation that requires 100% of light duty vehicle sales in California to be zero emission vehicles by 2035. Since being adopted in California, multiple other states have adopted ACC II. For more information: CARB Advanced Clean Cars II

by 2045. Currently, Hawaiʻi has 2.6% of battery electric vehicle stock as of October 2023, relative to ICCT's forecasted 1.6%, showing that Hawaiʻi is currently ahead of the ICCT forecasts.[264]

All three mitigation scenarios assume Hawaiʻi will have 100% zero-emission light-duty vehicle sales by 2035. Long vehicle lifetimes limit the pace of the stock transition for on-road vehicles given that vehicles are typically replaced at the end of useful life. Despite all three mitigation scenarios achieving 100% zero-emission vehicle sales shares by 2035, S1 and S2 only achieve 21% light-duty vehicle ZEV stock shares by 2030 (see Table 26). S3 assumes that a fraction of (ICE) light-duty vehicles are retired early through a stock buy-back program from 2025-2035. This leads to an accelerated transition of light-duty vehicle stocks compared to S1 and S2 (S3 achieves a 42% ZEV stock share by 2030). This suggests that stock buybacks would be necessary to dramatically increase the 2030 ZEV stock share. There are remaining internal combustion engine vehicles on the road through 2045 because of the long lifetimes of the vehicles (Figure 56). It is assumed the remaining fuel demand for internal combustion engine vehicles is met with 100% renewable gasoline and renewable diesel by 2045.

Table 26 Share of light-duty vehicle (LDV) stocks that are zero-emission vehicles (ZEVs)

Scenario	2030 LDV ZEV Stock Share	2045 LDV ZEV Stock Share
Reference	18%	63%
S1	21%	86%
S2	21%	86%
S3	42%	88%

Medium and Heavy-duty Vehicle Sales and Stocks

Similar to light-duty vehicles, medium and heavy-duty vehicles in the Reference scenario follow the ICCT's projection of zero emissions vehicle sales forecasts of between 43% and 73% battery electric sales by 2035, depending on vehicle class. Additionally, the ICCT forecasts 7% of buses will be fuel cell electric vehicles (FCEV) by 2035. The mitigation scenarios assume 100% zero emissions vehicle sales for medium and heavy-duty vehicles by 2045. By 2045 99% of MHDV sales are electric, with the remaining 1% being fuel-cell electric buses. This reflects a high level of electrification of heavy-duty trucks compared to prior decarbonization studies on the US mainland, where the options considered for long-haul trucking generally include hydrogen fuel

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[264] DBEDT (2023) Monthly Energy Trends

cell vehicles and decarbonized fuels in addition to electrification.[265] However, trucking in Hawaiʻi reflects much shorter distances traveled than the US continent, leading to the assumption in this study that electrification is a feasible decarbonization strategy for the majority of heavy-duty trucks in Hawaiʻi, noting Hawaiʻi Island will face the biggest challenges given the longer distances travelled and the topographical (elevation) differences of the island.

Vehicle Miles Traveled

DBEDT publishes historical data[266] that indicates an essentially flat trend in the vehicle miles traveled (VMT) per vehicle in Hawaiʻi, between 1995 and 2019. The Reference scenario assumes that this trend continues for Hawaiʻi, Kauaʻi, and Maui counties. The 2045 Oʻahu Regional Transportation Plan[267] estimates a 5% reduction in total VMT per vehicle because of transportation system improvements. These transportation improvements included completion of all three phases of the Honolulu Authority for Rapid Transportation (HART) rail system by 2030. These improvements are incorporated in the Reference scenario VMT for Honolulu County. Despite the flat or declining VMT per vehicle, continued population growth leads to a steady increase in total statewide VMT for the Reference scenario.

A study published by The State Smart Transportation Initiative (SSTI) and Smart Growth America with Rhodium Group, in 2019, describes methods for estimating future VMT in Hawai'i under a policy scenario[268]. This policy scenario was developed as a framework for the State of Hawai'i to meet its ambitious climate goal of 100 percent clean energy by 2045. The impacts of VMT reduction measures estimated under this policy scenario were used to build VMT assumptions for the PATHWAYS S2 scenario.

Under this study, the future household growth for the mitigation scenario was shifted to higher density locations in all counties, including the largest shift occurring in Honolulu, along with the policy actions that include:

- Increased land use mixing and street connectivity in Honolulu and Maui.
- A doubling of direct parking costs in Downtown Honolulu, a twenty-five percent increase in parking costs in the rest of Honolulu, Hawaiʻi and Kauaʻi counties, and a ten percent increase in parking costs in Maui.

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[265] Energy and Environmental Economics, Inc. (June 2018). Deep Decarbonization in a High Renewables Future. Prepared for the California Energy Commission.

[266] DBEDT (2023) Data Book Section 18.

[267] Oʻahu Metropolitan Planning Organization (2023) 2045 Oʻahu Regional Transportation Plan

[268] McCahill, C., Sundquist, E., Osborne, B., State Smart Transportation Initiative (SSTI) and Smart Growth America (2019) Estimating policy effects on reduced vehicle travel in Hawaii, Prepared for Transcending Oil: Hawaii's Path to a Clean Energy Economy Commissioned by Elemental Excelerator

- A ten percent improvement in transit access in Honolulu and Maui and a forty percent improvement in transit access in Hawaiʻi and Kauaʻi, .
- Road or mileage pricing measures that increase the cost of driving by fifty percent statewide.

The SSTI study utilizes elasticities for these measures from academic literature to estimate the total impacts on VMT reduction under the mitigation scenario. The measures including road or mileage pricing and increased parking costs were the largest contributors to reduced VMT, followed by various land use and transit measures. The combined impact of these policy measures modeled by SSTI is a 20.5% reduction in total statewide VMT by 2045.

The VMT reduction measures considered in this study would serve to disincentivize additional development outside of currently developed transportation corridors, reducing on-road transportation. This would occur through various means including land use mixing, as well as reduced demand for transportation in personal vehicles in favor of other transit methods (e.g., rail).

Notably, ensuring these incentives and disincentives are administered in a matter that is not regressive is critical. When implementing measures that increase the costs of driving, it must be paired with infrastructure that enables alternative forms of transportation to ensure better options are available. To this end, infrastructure improvement should be prioritized before disincentivizing regressive action is implemented. To that end, money collected from these measures could be used to fund the necessary measures enabling VMT reduction.

Aviation

Aviation Fleet Efficiency

Aviation fleet efficiency improvement trajectories follow the projected reductions from the 2023 Annual Energy Outlook[269]. Based on conversations with stakeholders, the Reference, S1, and S3 scenarios' efficiency improvements are set to achieve 50% of the AEO projection rather than the full 100% since the commercial fleet based in Hawaiʻi is thought to be newer than the national average fleet. In S2, efficiency improvements are modeled to reach the 100% of the improvement in the AEO projection, representing additional efficiency improvement efforts relative to S1 and S3. Note that efficiency improvements in the PATHWAYS model represent the combination of various types of efficiency, including fuel efficiency of the fleet of aircraft, as well as operational efficiencies that reduce overall fuel demand.

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[269] US EIA (2023) Annual Energy Outlook

Aviation Fuel Blending

The Reference scenario has no fuel blending on sustainable aviation fuel (SAF). In all mitigation scenarios, the study assumes a 10% blend of SAF by 2030, which is in line with Hawaiian Airlines' net zero commitments[270]. The level of SAF blending was used as a gap closing measure towards the economywide Net-negative by 2045 target. In 2045, the SAF blending levels for S1, S2, S3 are 70%, 64%, and 100% respectively.

Visitor Arrivals

Reference visitor arrivals are modeled to follow the DBEDT short-term forecast[271]. This visitor arrivals forecast is applied in the Reference scenario as well as S1 and S3.

S2 considers the possibility of demand reductions in the aviation section, with a focus on sustainable tourism given the important role that tourism plays in Hawaiʻi's economy. A hypothetical sustainable tourism measure was modeled, which assumed that a smaller number of visitors stayed for a longer time. This would lead to the same number of total visitor-days, but a reduced number of flight miles from tourists. S2 assumed that the length of stay was increased by one day. Based on data from the Hawaiʻi Symphony Dashboards, the average tourist length of stay in July 2023 was 9 days[272]. Therefore, S2 assumed that the average trip length was extended to 10 days, and aviation demand was reduced by 10% accordingly. This measure was assumed to begin ramping up in 2025, reaching the full 10% reduction in flight miles by 2030.

4.4. Buildings

Figure 50 shows snapshots of energy demand across fuel types in the residential and commercial sectors in 2019, 2030, and 2045. Electricity serves most of the demand in buildings today. In the mitigation scenarios, electricity makes up almost the entirety of energy demand in buildings due to electrification across all major end-uses (e.g. water heating and cooking). Energy efficiency plays a major role in all scenarios to curb load growth in buildings despite additional electrification. By 2045, the remaining fuel demands in buildings are assumed to be met with decarbonized fuels.

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[270] Hawaiian Airlines, Newsroom (March 2023) Hawaiian Airlines Commits to New Milestones on Path to Net-Zero Carbon Emissions

[271] DBEDT (2023) Visitor Tourism Forecast

[272] Hawai'i Tourism Authority (2023) Hawaii Summary Dashboards – Visitor Arrivals

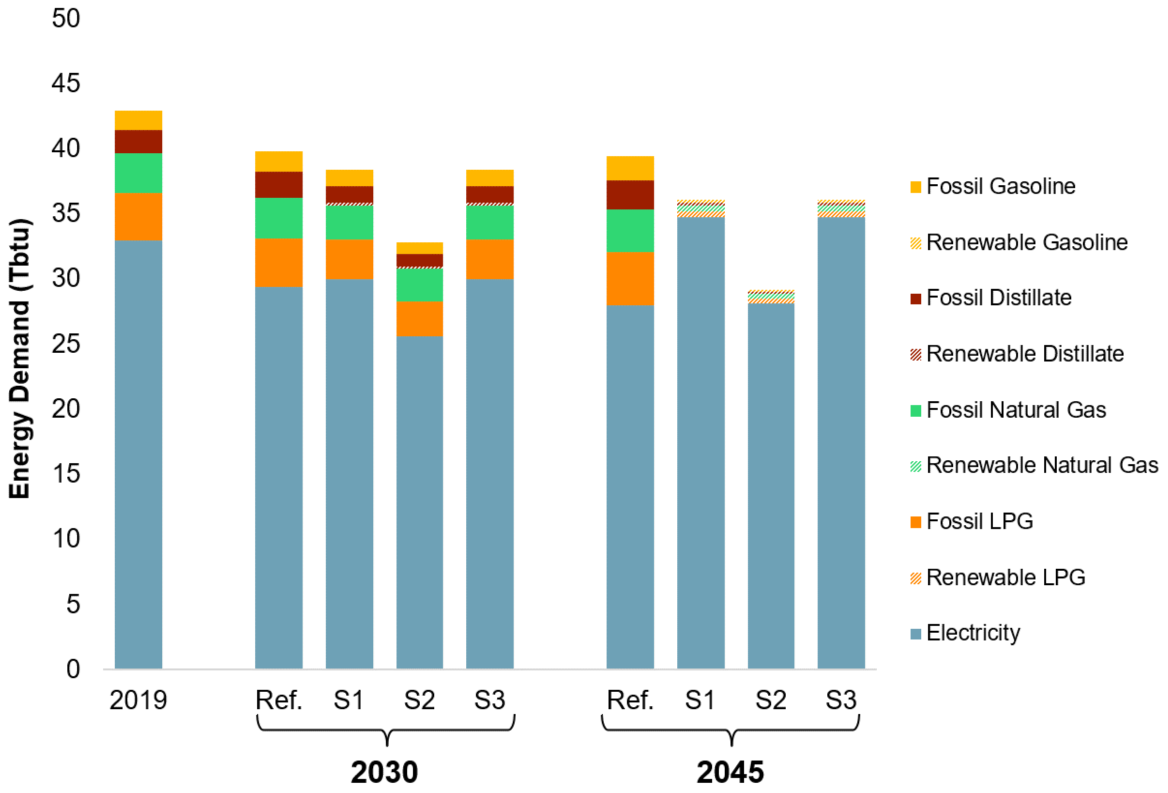

Figure 57 Residential & commercial energy demand snapshots in 2019, 2030, and 2045

Energy Efficiency

All scenarios include energy efficiency (EE) improvements based on the Hawai‘i PUC’s market potential study.[273] The Reference scenario assumes energy efficiency in line with the “Achievable Potential – BAU” scenario. S1 and S3 assume energy efficiency in line with the “Achievable Potential – High” scenario. S2 assumes even greater levels of energy efficiency in buildings, using the "Economic Potential” scenario. Energy efficiency is employed across all residential and commercial end-uses, including air conditioning, water heating, lighting, cooking, refrigeration, amongst others. Note that energy efficiency trajectories were applied such that consumption in buildings was generally aligned with the consumption scenarios shown in Figure ES-5 in the market potential study prior to layering on additional mitigation measures in buildings beyond EE. The consumption projections in the market potential study are declining over time for the scenarios used in the present study. This results in a decline in baseline building loads over time in the Reference scenario. This is notably different than the implied building load forecast in the Hawaiian Electric IGP Base scenario, which grows over time due to underlying drivers.[274] The level

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[273] Applied Energy Group (AEG) (2020) State of Hawai‘i Market Potential Study. Prepared for the Hawai‘i Public Utilities Commission.

[274] Hawaiian Electric (2023). Integrated Grid Plan (full report)

of energy efficiency achievement has a major indirect impact on emissions given that buildings account for most of the electricity demand.

Building Electrification

All four scenarios include solar water heaters in all new residential buildings. Additionally, the three mitigation scenarios include 100% sales of electric devices for all residential end uses by 2035. All three mitigation scenarios include 100% sale of electric devices across all end uses by 2040 in commercial buildings.

Electrification of Aviation

Current and near-term technology limits restrict electric aviation to short distance flight using small planes. Therefore, this study assumed that electric aviation would only be applied to a small subset of inter-island flights that could potentially be served using small electric aircraft. This study assumed that the upper bound on electric aviation in Hawaiʻi was equal to the inter-island aviation demand served by Mokulele Airlines. Based on the current flight schedules, flight paths, and passenger information obtained from the Bureau of Transportation Statistics (BTS) [275] and corroborated based on fuel usage data from Mokulele airlines, it is estimated that only 0.2% of current inter-island aviation could be electrified by 2045. This is reflected in all three mitigation scenarios, with a ramp up beginning in 2035.

Other Off-Road Transportation

Other off-road transportation includes domestic marine transportation and military transportation (excluding aviation). Emissions from off-road transportation are largely from combustion of diesel fuel and from residual fuel oil combusted in marine transport. Off-road transportation likely includes a larger variety of vehicle types compared to on-road transportation, some of which may not be readily electrified. In the mitigation scenarios in the present study, off-road transportation is decarbonized through 100% renewable fuel blending by 2045. However, potential pathways for decarbonizing military and marine transportation will depend on the available vehicle technologies.

4.5. Refining

The Reference scenario assumes that 5% of the Par Refinery's operations will transition to renewable fuel production in 2025. This is meant to represent the planned conversion of one facility[276] to produce renewable fuels. All three mitigation scenarios assume that the Par Refinery will transition to producing renewable fuels beginning in 2025 and reaching 100% renewable fuel production by 2045. The mitigation scenarios assume that 16% of refinery operations are

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[275] US Bureau of Transportation Statistics, Form 41 BTS Filings T-100 Segments (all carriers)

[276] Par Pacific (April 2023) Par Pacific Announces Significant Investment in Hawaii Renewable Fuels Production

converted by 2030, meant to represent the planned conversion plus the conversion of the most suitable existing hydrocracker unit.

This study assumed an 83% emissions reduction from the production of renewable fuels relative to the production of fossil fuels. This assumption was based on the lifecycle carbon intensity of Fischer-Tropsch Diesel relative to the carbon intensity of fossil diesel.[277]

4.6. Non-combustion Sources

Figure 51 shows the emissions from non-combustion sources, including non-energy emissions from the oil and gas system, refrigerants, waste, agriculture, forestry, and other land uses. Non-energy emissions from the oil and gas system decline to zero by 2045 with the phaseout of fossil fuel production. Assumptions for refrigerant and waste mitigation were the same across the three mitigation scenarios. Notably, there are two distinctly different trajectories for agriculture, forestry, and other land uses (AFOLU) shown in green.

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[277] California Air Resources Board (2023) LCFS Pathway Certified Carbon Intensities

Figure 58 Non-combustion emissions in 2019, 2030, and 2045

Waste Management

The Reference scenario assumes reference levels of waste management based on the EPA's U.S. State-level Non-CO_2 GHG Mitigation Report[278]. All three mitigation scenarios assume the maximum abatement available below \$200/tCO_2e from the same report. The report examines multiple waste subsectors, including landfills, wastewater treatment facilities, and composing facilities. The report does not fully abate waste emissions, in part due to technical limitations including the inability to abate N_2O emissions.

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[278] US EPA (2023) U.S. State-Level Non-CO2 GHG Mitigation Report

Refrigerant Management

In the Reference scenario, refrigerant management follows the Kigali Amendment to the Montreal Protocol[279], which mandates the phaseout of hydrofluorocarbons (HFCs) commonly used as refrigerants in HVAC systems and refrigerators. In the mitigation cases, refrigerant management follows the EPA's Significant New Alternatives Policy (SNAP) Program[280].

Agriculture, Forestry, and Other Land Uses

As mentioned previously, there are two distinct trajectories for sources and sinks within agriculture, forestry, and other land uses (AFOLU). S3 follows the same trajectory as the Reference scenario, which assumes that the net land sink shrinks over time relative to 2045. This reference trajectory is based on a 2017 Hawaiʻi-specific report by the US Geological Survey that projects future carbon fluxes.[281]

S1 and S2 assume a greater level of effort towards mitigation in AFOLU, and therefore a growing net land sink through 2045 relative to 2019. Potential mitigation measures were identified based on a 2020 report by Conservation International: *Reversing Climate Change: A study of pathways through Hawaiʻi's natural & working lands*.[282] These include wide-ranging measures focused on sustainable agricultural practices, protection of natural lands, and restoration. The Conservation International report estimated a maximum technical potential from each mitigation measure but did not account for competing land uses or other feasibility constraints when calculating abatement potential. Therefore, the growth rate from the "High Sequestration" case from White House 2021 Biennial Report was used to provide an appropriate upper bound on the total change in the net land sink by midcentury, and trajectory was found to be well within the range of the non-overlapping technical potential from the Conservation International report.[283]

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[279] US Department of State (2022) U.S. Ratification of the Kigali Amendment

[280] EPA (2023) Significant New Alternative Program

[281] Giardina, C. P. (2017). United States Geological Survey, Professional Paper 1834 Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawaiʻi.

[282] Conservation International for the State of Hawaiʻi Office of Planning on behalf of the Greenhouse gas sequestration task force (2020). Reversing Climate Change: A study of pathways through Hawaiʻi's natural and working lands.

[283] US 7th National Communication. (2021) White House.gov A review of sustained climate action through 2020

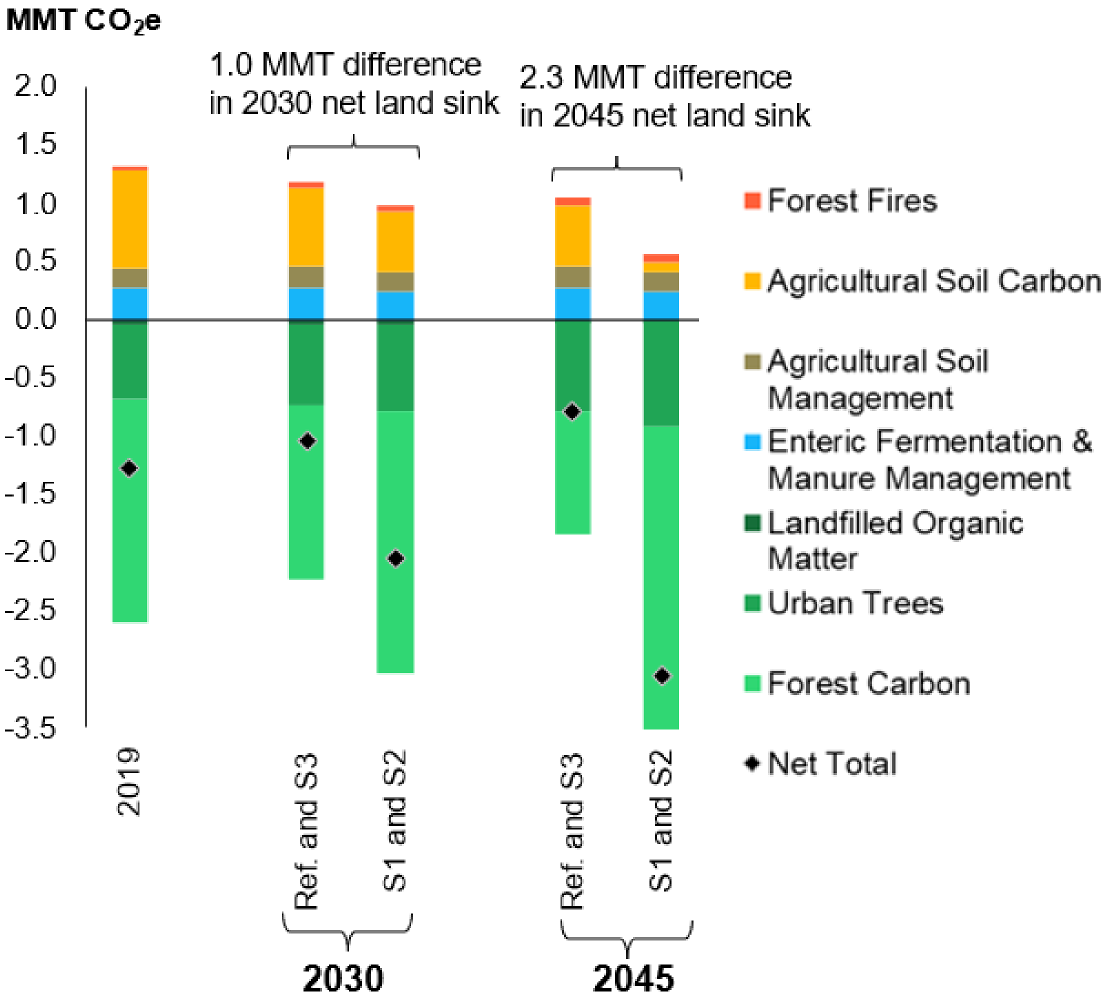

Figure 59 Breakdown of sources and sinks within agriculture, forestry, and other land uses.

Emissions sources and sinks were attributed to the subsectors shown in Figure 52 based on the sequestration potential for various measures in the Hawaiʻi Conservation International report. As shown in Figure 52, forest carbon is the largest contributor to the growing land sink. By 2045, the AFOLU measures in S1 and S2 lead to a net land sink of ~3MMT, compared to just 0.8 MMT for the Reference scenario and S3 (see Table 27).

Table 27 Net land sink (MMT CO_2e)

Scenario	2030	2045
Reference & S3	1.0	0.8
S1 & S2	2.1	3.1

4.7. Electric Power, Statewide Electric Sector Results

From the statewide perspective, the electric sector modeling results demonstrate several key findings and areas for further consideration:

> **First**, the models find that building and operating electric systems with renewable generation penetration levels higher than those outlined in the RPS requirements is more cost-effective than building and operating a system that just meets the RPS requirements between 2030 and 2040.
>
> **Second,** the Reference and S2 scenarios have lower demands, lower statewide electricity supply costs (total and $/MWh costs), and smaller large-scale solar and land-based wind land use impacts than the S1 and S3 scenarios.
>
> **Third,** large-scale and distributed solar generators together make up more than 60% of annual statewide generation in each analysis year. Because solar can only generate electricity when the sun is shining, storage technologies are necessary to reserve excess solar generation to help meet electricity demands during other periods of the day.
>
> **Fourth**, the estimated land use impacts of these decarbonization scenarios are most dramatic on Oʻahu (52–86% and 100% of technically feasible land for solar and wind development, respectively, used across scenarios by 2045) and Maui (4% and 11–16% of technically feasible land for solar and wind development, respectively, used across scenarios by 2045). All other islands experience 1% or less utilization of technically feasible lands across scenarios.
>
> **Fifth**, biodiesel, biomass, geothermal, and/or hydropower generation play a notable role in allowing all islands to meet the 2045 100% RPS requirement.[284]

The electric sector subsections below discuss the results that support these key findings.

As Oʻahu sees the highest electricity demand in the state, the Oʻahu model results also have the greatest influence on the statewide results. See Appendix C for island-specific results and analysis.

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[284] It is important to note that the technologies that will be available in 2045 as well as the costs associated with those technologies are highly uncertain. Currently, biodiesel or biomass generators are the least expensive dispatchable renewable technology option. As technologies develop through the 2045 time horizon, other dispatchable renewable technologies may become more cost-competitive.

RPS, Demands, and Costs

***Key Finding:** The models find that building and operating electric systems with renewable generation penetration levels higher than those required by the RPS is more cost-effective than building and operating a system that just meets the RPS between 2030 and 2040.* [285]

In the years leading up to 2045, the statewide results achieve renewable penetration levels higher than the RPS requirements. The RPS mandates 40%, 70%, and 100% renewable generation by 2030, 2040, and 2045 respectively, and Figure 60 shows that all scenarios achieve greater than 88% renewable generation by 2030, and greater than 93% renewable generation by 2040. These achievements indicate that achieving higher levels of renewable generation in Hawaiʻi is more cost-effective than just meeting the electric sector RPS. Specifically, building and operating renewable resources and storage is less costly than running much of the existing fossil fleets or building and running new fossil generation prior to 2045.

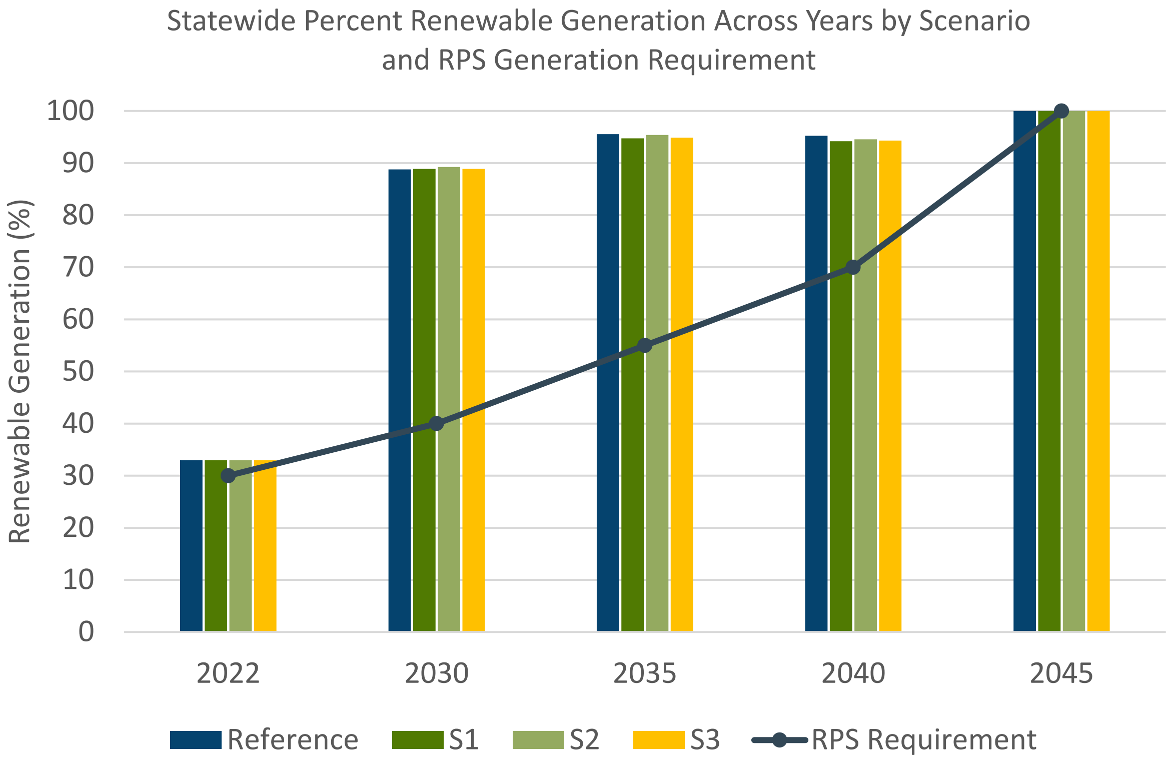

Figure 60. Statewide renewable energy generation penetration by year across scenarios relative to the 2022 33% statewide proportion of renewable energy generation. The electric sector surpasses the RPS requirements in all analysis years prior to 2045.

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[285] Emissions results from the electric sector are aggregated with the broader economy-wide results and discussed from the economy-wide perspective in Section 4.1

All scenarios experience a slight decrease in the proportion of renewable energy generation between 2035 and 2040. This decrease occurs because the model finds running a slightly larger proportion of fossil fuels more cost-effective than procuring additional storage or variable renewable generation to meet the growing demand during time periods with low variable renewable generation. Statewide estimated emissions are reported in Table 22 within the Economy Wide Overview, Section 4.1. The island-specific renewable energy penetrations are outlined in Appendix C.

Key Finding: *The Reference and S2 scenarios have lower demands, lower statewide electricity supply costs (total and $/MWh costs), and smaller large-scale solar and land-based wind land use impacts than the S1 and S3 scenarios.*

Figure 61, Figure 62, and Figure 63 show the statewide electricity supply costs, demands, and unit cost of electricity supply across all simulation years and scenarios. The total costs presented in Figure 61 include the costs associated with procuring new renewable energy through PPA contracts and operating the preexisting system in each year and scenario. These costs only include generation, storage, and transmission costs in each scenario, not all costs incurred by the energy system operator. Because these total annual costs do not include all costs incurred by the energy system operator, the unit cost of electricity supply in Figure 63 does not represent a utility rate. The unit cost of electricity supply is included in this study to illustrate the relative scenario costs and how the relative costs change over the analysis period.

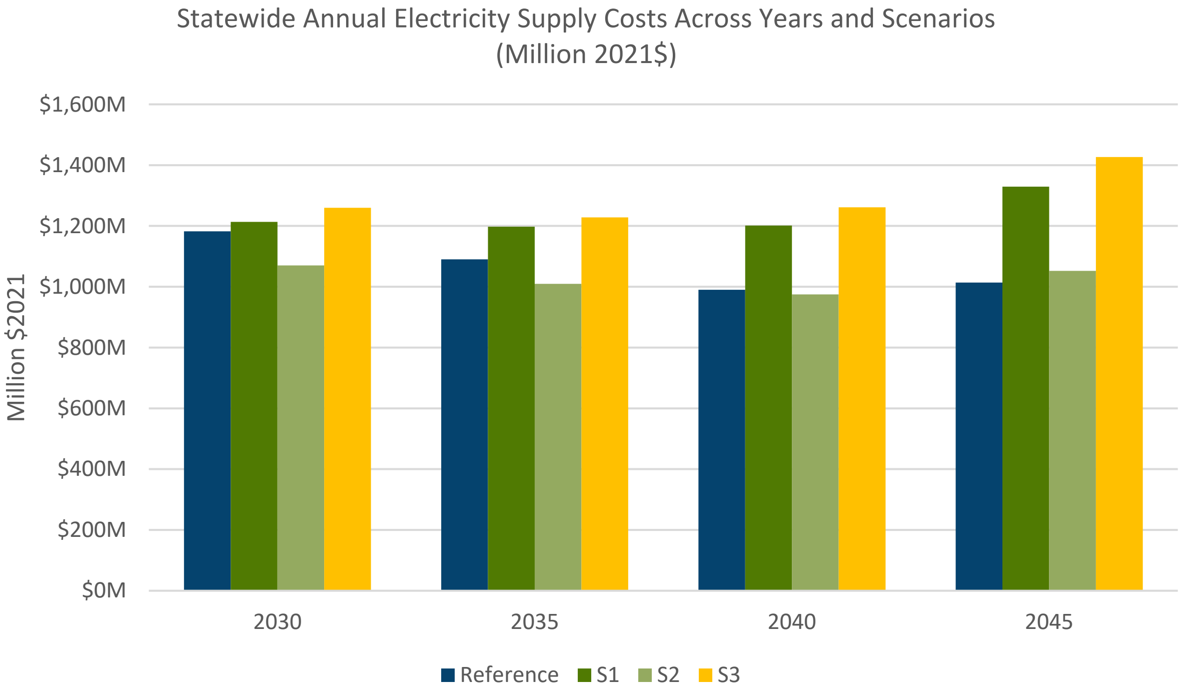

Figure 61. Statewide total cost of electricity supply across model simulation years and scenarios (in million 2021$).

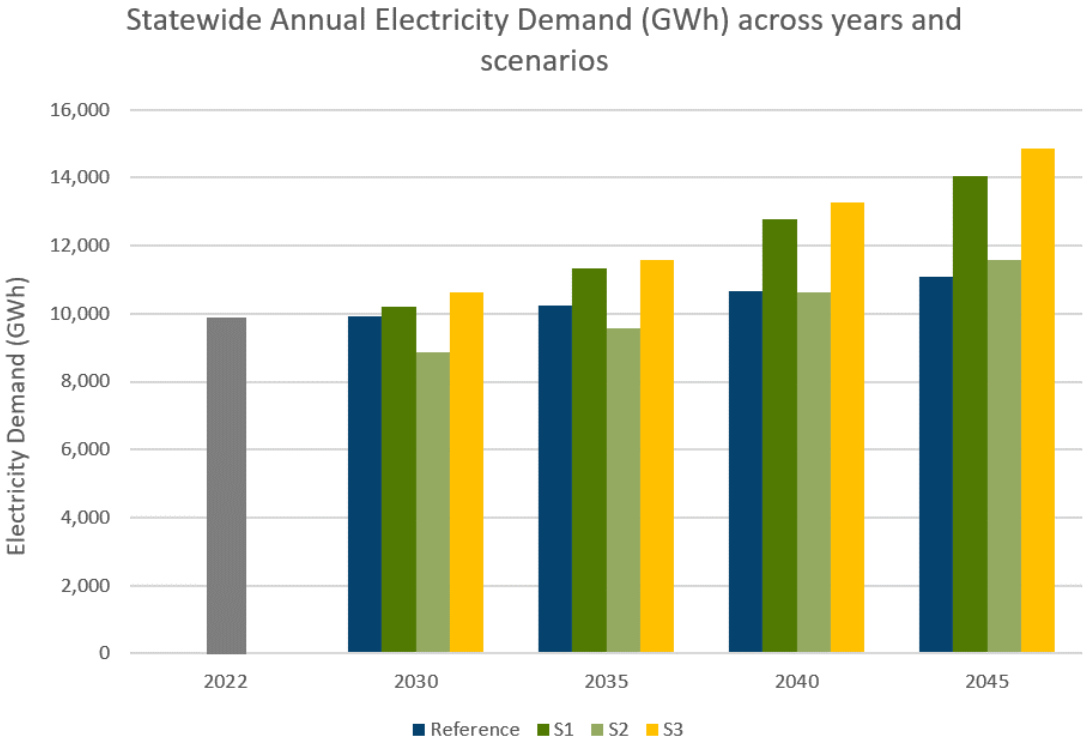

Figure 62. Statewide annual electricity demands (GWh) across scenarios and years relative to 2022 electricity demand.

Figure 63 shows the change in the unit cost of electricity supply over time. Between 2030 and 2040, the unit cost of electricity supply declines relatively rapidly, at a rate of ~$2.6/MWh-year across scenarios. However, in 2045, the reductions in unit cost of electricity supply projected between 2030 and 2040 slow in the Reference and S2 scenarios, remain constant in S1, and increase slightly in S3. This slowing or flattening of the reductions in the unit cost of electricity between 2040 and 2045 is due to the cost to transition from a system operating with 92–94% to a system operating with 100% renewable generation.

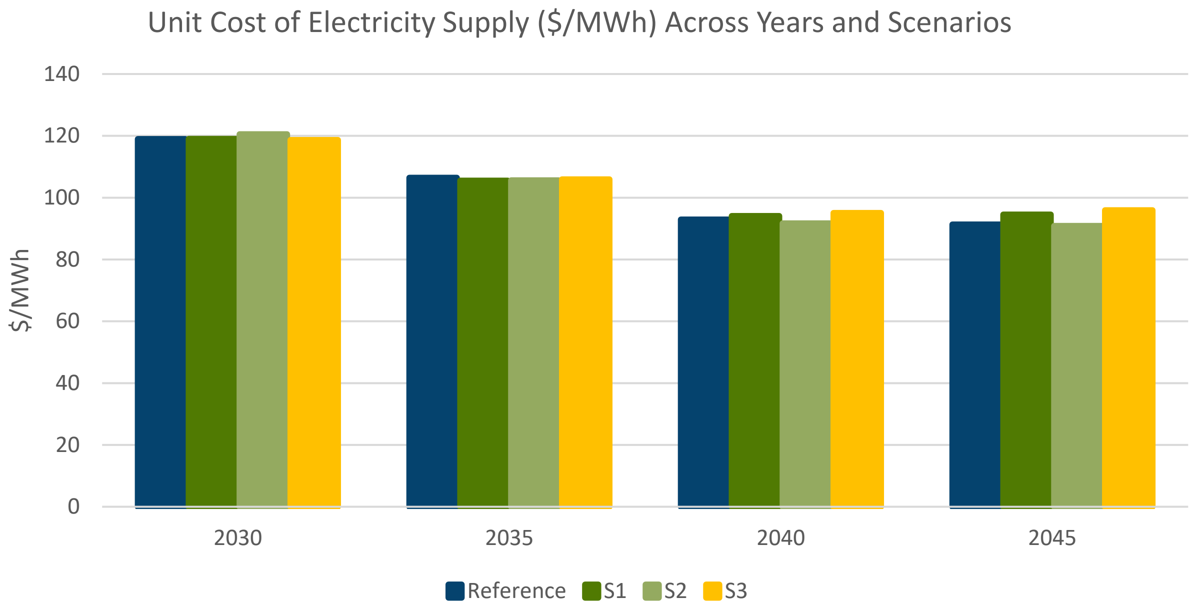

Figure 63. Statewide unit cost of electricity supply ($/MWh) across years and scenarios.

In this analysis, the primary driver of the relative cost to meet the 100% renewable generation requirement as compared to 92–94% renewable generation is the transition to the more expensive renewable fuel source, biodiesel.[286] When the models transition the remaining fossil units to run on biodiesel instead of the relatively less-expensive fossil fuels, the model must build to not only meet the increased demands (Figure 62) but also run the more expensive biodiesel generators. The transition to meet the 100% RPS in 2045 is explored further in the island-specific results subsections below.

2030 and 2045 Technology Mixes Across All Islands[287]

Oʻahu, Maui, and Hawaiʻi Island have the largest electric systems and several system similarities that lend themselves to comparison. As can be seen in Figure 64, in 2030, the islands' electric systems contain similar mixes of solar, land-based wind, storage, and thermal generation. Between 2030 and 2045, each electric system procures significant capacities of solar and storage,

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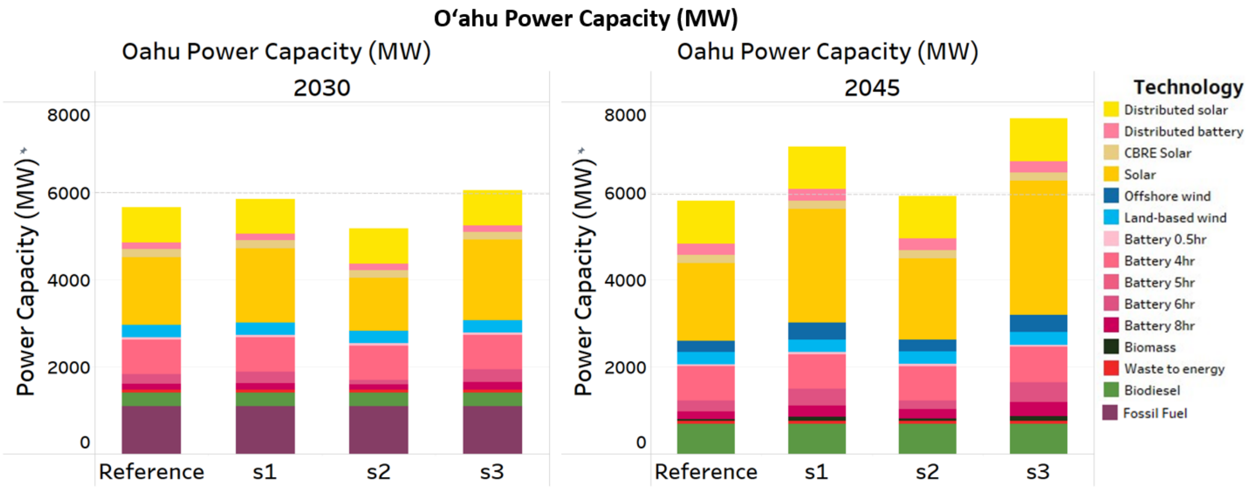
[286] This analysis did not perform any reliability modeling or analysis to assess the power flow dynamics of a 100% renewable system.

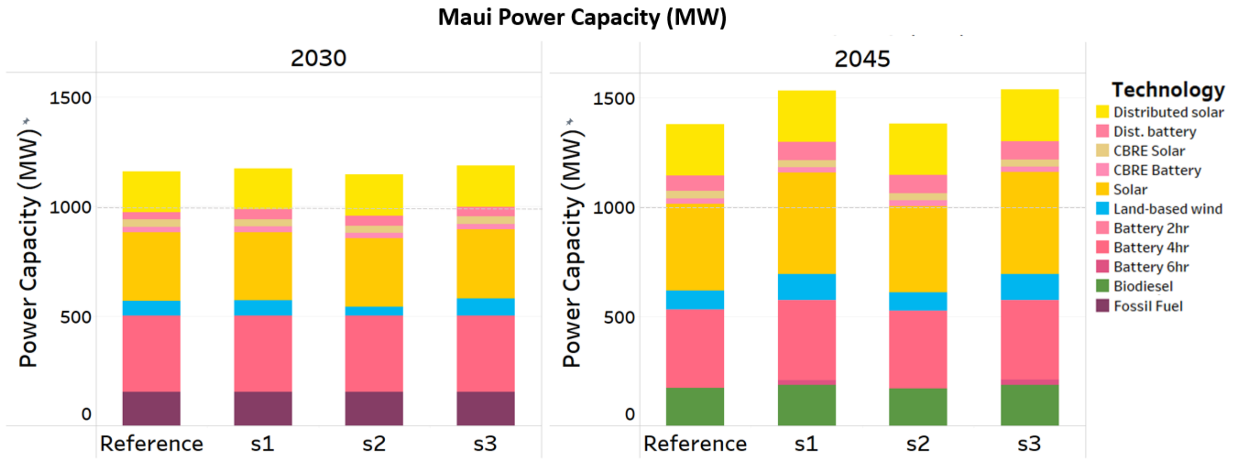
[287] The technology mixes outlined in this section do not represent proposed procurement plans, but rather the modeled least cost pathways to achieving the state's renewable generation and emissions targets. Refer to Chapter 1 for information on equitable and stakeholder driven procurement processes that would be required to achieve these pathways in an equitable way.

while also building out a proportionally smaller capacity of land-based wind. In 2045 for all islands, fossil fuel generation that has not been retired switches to run on biodiesel.

Despite these similarities, there are several key differences among the projected evolutions of the islands’ electric systems. Again, as shown in Figure 64, in 2030, Oʻahu has the greatest proportion of existing and planned thermal generation capacity, while Maui has the greatest proportion of planned solar and storage capacity, and Hawaiʻi Island has unique geothermal and hydropower technologies. In 2045, Oʻahu’s technology mix differs from those of the other two islands in its utilization of offshore wind and biomass. Both the Maui and Hawaiʻi Islands continue to procure solar and land-based wind, whereas Maui procures additional biodiesel generators in 2045 and the Hawaiʻi Island procures geothermal.

The technologies available in each island model drive the different technology build-outs across islands. Due to the economies of scale required to build an economic offshore wind plant, Oʻahu is the only island with an offshore wind capacity expansion option. Additionally, Hawaiʻi Island is the only model with a geothermal option. Maui has no offshore wind, biomass, or geothermal technology options, so the model builds biodiesel to add system flexibility in 2045.





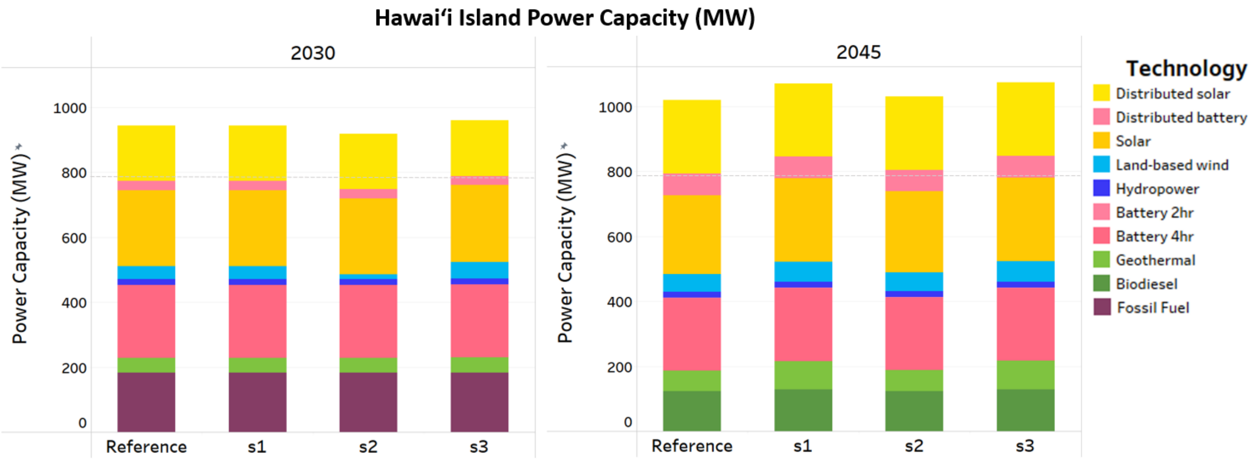


Figure 64. O‘ahu, Maui, and Hawai‘i Island 2030 and 2045 electric sector generation technology mixes. Distributed battery resources have an average 2.7-hour storage duration.

Kauaʻi, Lānaʻi, and Molokaʻi can also be grouped for comparison, as these three island systems are composed of principally solar, storage, and thermal generation across the study years. Prior to 2030, the Kauaʻi electric system was already composed of a large proportion of solar and storage, and as shown in Figure 65, the model continues to expand the capacity of solar and storage across most scenarios and run years. Both Molokaʻi and Lānaʻi have CBRE solar and storage projects that are planned to come online prior to 2030, adding a large proportion of renewables to the existing predominantly thermal generation systems. Like Kauaʻi, Molokaʻi procures additional solar and storage through 2045.[288] In contrast, Lanai does not procure any storage and only procures solar between 2030 and 2045, relying on the large, planned storage capacity targeted in the Phase 2 Lānaʻi CBRE.

No wind technologies were considered on Kauaʻi island due to the shearwater and endangered seabird populations that nest on Kauaʻi (the last island with an absence of mongoose).[289] Thus, the Kauaʻi model's only procurement options were solar, storage, and thermal generation. Molokaʻi and Lānaʻi both had land-based wind resources represented, but the available wind resources were more expensive than the land-based wind resources on the other islands. The wind resources were more expensive because the scale of renewable capacity needed on Molokaʻi and Lānaʻi does not achieve the same scale as traditional utility-scale wind plants. The costs assume that building wind plants with small capacities is more costly than building wind plants at scale. As a result of these high wind turbine costs, as is also shown in Figure 65, the Molokaʻi and Lānaʻi models do not elect to build any land-based wind.

In 2045, the Lānaʻi and Kauaʻi models transition the existing fossil fleets to biodiesel generation. Due to feedback that the Molokaʻi units would not feasibly be operational through 2045, the existing Palaʻau power plant is retired instead of transitioning to biofuel burning units. Thus, as is also shown in Figure 65, the Molokaʻi model builds new biofuel generation in 2045.

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[288] Capacity expansion options included the costs for battery energy storage technologies, as these are currently the most cost-effective storage technology options. Emerging technologies such as hydrogen, pumped storage hydropower or other long-duration storage technologies could become more cost-competitive with the dispatchable technologies represented in this study by 2045.

[289] KIUC (2020) Save our shearwaters

Figure 65. Kauai, Moloka'i and Lanai 2030 and 2045 electric sector generation technology mixes. Distributed battery resources have an average 2.7-hour storage duration.

Modeled Generation Mixes Across All Islands

Key Finding:* *Large-scale and distributed solar generators together make up more than 60% of annual statewide generation in each analysis year. Because solar can only generate electricity when the sun is shining, storage technologies are necessary to reserve excess solar generation to help meet electricity demands during other periods of the day.

Figure 66 illustrates that across all scenarios and islands, large-scale and distributed solar generate more than 60% of statewide generation in 2030. Solar continues to generate more than 60% of statewide generation through 2045. Large-scale solar generates 43% of the total generation, while distributed and CBRE solar generates 23–26% of the total generation. The distributed solar in these charts refers to the forecasted contribution of distributed solar adoption.

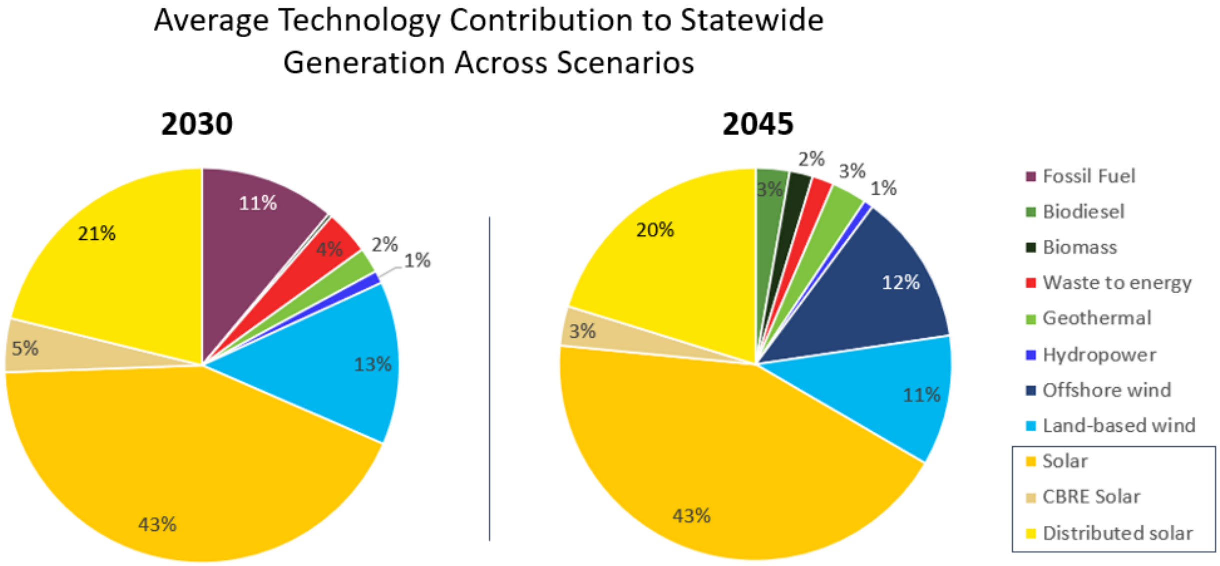

Figure 66. Average statewide generation by technology type across all scenarios in 2030 and 2045. On average, solar generates greater than 60% of the total generation across all islands and scenarios.

***Key Finding**: The dispatchable generation technologies considered in this study (biodiesel, biomass, and geothermal generation) are the known, proven renewable resources currently deemed to play a notable role in enabling all islands to meet the 2045 100% RPS requirement.*

Flexible, dispatchable generators can quickly turn on or off to meet the demands of the system. These types of generators are not reliant on variable renewable resources such as solar or wind and thus can generally be used during any time of the day, regardless of weather conditions. As shown in the 2040 and 2045 generation plots in Figure 67, the Oʻahu model still generates 5–6% of total generation in 2040 from dispatchable fossil units. In 2045, when the 100% RPS constraint is enforced, a similar proportion of generation (5–6%) transitions to biofuel and biomass generation. Although a kilowatt-hour of electricity from biofuel and biomass generators is expensive relative to solar and storage generators, current energy market simulation models are configured to deploy some proportion of the energy mix with these [290][291]

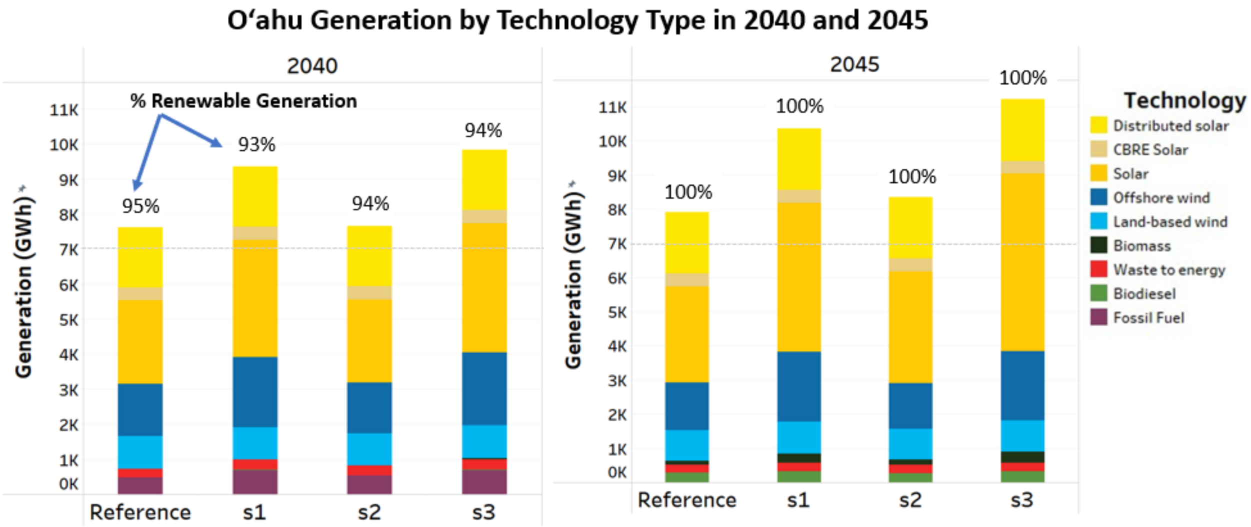

Figure 67 O‘ahu generation by technology type in 2040 and 2045.

In contrast to O‘ahu, Hawai‘i Island has access to geothermal resources. Figure 68 shows that Hawai‘i Island achieves the highest renewable generation, nearly 100%, of all islands by 2030 with access to the planned Puna Geothermal Venture expansion. Geothermal offers a dispatchable renewable generation that is less expensive to operate than biodiesel generators, which have a high fuel cost. The model procures additional geothermal capacity in 2040 and 2045, allowing Hawai‘i Island to burn the smallest proportion of biofuel across the islands in 2045. Kaua‘i burns the second lowest proportion of biofuel in 2045, running the existing biomass facility as additional dispatchable generation.

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[291] The capacity expansion model only represented the hourly needs of the system. In systems with high penetrations of variable renewable generation resources, the needs for intra-hour flexibility would be even greater than the needs for hourly flexibility. Engage does not represent the intra-hourly needs of the system or sub-hourly dispatch costs.

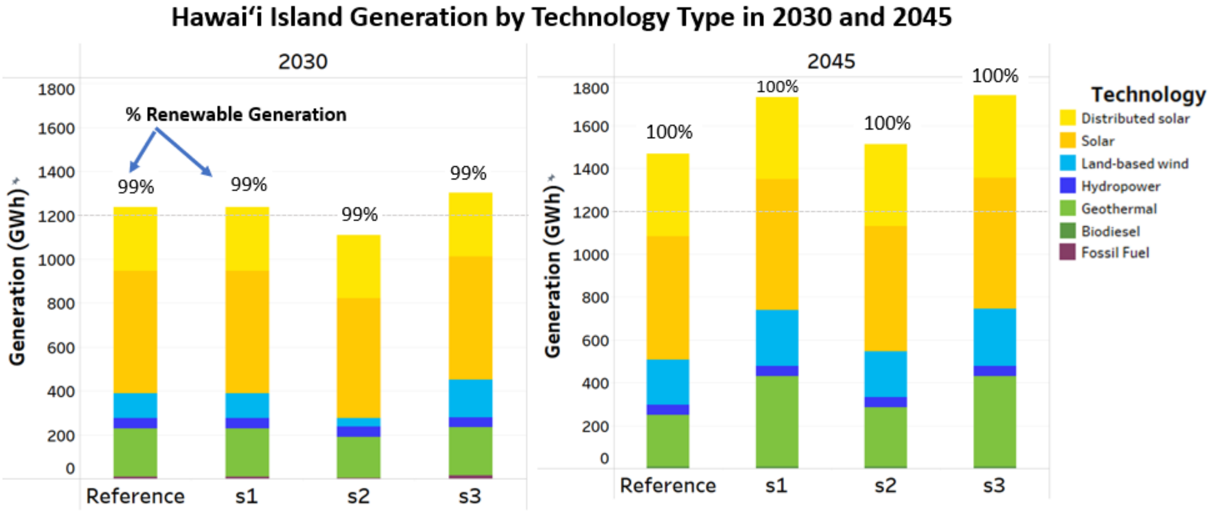

Figure 68. Hawai'i generation by technology type in 2030 and 2045.

As illustrated in the Oʻahu and Hawaiʻi Island generation figures, Figure 67 and Figure 68, respectively, dispatchable renewable energy plays an important role in achieving a 100% RPS. In this analysis, islands used a mix of geothermal, biodiesel, and biomass generation to fill dispatchable needs. Other emerging technologies such as hydrogen or other long-duration storage technologies could become cost-competitive by 2045.

Land Use

***Key Finding:** The estimated land use impacts of these decarbonization scenarios are most dramatic on Oʻahu, with Maui in a distant second. All other islands realize 1% or less utilization of technically feasible lands across scenarios.*

The electric sector analysis found that multiple gigawatts of new solar and several hundred megawatts of land-based wind are key contributors to meeting the state's electricity demands and decarbonization goals in a cost-effective manner. Table 28 presents the estimated percent of technically feasible land that would be used by solar and wind development on each island by 2045. The land areas considered "technically feasible" for solar and land-based wind are defined in the Alt-1 scenario of the 2021 NREL solar and wind technical potential study.[292] Land use, or capacity density values, were set to 0.154 MW/acre for solar PV and 0.012 MW/acre of wind.[293,294]

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[292] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[293] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[294] The land use footprint, associated with solar and wind developments vary by site and technology type.

	Technology	O‘ahu [295]	Maui	Hawaii	Kauai[296, 297]	Molokai [298,299]	Lanai[300]
Total Island Area (acres)	Wind and Solar	383,000	465,000	2,580,000	353,000	166,000	89,900
Technically Feasible Land Area for Development (acres)	Solar	24,700	89,000	495,000	--	67,700	63,000
	Wind	13,400[301]	63,300	415,000	--	42,500	42,000
Scenario		**Percent of Technically Feasible Land Used for Electric Sector by 2045**					
Reference Land Use	Solar	52	3.5	0.32	0.32	0.27	0.21
	Wind	100	11.1	0.87	--	--	--
S1 Total Land Use	Solar	74	4.0	0.34	0.45	0.33	0.24
	Wind	100	15	1.0	--	--	--
S2 Total Land Use	Solar	54	3.5	0.33	0.37	0.28	0.20
	Wind	100	11	0.95	--	--	--
S3 Total Land Use	Solar	86	4.0	0.34	0.45	0.33	0.24
	Wind	100	16	1.0	--	--	--

Table 28. Estimated land use impacts from solar and wind build-out across islands and scenarios. The percent of land used by the electric sector by 2045 includes both the new solar and wind capcity results from the electric sector

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[295] O‘ahu solar land use impacts represent an upper estimate of large-scale solar buildout in each scenario. See Appendix C [O‘ahu], for a more detailed discussion of these results.

[296] As noted in the electric sector inputs section, no study has assessed the land availability for solar development on Kauai. As a result, this study does not measure against the total developable land on Kauai.

[297] No wind technologies were considered on Kaua‘i island due to the shearwater and endangered seabird populations that nest on Kaua‘i (the last island with an absence of mongoose).

[298] Moloka‘i solar land use impacts represent an upper estimate of large-scale solar buildout in each scenario. See Appendix C [Moloka‘i], Large-scale versus distributed solar capacity expansion results section for a more detailed discussion of these results.

[299] Moloka‘i available wind resources were more expensive than the land-based wind resources on the other islands, as the costs assume that building wind plants with small capacities is more costly than building wind plants at scale. As a result of these high wind turbine costs, the Moloka‘i model does not elect to build any land-based wind.

[300] Lana‘i available wind resources were more expensive than the land-based wind resources on the other islands, as the costs assume that building wind plants with small capacities is more costly than building wind plants at scale. As a result of these high wind turbine costs, the Lana‘i model does not elect to build any land-based wind.

[301] The Alt-1 scenarios developed by Grue et al. (2021) did not exclude land with existing land-based wind developments from the total developable land capacity value. The technically feasible land area for land-based wind referenced in this table is smaller than the value provided in Alt-1 scenarios to reflect only the remaining undeveloped land-based wind area.

modeling including the planned and targeted Stage 1, Stage 2, Stage 3, Tranche 1 and LMI CBRE, and WKEP land impacts.

Oʻahu electric sector results realize the greatest land use impacts of all Hawaiian Islands, while Maui electric sector results realize the second greatest land use impacts across all islands. Oʻahu is the only island with capacity expansion results that approach the maximum land area available for solar and land-based wind development, using up to an estimated 85% and 100% of technically feasible land for solar and land-based wind, respectively, in S3. Maui electric sector analysis results also indicate small to moderate land use impacts, up to an estimated 4% and 16% of technically feasible land for solar and wind, respectively, in S3. All other islands see 1% or less utilization of technically feasible lands across scenarios.

Key Finding: *The Reference and S2 scenarios experience lower demands, lower statewide electricity supply costs (total and $/MWh costs), and smaller large-scale solar and land-based wind land use impacts than the S1 and S3 scenarios.*

The land use impacts associated with each scenario directly correlate with the final 2045 gigawatt-hour demands for each scenario. As shown in Table 28 and Table 29, the greatest land use impacts are associated with S3, the scenario with the highest 2045 gigawatt-hour demands, and greatest combined solar and land-based MW procurements. The smallest land use impacts are associated with the Reference scenarios, the scenario with the lowest 2045 gigawatt-hour demands and smallest combined solar and land-based wind megawatt procurements (Figure 62).

Table 29. New solar and wind capacity (MW) results from the electric sector modeling as well as the planned and targeted RFP2, RFP3, Tranche 1 and LMI CBRE, and WKEP capacities (MW).

	Technology	O‘ahu[302]	Maui	Hawai‘i	Kaua‘i[303]	Moloka‘i[304]	Lāna‘i
Technically Feasible Land Area for Development (acres)	Solar	24,700	89,000	495,000	--	67,700	63,000
	Wind	13,400[305]	63,300	415,000	--	42,500	42,000
Scenario		**Solar and Wind Capacity Results (MW)**					
Reference Land Use	Solar	1,968	476	244	176	28	20.1
	Wind	163	86	44	--	--	--
S1 Total Land Use	Solar	2,798	543	257	244	34	23.2
	Wind	163	119	52	--	--	--
S2 Total Land Use	Solar	2,049	473	249	199	29	19.1
	Wind	163	85	48	--	--	--
S3 Total Land Use	Solar	3,270	544	259	246	35	23.3
	Wind	163	120	52	--	--	--

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[302] O‘ahu solar capacities represent an upper estimate of large-scale solar buildout in each scenario. See Appendix C, Large-scale versus distributed solar capacity expansion results section for a more detailed discussion of these results.

[303] As noted in the electric sector inputs section, no study has assessed the land availability for solar development on Kaua‘i. As a result, this study does not assess the impacts of the Kaua‘i capacity expansion results relative to the total developable land.

[304] Moloka‘i solar capacities represent an upper estimate of large-scale solar buildout in each scenario. See Appendix C [Moloka‘i] Large-scale versus distributed solar capacity expansion results section for a more detailed discussion of these results.

[305] The Alt-1 scenarios developed by Grue et al. (2021) did not exclude land with existing land-based wind developments from the total developable land capacity value. The technically feasible land area for land-based wind referenced in this table is smaller than the value provided in Alt-1 scenarios to reflect only the remaining undeveloped land-based wind area.

4.8. Scenario Costs

Annual Direct Costs

Figure 69 shows the annual incremental costs of each scenario relative to the Reference scenario. The colors represent the different modeled costs by sectors. Bars above the x-axis are positive while those below are negative. The negative costs represent savings relative to the Reference scenario. The diamonds represent the net total cost for each year, which is the sum of all positive and negative cost categories. Note that some emissions reductions don't have modeled costs. These include the reductions in vehicle miles traveled and flight miles.

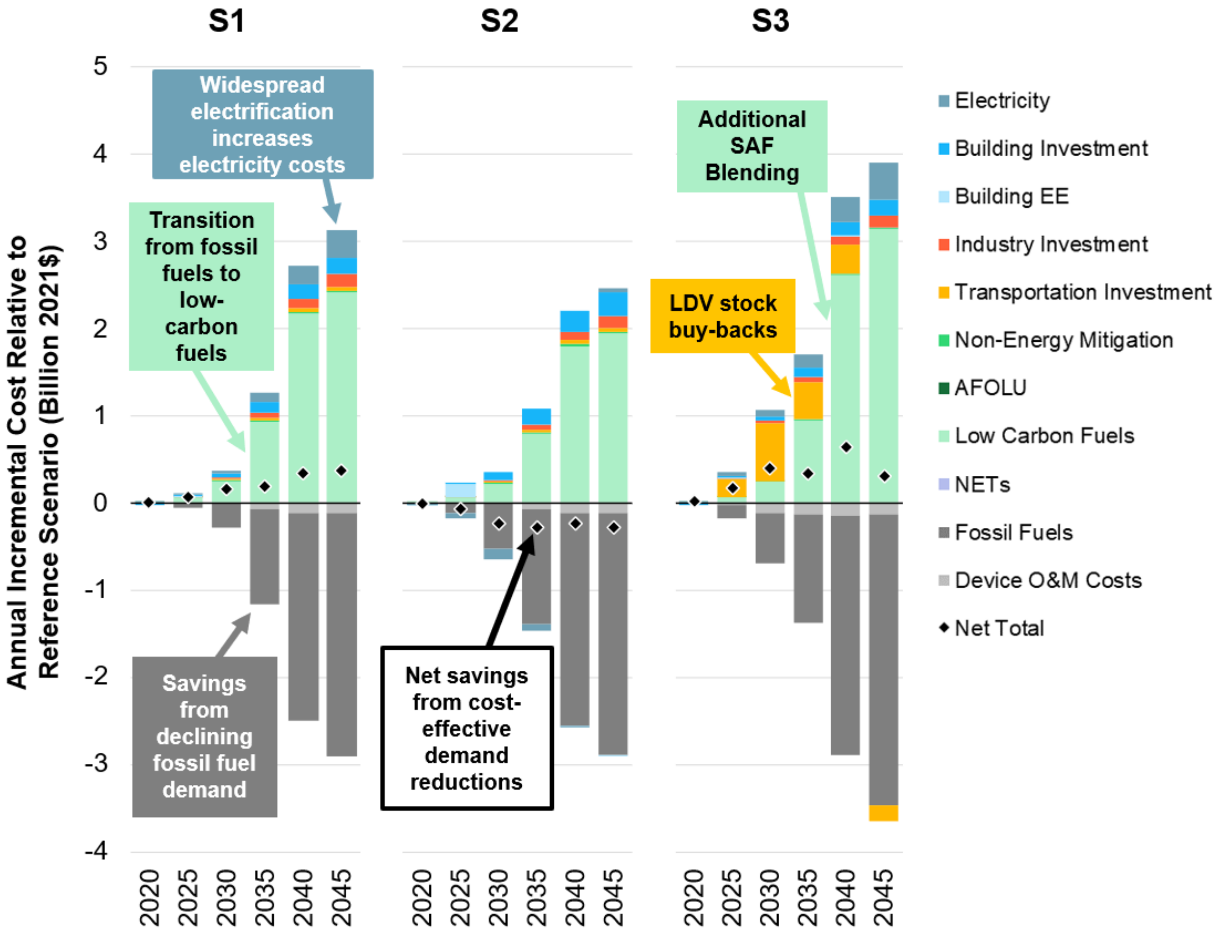

Figure 69 Annual cost results incremental to the Reference scenario for each mitigation scenario

In all three scenarios, the largest cost savings come from reduced fossil fuel consumption, as seen in the gray bars. On the positive side of the axis, there are large costs associated with the demand for low-carbon fuels, which can be seen in the light green cost bars. The bulk of the low carbon fuel demand is for sustainable aviation fuel, which is one of the main drivers of cost. The size of the fuel cost bars relative to the other costs highlights the key role that decarbonized fuel is playing across the board in these scenarios.

In S2, there are net savings relative to the Reference scenario in all years because of the cost-effective demand reductions included in this scenario. These demand reductions include energy efficiency measures in buildings, reduced flight miles, and vehicle miles traveled. In addition to reductions in fuels serving those sectors, there are also small savings in electricity in this scenario due to the energy efficiency in buildings.

S3 is generally more expensive, especially in the early years due to the stock buy-backs of internal combustion engine vehicles. Note that stock buy-back costs are reflected by the incremental costs of vehicles fuel, and no additional program costs are included given that these costs would represent an internal cost transfer within the state boundary. In S3, there are also additional costs for the increased amount of sustainable aviation fuel in that scenario.

2045 Net Direct Costs as a Share of GDP

One metric that can be used to consider the cost of decarbonization is the net direct costs in a target year relative to gross domestic product (GDP). In this study, the 2045 cost relative to state GDP ranges from 0.2% savings to a 0.2% cost, as seen in Table 30. Hawaiʻi GDP in 2045 is forecasted by the DBEDT.

Table 30 2045 net direct costs as a percentage of Hawaiʻi 2045 projected state GDP

S1	S2	S3
0.2%	-0.2%	0.2%

This cost is lower than similar studies in other jurisdictions. For example, the Illinois Decarbonization Study found that decarbonization would cost between 1.4% and 1.7% of the state's GDP, the Princeton Net-Zero America study found that national decarbonization would cost between 1% and 2% of the US national GDP, and the New York Scoping Plan was estimated to cost 1.3% of state GDP.[306, 307, 308] There are a number of key differences in Hawaiʻi relative to other jurisdictions in the US that contribute to these lower cost values. Some examples include

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[306] E3 (2022) Illinois Decarbonization Study Climate and Equitable Jobs Act and Net Zero by 2050

[307] E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan (2020) Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report Princeton University, Princeton, NJ

[308] E3 (2022) *Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan* Prepared for New York State Energy Research & Development Authority and Department of Environmental Conservation

much higher fossil fuel prices, fewer hard-to-decarbonize industrial sites, and less heavy-duty trucking.

Net Present Value Direct Scenario Costs

Figure 70 shows the net present value (NPV) of incremental costs relative to the Reference scenario from 2019-2045. This is a different way to look at the costs of each scenario, representing the total scenario cost over the modeled time horizon, 2019 through 2045. NPV costs were calculated using a 2% discount rate.

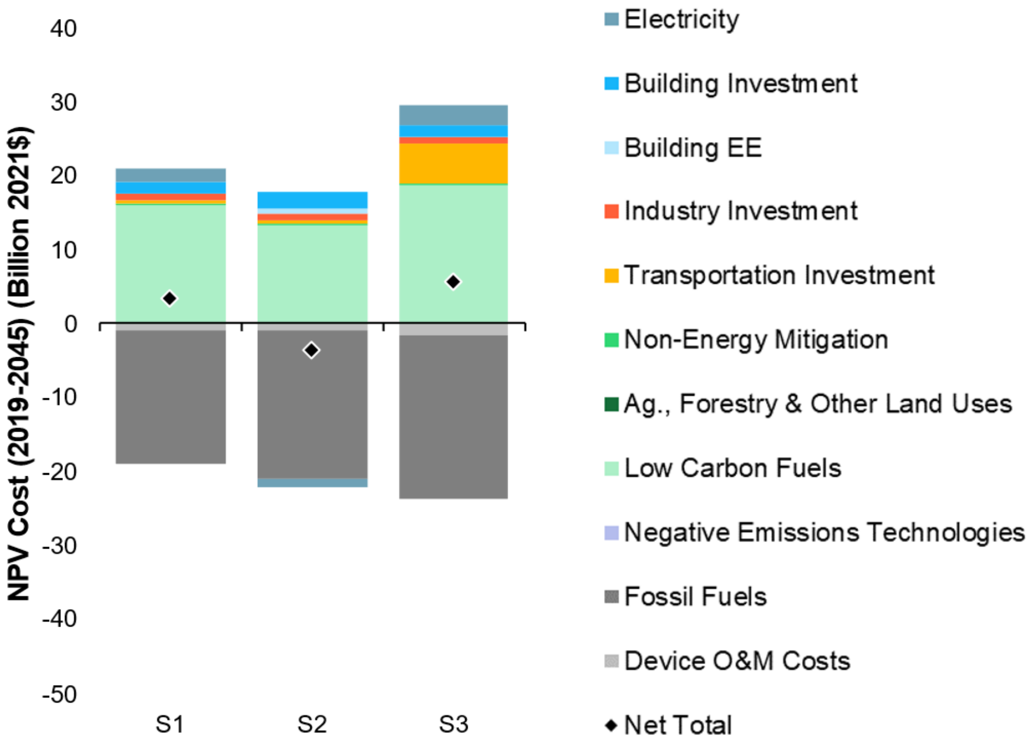

Figure 70 Net present value (2019-2045) of incremental costs by sector over the Reference case for each mitigation scenario

S1 has a total NPV cost of $3.4B, S2 has a savings of $3.4B, and S3 has a total NPV cost of $5.8B (Table 31). Notably, S2 has net savings relative to the Reference scenario, despite its accelerated emissions reductions relative to S1 and S3. This is due to the demand reductions, which simultaneously reduce emissions *and* costs because of the decreased demand for electricity and fuels. S3 is the most expensive scenario because of the additional gap closing measures applied, including the stock buybacks, additional sustainable aviation fuel, and negative emissions technologies. Note that the reported electric sector costs in this study do not include costs for necessary distribution upgrades. Distribution upgrade costs may be especially relevant to scenarios with high amounts of electrification relative to today. Including distribution cost impacts would likely increase the incremental cost of S1 and S3 relative to the Reference scenario.

Table 31 2019-2045 NPV direct scenario costs relative to the Reference Scenario (Billion 2021$)

S1	S2	S3
3.4	-3.4	5.8

4.9. Climate Benefits

The previous sections of this report only include direct costs in the cost analysis to implement the described measures. However, when the societal benefits from avoided greenhouse gases are considered in addition to direct costs, all three scenarios show large net benefits. Figure 71 shows the added benefits from avoided greenhouse gases using the EPA Draft "Report on the Social Cost of Greenhouse Gases".[309] These benefits are shown in the purple hashed bar.

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[309] US EPA (2022) Supplementary Material for the Regulatory Impact Analysis for the Supplemental Proposed Rulemaking, "Standards of Performance for New, Reconstructed, and Modified Sources and Emissions Guidelines for Existing Sources: Oil and Natural Gas Sector Climate Review

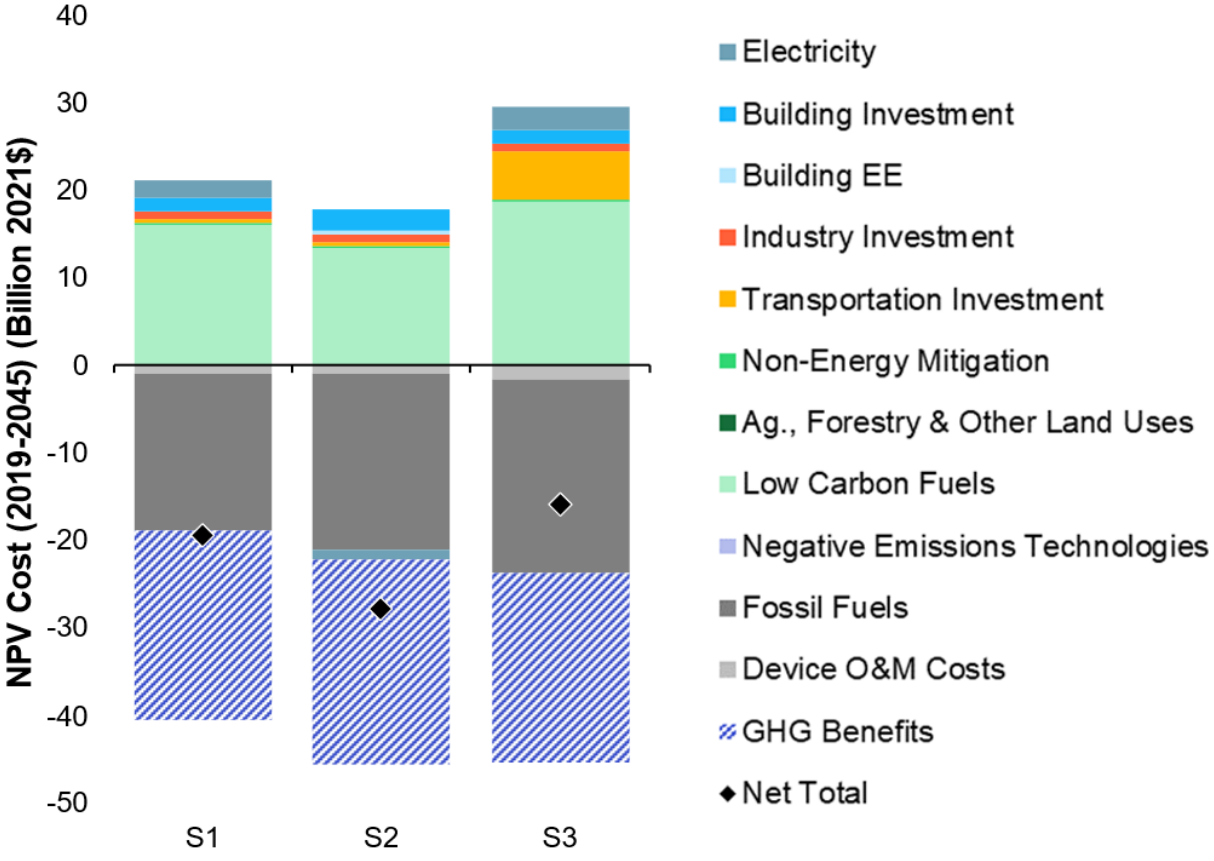

Figure 71 Net present value (2019-2045) of incremental costs by sector over the Reference scenario for each mitigation scenario, including social benefits from avoided greenhouse gases.

The social cost of greenhouse gases represents the marginal benefits of greenhouse gas abatement to society at large. The EPA Draft Report used in this study values CO_2 at $287/ton in 2045 with a 2% discounting rate. These benefits are not specific to Hawaiʻi, but they include impacts to things like net agricultural productivity, damage from increased flood risk, and changes to the frequency and severity of natural disasters. Once the societal benefits are considered, the benefits of decarbonization far outweigh the costs, with net benefits ranging from $16-28B (Table 32). While all three scenarios achieve the same GHG emissions levels in 2045, the NPV GHG benefits differ between scenarios because of differences in emissions reductions in earlier years. S2 has the largest GHG benefits because of the accelerated emissions reductions in early years relative to the other scenarios.

Table 32 2019-2045 NPV social cost of GHGs (SC-GHGs) and NPV scenario cost relative to the Reference Scenario including SC-GHGs (Billion 2021$)

	S1	S2	S3
SC-GHGs	-21.6	-23.5	-21.7
NPV Scenario Cost (including SC-GHGs)	-19.5	-27.8	-15.9

Chapter 5. Emissions Beyond the Inventory

5.1. Imported and Consumption-Based Emissions

This report relied on DOH emissions accounting to determine progress toward Hawaiʻi's net-negative GHG targets established by HRS §225P-5. The method currently used to count the statewide greenhouse gas inventory, published pursuant to HRS §342B-71 by DOH, focuses on the emissions based on production emissions within the state, called a production-based emissions inventory (PBEI), also known as a sector based or territorial GHG inventory. PBEI balances the ease of counting emissions with accuracy, making it relatively easy to get a more accurate measure of emissions.

Production-based inventories are compiled using broadly accepted methods established by the EPA, IPCC, and other leading bodies. These methods always set a boundary that defines which emissions count, and which do not. In PBEI, the emissions associated with goods and services produced within a geographic boundary are counted, and emissions for products made elsewhere are not.

Because PBEI methods do not count emissions associated with imports, this approach can unfairly penalize locally produced items and may favor outsourcing. PBEI methods also do not account for the emissions associated with the transport of goods to Hawaiʻi. These well-known shortfalls are a compromise to allow for easy compilation of PBEI.

Alternative Ways to Capture Emissions

As an alternative to traditional PBEI, a consumption-based emissions inventory (CBEI) considers the total emissions associated with the consumption of goods and services within a specific region regardless of where they are made. CBEI provides a more holistic view of a state's climate impacts because it counts emissions produced within the state (direct) and the emissions associated with the production of goods and services imported into the state (indirect). The tradeoff for this increased accuracy is increased effort to compile the inventory.

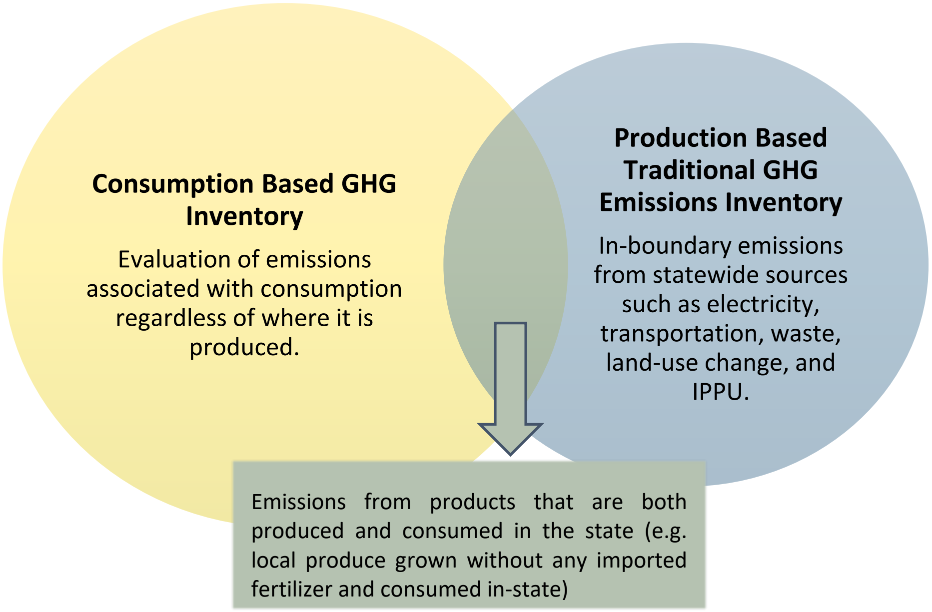

Figure 72 Production-based inventory v. Consumption-based inventory depiction. Adapted from US EPA 2021. Consumption-Based GHG Inventories for States: An Approach with USEEIO. For many states, the production-based inventories represent a small portion of a state's contribution to GHGs (indicated by a smaller blue bubble), whereas consumption-based or imported emissions represent a larger portion of total emissions (yellow bubble).[310]

Items 1 through 5 below describe how a consumption-based emissions inventory could work in Hawaiʻi as a supplement to the PBEI:

1. **Direct Sector Based Emissions (Production-Based Emissions) should remain accounted for:**

The inventory would first account for the GHG emissions directly produced within Hawai'i's borders, including emissions from sources like power plants, industrial facilities, transportation within the state, waste management, and agricultural activities. This is the scope of the current GHG inventory produced by the Department of Health, as required by HRS §342B-71. These emissions should remain accounted for separately to avoid potential double counting and to allow for aggregation at a national level.

2. **Indirect Emissions or Embodied Emissions would be accounted for separately:**

The consumption-based approach goes beyond direct emissions and considers the emissions "embodied" in the goods consumed in Hawai'i but produced or manufactured elsewhere. These emissions occur during the production, processing, and transportation of products outside

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[310] US EPA (2021). *Consumption-Based GHG Inventories for States*: An Approach with USEEIO.

Hawaiʻi's borders. For example, if Hawaiʻi imports refined fuel from another state or country, the emissions associated with refining the crude and transporting the refined product[311] would be part of Hawaiʻi's consumption-based emissions inventory. Similarly, emissions from manufacturing imported goods, such as electronics, vehicles, or clothing, could be included in the consumption-based inventory – although this becomes challenging to manage from an accounting perspective and methodology often exhibits substantial uncertainty, given reliance on economic data.

California has taken a hybrid approach with the understanding that imported emissions from certain sectors play a critical role in California's economy. Other states, including Oregon and Washington, have included CBEI in their emissions inventories. Local governments with CBEI include Boulder County, CO; Portland, OR; and San Francisco, CA. The US EPA has developed an approach to conducting CBEI using an environmentally extended input-output (EEIO) model.[312]

As an example, Figure 73 shows a summary of Oregon's consumption-based inventory, and indicates that about 34% of emissions from Oregonians actions are accounted for in their traditional PBEI, with remaining emissions coming from other U.S. states and foreign imports, 22% and 44% respectively.

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[311] Rocky Mountain Institute. (2022, November). *Report on Roadmap to Slash Oil Refining Emissions.*

[312] US EPA (2021) Consumption-based GHG Inventories for States: An Approach Using USEEIO

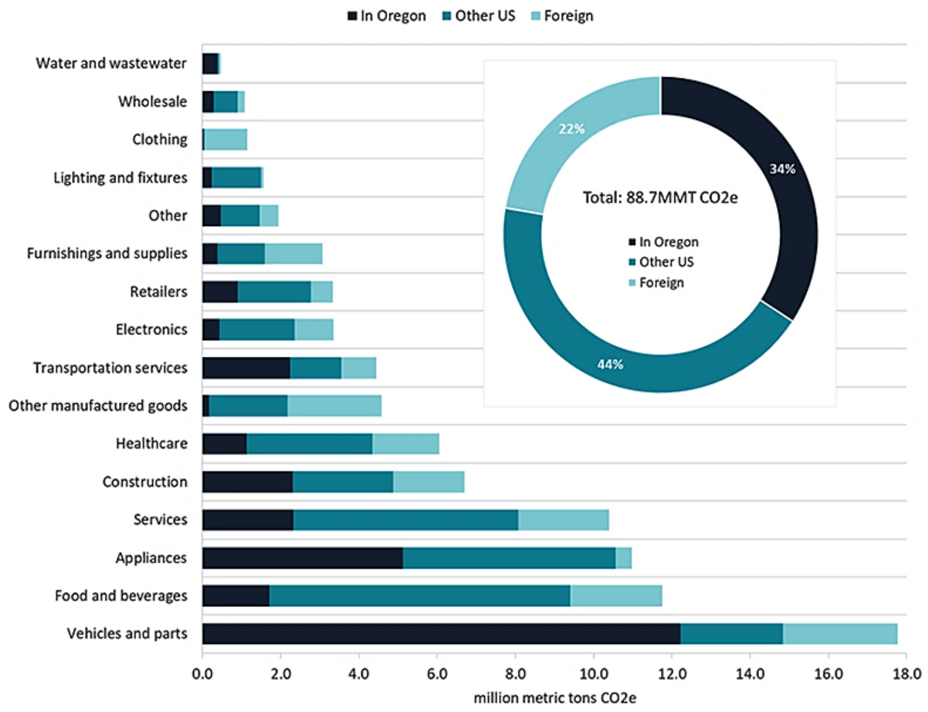

Figure 73 The consumption-based greenhouse gas emissions inventory tracks emissions produced in Oregon and around the world due to the products and services Oregonians consume. Used with permission, image source Oregon Department of Environmental Quality.[313]

Demonstrates a large part of emissions for certain sectors is associated with the production of products outside of the state boundary.

While these approaches have high uncertainty associated with methodologies, and input data can be a challenge, accounting for these emissions in some manner is important as it provides a more holistic perspective and understanding of Hawaiʻi's contribution to the climate crisis.

3. Analysis and Reporting:

Once the data on direct and indirect emissions has been collected, the inventory compiled, and the total consumption-based emissions for Hawaiʻi calculated, a more comprehensive and holistic view of Hawaiʻi's contribution to climate change beyond a traditional production-based emissions inventory can be established. Reporting for CBEI should be supplemental to PBEI.

As a best practice, all input data files should be shared publicly.

4. Policy and Decision Making:

A consumption-based emissions inventory can serve as a valuable tool for policy and decision-makers to understand the broader impact of consumption patterns on the state's carbon

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[313] Oregon Department of Environmental Quality (2020) Consumption-based Greenhouse Gas Inventory for Oregon

footprint. It can help identify areas where emissions can be reduced, such as by promoting local renewable energy production, local sustainable agriculture incentives, and emissions tradeoffs.

By considering the full extent of emissions associated with consumption, the inventory provides a clearer picture of Hawaiʻi's greenhouse gas impact and can better inform strategies to reduce Hawaiʻi's emissions more effectively at both local and global levels.

While accounting for these emissions will likely make achieving the decarbonization goals described by HRS §225P-5 more difficult to attain, it will also make attainment, or substantive reductions more meaningful.

5.2. Lifecycle Greenhouse Gas Analysis

Lifecycle greenhouse gas analysis quantifies or evaluates the environmental impact of specific products or systems throughout their entire lifecycle - from extraction and assembly through distribution, use, to disposal and more, Figure 74. Lifecycle analysis focuses on the total emissions associated with the consumption of goods and services within a specific region, considering both domestically produced and imported items.

Both methods are valuable for understanding emissions and guiding efforts to reduce greenhouse gas emissions and promote sustainable practices. The methods defer slightly in that CBEI is aimed at accounting for the entire economy, while lifecycle analysis is more suited for individual products or fuels.

The current framework for analysis does not consider lifecycle emissions.

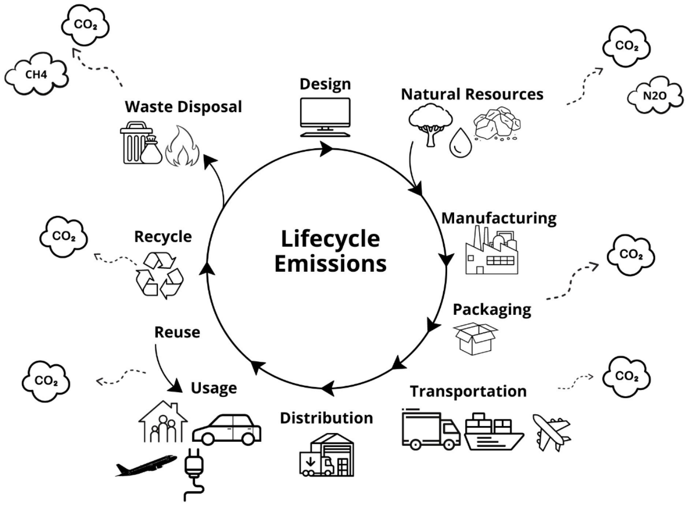

Figure 74 Lifecycle Analysis Considerations common for typical products consumed in the state.

Currently, the Hawai'i Public Utilities Commission (PUC) is required to "consider the need to reduce the State's reliance on fossil fuels through energy efficiency and increased renewable energy generation in exercising its duties" and is required to "explicitly consider" greenhouse gas emissions when making determinations on the reasonableness of the costs pertaining to the electric or gas utility system (HRS §269-96). This is a valuable analysis critical to ensuring energy projects for regulated utilities reduce net GHG emissions.

While the PUC is required to consider the lifecycle greenhouse gas emissions when making project decisions, there are no set standards for the utility, or applicant, to follow when completing the lifecycle analysis, nor are there statutory mandates or thresholds (i.e., fuel standards or carbon intensity thresholds) that must be met by renewable energy projects with gross emissions. Further, most PPA applications' GHG analyses are completed in proprietary software, and system boundaries and assumptions are determined by the applicant. Recent dockets and Hawaiʻi Supreme Court decisions have underscored the role of the PUC in conducting project-specific GHG analyses for projects seeking PPAs;[314] however, the lack of clear standards (e.g. carbon intensity standards and offset criteria) results in difficult and discretionary decision-making.

5.3. Bioenergy and Alternative Fuels

The importance of lifecycle-based emissions standards becomes evident when considering the vast range of lifecycle carbon intensities among various alternative fuels; inclusive of biofuels, hydrogen, and ammonia. While certain renewable energy technologies are known to have low lifecycle GHG emissions(e.g., geothermal, photovoltaic solar systems, wind energy, and run-of-the-river hydropower), other renewable and alternative fuel technologies have wide-ranging lifecycle GHG values sometimes exceeding the average emission intensity from fossil fuels. For example, for bioenergy, the range of lifecycle carbon intensity (g CO_2e/kWh) is wide-ranging and is highly dependent on feedstock characteristics, fertilizer application, and growth characteristics, and the lifecycle GHG is not always necessarily lower than that of fossil fuel.

Bioenergy

Biofuels are often assumed carbon *neutral* or net zero because in theory the carbon had once been captured from the atmosphere as photosynthesis.[315] However, this assumption is scientifically flawed and inappropriate[316]; however, given the technical and scientific issues

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[314] *"The PUC understood its public interest-minded mission. It faithfully followed our remand instructions to consider the reasonableness of the proposed project's costs considering its greenhouse gas emissions and the project's impact on intervenor Life of the Land's members' right to a clean and healthful environment. It stayed true to the language of its governing statute HRS § 269-6(b) (Supp. 2021) by measuring the project's cost and system impact. And it acted properly within its role as factfinder when it evaluated Hu Honua by its own statements and promises and, ultimately, found them unconvincing." SCOT-22-0000418, March 13, 2023.*

[315] *The overall IPCC approach to estimating and reporting bioenergy greenhouse gas emissions at the national level requires complete coverage of all IPCC sectors, including the AFOLU and Energy sectors. All CO2 emissions and removals associated with biomass are reported in the AFOLU sector. Therefore, CO2 emissions from biomass combustion used for energy are only recorded as a memo item in the Energy sector; these emissions are not included in the Energy sector total to avoid double counting. The approach of not including these emissions in the Energy Sector total should not be interpreted as a conclusion about the sustainability, or carbon neutrality of bioenergy.*

[316] IPCC Inventory Approach to Accounting for All Anthropogenic GHG Emissions, Appendix A (Nov 2014)

associated with accounting for carbon dioxide emissions an established framework has yet to be adopted nationally. In 2014, the EPA's Scientific Advisory Board (SAB) developed a method for calculating a Biogenic Assessment Factor (BAF), for CO_2 emissions associated with the combustion of biogenic feedstocks at stationary facilities by accounting for the biological carbon cycle effects associated with growth, harvest, and processing of these feedstocks. [317] These recommendations could play an important role in providing guidelines for evaluation of lifecycle emissions required by the PUC for stationary combustion facilities, but could also apply beyond large stationary facilities. The SAB report recommends BAFs vary depending on their specific objective, noting it is inappropriate to use default assumptions, including the assumption that there are no net emissions or conversely that all biogenic emissions are additive. It further recognizes that energy facilities require a continuous supply of feedstock, and a landscape approach is appropriate for accounting the impacts of feedstock demand. Importantly, the framework also represented BAFs by feedstock and region rather than facility-specific BAFs.

Consideration must be given to the additional input processes required in both agricultural and forestry to grow the fuels, as well as the time it takes for the feedstock to grow (temporality). In some cases, the lifecycle carbon intensity may have higher climate warming potential than the fossil fuels.[318] For dedicated energy crops, the conversion of vegetation or forest to cultivate biofuel feedstocks may release a significant amount of carbon from soil and plant biomass, resulting in a 'carbon debt' in the ecosystem that can take years or decades to repay[319], this nuance is not considered in the inventory accounting framework currently adopted by the state.

It is important to note that there are several types of biofuels – and not all are created equal. They are generally categorized into four generations, based on the sources of biomass used for their production and/or biosynthetic platform. Each has their own benefits and challenges.

The First-generation biofuels, or Conventional biofuels, are the first biofuels to have been used. They are produced largely from sugar, starch, and vegetable oils from crops such as corn, soy, sugar, and sunflower. These biofuels initially showed promise in reducing GHG emissions; however, their widespread adoption has encountered scrutiny, and skepticism from scientists, due to concerns relating to their impact on food security and raising food prices, the competition

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[317] US Environmental Protection Agency, Office of the Administrator, Science Advisory Board (SAB). (2019). SAB Review of Framework for Assessing Biogenic CO2 Emissions from Stationary Sources (2014).

[318] National Renewable Energy Laboratory (NREL). (2021). Life cycle greenhouse gas emissions from Electricity Generation

[319] Jeswani, H. K., Chilvers, A., & Azapagic, A. (2020). Environmental sustainability of biofuels: a review. Proceedings of the Royal Society A, 476(2243), 20200351

for arable land, fertilizer input requirements, and overall lifecycle emissions; prompting increased exploration into more sustainable and advanced biofuel alternatives.[320]

The Second generation of biofuels, Advanced biofuels, try to address the food-fuel dilemma by avoiding food crops and instead using agriculture and forestry non-food products usually high in lignin such as wood and grasses, but also waste products such as waste oil, sawdust, rice straw, rice husk, and municipal waste inclusive of construction and demolition debris. Waste products inherently exhibit a reduced environmental footprint as they do not require additional land, water, and fertilization to be produced, compared to resources like wood. Nevertheless, a primary constraint lies in their limited availability, as the current volume of such waste products is insufficient to meet the energy demands. As a result, second-generation biofuels must be paired with other technologies to ensure adequate fuel supply.

Third-generation biofuels are fuels derived from photosynthetic microorganisms, predominantly microalgae and cyanobacteria biomass, and represent a promising option for long-term energy production. These microorganisms do not require arable land or freshwater to grow because they flourish in a variety of conditions such as wastewater, saltwater, or brackish water, avoiding conflict with agricultural land. Efficient algae/cyanobacteria cultivation requires a direct CO_2 supply, which can be derived from industrial emitters or by atmospheric carbon capture (DAC). When compared to terrestrial plants, algae exhibit higher photosynthesis rates, resulting in faster biomass growth and higher productivity. The oil content is higher than that of any terrestrial oil-seed crop as well. Due to this high oil content, a promising pathway is converting microalgae into biodiesel or high-energy density biofuels.

Although the third generation of biofuels do not exhibit many of the concerns present in first and second-generation biofuels, third-generation biofuels come with their own set of challenges. As a result, these biofuels are not yet commercially available. Transitioning from laboratory-scale experiments to large-scale production poses challenges. Despite the potential of algae being grown in diverse environments, large-scale cultivation requires considerable land and water resources, posing potential environmental and sustainability concerns. Harvesting and processing microalgae efficiently at a large scale remains a challenge and requires further technological advancements and cost reduction.

Fourth-generation biofuels are the newest type of biofuels. Similarly, to the third generation, they use microalgae, macroalgae, and cyanobacteria as feedstocks. But in the fourth-generation biofuels the algae are genetically modified to improve its photosynthesis efficiency (allowing algae to capture and store more CO_2) and lipid synthesis, thus enhancing biofuel production. The

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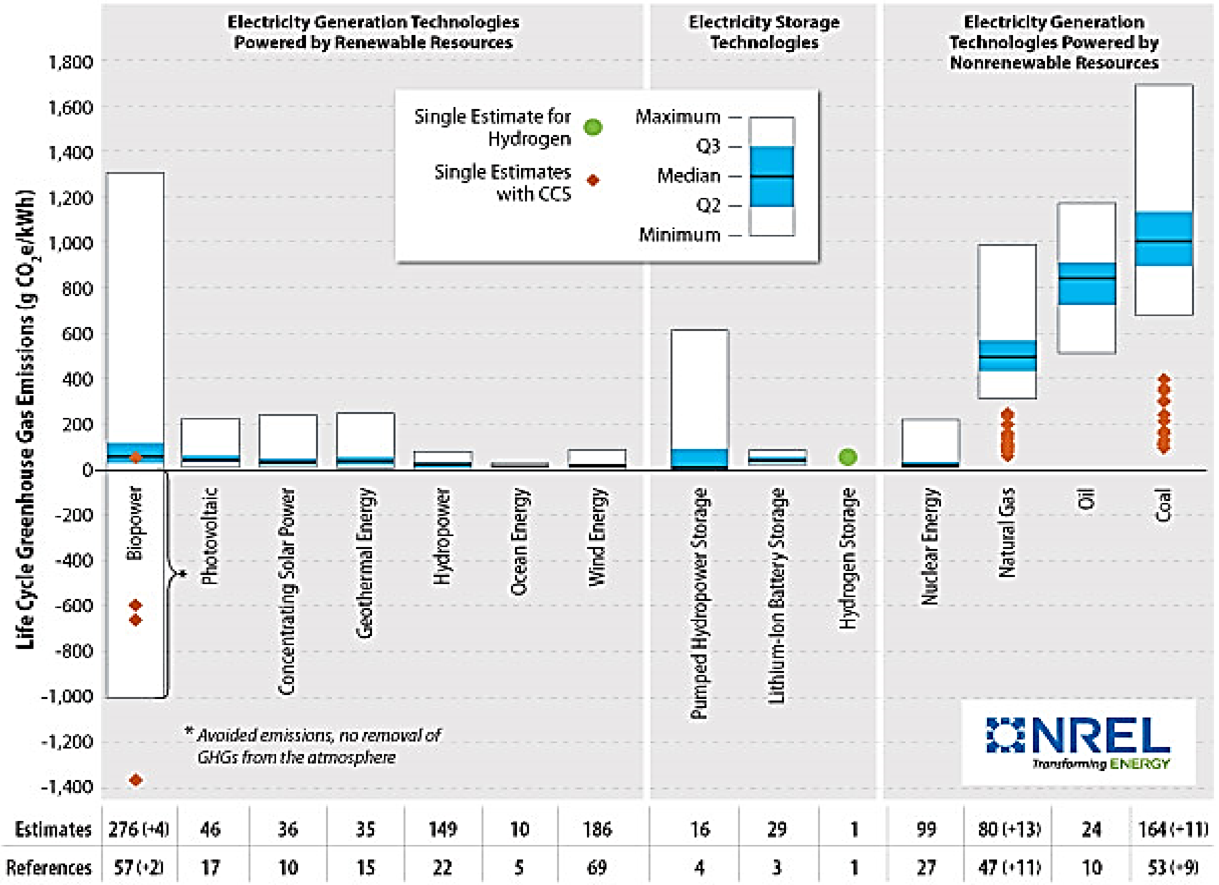
[320] Phwan, C.K., Ong, H.C., Chen, W.H., Ling, T.C., Ng, E.P. and Show, P.L., 2018. Overview: comparison of pretreatment technologies and fermentation processes of bioethanol from microalgae. *Energy Conversion and Management*, *173*, pp.81-94.

processing of the feedstock is also different from the third generation, often with an emphasis on capturing and storing CO_2, potentially resulting in net neutral or net negative CO_2 production. Fourth generation biofuels; however, are still in the research and development stages and not yet commercially available.

In a study completed by NREL in 2021, the review and harmonization of over 3000 lifecycle analyses (LCAs) for utility-scale electricity generation found that when considering the full lifecycle of electric generation technologies, the technologies powered by renewable resources had lower lifecycle GHG emissions per kWh of energy produced than their non-renewable alternatives, except biopower which was wide-ranging.



	Biopower	Photovoltaic	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Pumped Hydropower Storage	Lithium-Ion Battery Storage	Hydrogen Storage	Nuclear Energy	Natural Gas	Oil	Coal
Estimates	276 (+4)	46	36	35	149	10	186	16	29	1	99	80 (+13)	24	164 (+11)
References	57 (+2)	17	10	15	22	5	69	4	3	1	27	47 (+11)	10	53 (+9)

Figure 75 – Wide-ranging estimates of lifecycle emissions from various renewable and non-renewable technologies. Used for exemplary purposes only.

The PATHWAY modeling presented in Chapter 3 and Chapter 4 assumes a lifecycle CI of zero—this is the current assumption used in the GHG inventory pursuant to HRS §342B-71, in which the

Pathways models are benchmarked. A better understanding of the current CI for alternative fuels in the state would be needed to update the models.

This is a shortfall of the current modeling efforts presented in Chapter 4 and the current GHG inventory.[321]

Data collection and inventory accounting using the EPA's Scientific Advisory Board framework for assessing biogenic CO_2 emissions (from the production, processing, and use of biogenic material) could be the next step aiding this type of analysis. Implementing these policies at the facility level, particularly for stationary combustion facilities, could improve the accounting for biogenic emissions. Appropriate lifecycle accounting is of particular importance given the volume of fuels anticipated to meet demand, particularly for the transportation sector, but also for the electric sector. For example, sourcing fuels from deforested rainforests, and calling it "clean", is unacceptable from a GHG and climate perspective.

Biogenic Emissions in the Energy Sector are accounted for separately and are not aggregated for the inventory:

IPCC protocol, 2019 refinement requires CO_2 emissions from biomass combustion in the energy sector be reported as a memo item and not aggregated in the totals. The reason for not including these emissions in totals is that it is assumed emissions from biomass/bioenergy would be accounted for in the Agriculture, Forestry, and Other Land Use (AFOLU) Sector as part of net changes in carbon stocks, further undermining imports of biofuel and bioenergy sources. Other challenges associated with carbon accounting for biogenic sources include:

- Temporality[322] and time-lag dynamics: Carbon accounting for biogenic sources involves challenges due to the temporal nature of biological processes. Biological processes, like plant growth, do not occur instantaneously; they are gradual and vary in time. This creates challenges in accurately measuring and accounting for carbon, because the absorption and release of carbon by plants and ecosystems are not immediate nor constant. The growth of plants and their carbon absorption is dependent on various factors. For instance, natural ecosystems like forests and wetlands can act as carbon sinks, absorbing carbon from the atmosphere. However, this capacity fluctuates over time. Factors including (but not limited to) water availability/drought conditions, temperature fluctuations, natural and climate exacerbated disturbances like insect infestations and fire, soil condition, or even the successional stage of the ecosystem all affect the growth rate and carbon absorption of these ecosystems. As all these factors vary through time (some unpredictably) so does carbon absorption.

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[321] IPCC Guidelines as an overall framework for a national GHG inventory do not provide an analytical approach for assessing the full bioenergy emissions at sub-national entities such as industry sectors.

[322] Temporality is one of the hardest items to account for in lifecycle analysis.

- Challenges associated with measurement and monitoring: Accurately quantifying emissions from biogenic sources requires substantial investment in monitoring programs due to the variability and complexity of biological systems. The quantification of carbon stocks, carbon sequestration, and emissions from natural sources like forests and wetlands thus requires sophisticated measurement techniques and continuous monitoring.
- Assessing the net carbon emissions associated with bioenergy production involves accounting for the entire lifecycle, including emissions from land use changes, transportation, and processing. Determining the sustainability of bioenergy sources requires comprehensive lifecycle analysis and the consideration of various environmental and social impacts.

The DOH inventory includes a line item for *CO_2 from Wood Biomass and Biofuels Consumption*, however, it is hard to determine with the information presented exactly how the figure is derived without disaggregated data available. For this category, disaggregating the information to the facility level is critical. It is likely that the inventory is underestimating these emissions without including facility level information.

Hydrogen as a Clean Fuel

Hydrogen, H_2, is an energy carrier that can be used as a storage mechanism like a battery. It is not a primary source of energy, like sunlight or wind. The energy that is "stored" in hydrogen needs to come from another input source – solar, wind, or even fossil fuel for example. Hydrogen is thus not a low-cost fuel source and green hydrogen—hydrogen produced through water electrolysis requires substantial energy to produce. The overall benefit of hydrogen is largely dependent upon the type of hydrogen and its production process. Types of hydrogen are often color coded. Hydrogen itself is not classified by color, as it is a colorless gas; however, we use different colors to categorize its types based on the distinct production processes involved – colors range from green, blue, brown, pink, and more. The color largely, with few exceptions, refers to the source of energy used in hydrogen production. The main source of renewable hydrogen is water (via electrolysis) or biomass (via gasification). See Table 33 for a detailed explanation of the hydrogen production processes.

Table 33 Description of production pathways for hydrogen and the general description of colors of hydrogen applicable to Hawaiʻi.

H_2 Production Processes and Colors	**Description**
Electrolytic hydrogen	Electrolytic hydrogen is produced by using electricity to split water into hydrogen and oxygen. Substantial energy is required to break the H_2 and O bond. At the cathode, hydrogen ions combine with electrons from the external circuit to form hydrogen gas. Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e-$ Cathode Reaction: $4H+ + 4e- \rightarrow 2H_2$ Note: Presently, electricity from the grid is not an ideal source of electricity. This type of hydrogen production is very energy intensive. It takes more energy to make hydrogen than the H_2 molecule can produce. While electrolytic hydrogen is often referred to as “green hydrogen” this is not the case if the energy source is non-renewable.
Hydrogen produced w/ biomass gasification	Biomass gasification converts biomass to hydrogen and other products without combustion. This method has lower carbon emissions than combustion. It is a mature technology that is being used for biofuel production and can be used for hydrogen production. Simplified example reaction $C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2$ + other species *Note: The above reaction uses glucose ($C_6H_{12}O_6$) is used as a surrogate for cellulose. Actual biomass has highly variable composition and complexity with cellulose as one major component.* Water-gas shift reaction $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat) Pyrolysis is the gasification of biomass in the absence of oxygen (O_2).
Green Hydrogen	Produced from the electrolysis of water with the electricity sourced from renewable energy.

	Green hydrogen can also be produced via waste or biomass gasification or pyrolysis[323]
Grey Hydrogen	Emissions from grey hydrogen production are far worse than direct combustion of fossil fuels due to the energy required to drive the reaction forward. The reaction is endothermic, additional heat or energy must be applied for the reaction to move forward. Steam methane reformation (natural gas reforming) is the most common production process today. $CH_4 + H_2O$ (+heat) --> $CO + 3H_2$
Blue Hydrogen	Blue hydrogen is essentially grey hydrogen, however, includes the use of carbon capture and storage (CCS) to trap and store the carbon released in the process.

Hydrogen is often referenced as a clean fuel with zero emissions that holds great promise for decarbonizing certain sectors. On a life-cycle basis, however, there is continuing research on the climate consequences of hydrogen emissions. Hydrogen is not categorized as a GHG given that hydrogen's atmospheric warming effects are short-lived, lasting only a couple of decades. But standard methods of characterizing climate impacts of gases consider only the long-term effect. For gases like hydrogen, this long-term framing may not fully explain a potentially stronger warming potency in the near to medium term. The research question involves the measurement of hydrogen, a small molecule that can easily leak into the atmosphere, to accurately quantify the total amount of emissions from hydrogen systems.[324] Leakage and monitoring systems are imperative if this pathway is used in the future; additionally using hydrogen in only the hard to abate or hard-to-electrify sectors can minimize these relatively unknown emissions.[325]

5.4. Lifecycle Carbon Intensity Requirements for Alternative Fuel

Bioenergy, specifically biofuels, and alternative fuels will likely play a significant role in decarbonization, as demonstrated in Chapter 3 and Chapter 4 across all sectors. With the selection of Stage 3 projects alone setting aside over 650 MW nameplate capacity by 2033 for bioenergy.[326] The electric sector is anticipated to require significant biofuel production and feedstock imports.

However, as biofuels exhibit a diverse spectrum of lifecycle emissions, it becomes crucial to establish lifecycle carbon intensity standards which apply to all sectors. At minimum these

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[323] USDOE (2023). *Hydrogen Production: Biomass Gasification*

[324] Ocko, I. B., & Hamburg, S. P. (2022). Climate consequences of hydrogen emissions. *Atmospheric Chemistry and Physics*, *22*(14), 9349-9368.

[325] Environmental Defense Fund. (2023). BetterHubs.

[326] Hawaiian Electric (2023) Renewable Project Status Board.

standards should ensure that the carbon footprint throughout a biofuel's lifecycle remains consistently lower than that of fossil fuel. This approach ensures a stringent measure for environmental sustainability across various sectors. A clean fuel standard (CFS), or an adjustment to the RPS to account for the carbon emissions of biofuels, would require fuel suppliers to gradually reduce the CI of the fuels sold and distributed within the state.

Increasingly stringent CI reduction requirements can serve to decrease the CI of alternative fuels and help ensure that the state prioritizes low carbon fuel imports as they become commercially available.

To determine lifecycle CI, fuel production is broken down into stages. These stages are: 1) upstream (production, growth, and extraction), midstream (refining), transportation (to, within, and from Hawaiʻi), and operations (use, or operational emissions). Figure 60 depicts an example system boundary that apply from “farm” to “pump”; this type of system boundary would apply to energy crops used to produce biofuel.[327]

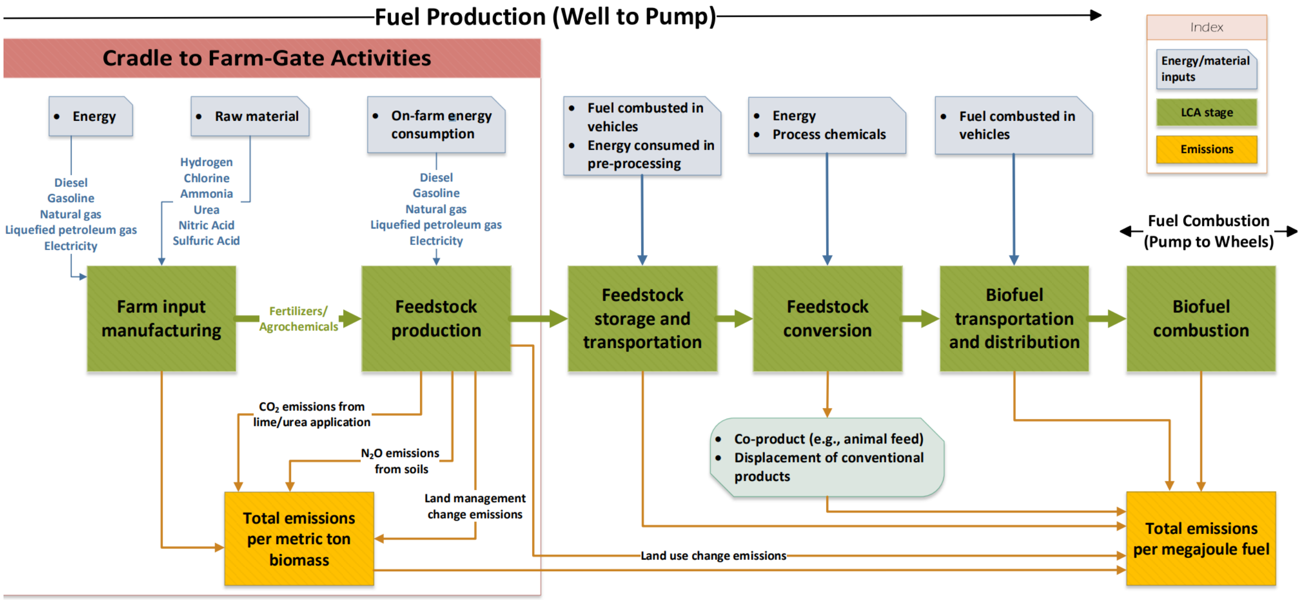

Figure 76 Example system boundaries to include in the lifecycle analysis of biofuels. Source: Liu, Kwon, Wang. 2022. Argonne National Laboratory, Energy Systems Division Feedstock Carbon Intensity Calculator, Technical Guidance Document for the GREET feedstock carbon intensity calculator (FDCIC).

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[327] Liu, X., Kwon, H., & Wang, M. (2022). Feedstock Carbon Intensity Calculator (FD-CIC) Users’ Manual and Technical Documentation (No. ANL/ESD-21/12 Rev. 1). Argonne National Lab.(ANL),

To compare emission intensities, the same stages shall be used in the LCA for renewable fuels, as described below.

- Upstream emissions include “cradle to farm-gate activities.” These include farm input manufacturing emissions including energy requirements for equipment, emissions from feedstock production including energy inputs for farming activities, raw material inputs, fertilizer input, and agrochemical usage, carbon dioxide emissions from lime/urea application, and nitrous oxide emissions from soils.
    - Waste fuels sourced entirely as a by-product of waste materials, or waste gas (e.g., waste cooking oil or gas produced from byproducts of wastewater treatment) may assume a zero value for upstream emissions.
- Midstream emissions include emissions from feedstock conversion and fuel production or biofuel refining (if applicable).
- Transportation emissions include transportation to, within, and from Hawaiʻi.

A total value or summation of all stages would be provided by the fuel supplier or distributor. Using this value, the regulating authority would determine whether the fuel(s) has lifecycle emissions less than that of the CFS. In accordance with EPA guidelines, the lifecycle assessment of fuel production should not include activities that are unrelated to the fuel lifecycle (e.g., offset projects) or emissions associated with physical and organizational infrastructure (e.g., facility construction).

As an exemplary use of CI, a CI threshold of 50 kg CO2e/MMBtu is currently used as the standard for the clean fuel production credit administered at the federal level through IRA. The threshold becomes increasingly “cleaner”, and the CI is lower. Fuels must become increasingly cleaner to be eligible for the credit. Fuels produced before 2026 may qualify if the fuel’s lifecycle emissions are less than 75 kilograms of carbon dioxide equivalents per million British thermal units (kg CO2e per mmBtu). This amount is reduced to 50 kg CO2e per mmBtu for 2026 and 2027, 25 kg CO2e per mmBtu for years 2028 and 2029, and, starting in 2030, only fuels with lifecycle emissions at or below zero may qualify for any incentive.[328] The clean fuel standard could apply to hydrogen and other fuels as well. Notably, USDOE has adopted a clean hydrogen production standard of 4.0 $kgCO_2e/kgH_2$ for well-to-gate production emissions, which is roughly equivalent to about 30 $kgCO_2e$/MMBtu based on higher heating value.[329]

A similar framework could be applied to a fuel standard that gradually gets “cleaner" with time. The Clean Fuel Standard, could be paired with Carbon Pricing, discussed in Chapter 1, Section 1.4 where the carbon price is applied to fuels not meeting the standard. Implementation of a low

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[328] Congressional Research Service (2023). The Section 45Z Clean Fuel Production Credit.

[329] US DOE (2023) U.S. Department of Energy Clean Hydrogen Production Standard (CHPS) Guidance

carbon fuel standard (LCFS) or Clean Fuel Standard (CFS) is a necessary discrete action to ensure a reduction in GHG emissions as the energy sector transitions to alternative energy sources.

Given that lifecycle assessment and resulting carbon intensity values are highly dependent upon the input assumptions and boundary settings applied to the modeling, it is critical that any program implemented also prioritize standardization and transparency. An accepted model, such as GREET from Argonne National Laboratory can be used to conduct the LCA, for upstream, midstream, and transportation emissions.[330] The GREET model is a universally used and accepted standard nationally and among many states for conducting emissions calculations. EPA Emission Factors for Greenhouse Gas Inventories (40 CFR Part 98) should be used in the chosen model as appropriate. The EPA's Emission Factors are widely recognized as an acceptable resource that is aligned with federal standards and practices used in other states. A list of Emissions Factors is available from the EPA's GHG Emission Factors Hub. This is consistent with the practices of other states.[331, 332] The calculations, models, and/or spreadsheets (with formulas included as applicable) used to complete any LCA should be made available to the public to ensure transparency and proprietary software should not be used. Assessment of fuel production will not include activities that are unrelated to the fuel lifecycle (i.e., offsite offset projects).[333]

5.5. Carbon Offsets

Reducing emissions will be key to achieving Hawai'i's decarbonization goals as established in §HRS 225P-5 and should be the immediate priority. However, scenario modeling demonstrates that to achieve the goals both sequestration projects and potentially negative emissions technologies will be needed to offset emissions from hard-to-abate sectors. However, offset programs and projects should be evaluated with scrutiny and caution, given the uncertainty, additionality, and temporal considerations associated with offsets, described below. Further, for the purpose of our analysis, the interpretation of the clean economy target HRS §225P-5 is that any applicable sequestration activity applied to emissions occurs only in-state.

Additionality

Additionality in carbon accounting is a concept used to evaluate the impact and integrity of carbon offset projects and ensures that the offset projects are explicitly contributing to emission reductions beyond what would have occurred without the offset project. It is a crucial principle in carbon offsetting and the consideration of additionality is designed to prevent the double-counting of emissions reductions and to verify that the claimed reductions are both real (verified with monitoring data) and additional. It is important to note that the GHG Inventory accounting

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[330] Argonne National Laboratory (2021) Summary of Expansions and Updates GREET 2021

[331] US EPA (2023) Renewable Fuels Standard Program. 40 CFR Subpart M

[332] California Air Resources Board (2023) LCFS Lifecycle Analysis Models and Documentation.

[333] EPA (2023) Lifecycle Analysis of Greenhouse Gas Emissions under the Renewable Fuel Standard

framework was not intended to evaluate additionality, which is critical when emission goals are based on “net” targets.

To determine whether an offset project is indeed an “additional project” eligible for offset credit, the following process can be used.

1. Baseline Emissions: Additionality evaluation starts with the establishment of a baseline. This baseline represents the emissions that would have occurred in the absence of the carbon offset project. It serves as a reference point for measuring an offset project's impact.
2. Project Emissions Reductions: The carbon offset project is then implemented with the goal of reducing emissions. The emissions reductions achieved by the project are compared to the baseline emissions.

Additionality Test: To determine if a project meets the additionality criteria, it must pass an additionality test. This test assesses whether the emissions reductions achieved by the project would not have happened under a business-as-usual scenario. In other words, the emissions reductions must be additional to what would have occurred without the project.

Below are some commonly used additionality tests:

1. Financial Additionality: The project would not have been feasible without the income generated from carbon offset sales.
2. Regulatory Additionality: The project should exceed what is required by regulations and standards.
3. Technological Additionality: The project should use innovative or advanced technologies that were not part of the standard practice.

Conceptually, once the project passes the additionality test, it may generate verified emissions reductions. These reductions can be used as carbon offsets, which may be sold or traded in carbon markets. Organizations can use these offsets to balance their own emissions, thereby helping them achieve their carbon reduction goals. However, even with these parameters in place, many verified offset regimes have faced major scrutiny, much of which has been justified with the largest voluntary carbon crediting program Verra, demonstrating substantial overstatement of emissions reductions with independent investigations and analysis indicating that “94% of the credits had no benefit to the climate.” [334]

This underscores the importance of clarifying that HRS §225P-5 indeed only applies to local sequestration that can be scientifically verified and meets the additionality tests. The concept of additionality is essential for evaluating the integrity of carbon offset programs or projects and is

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[334] Greenfield, P. (2023, January 18). *Revealed: more than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows | Carbon offsetting*; The Guardian.

essential to ensure that projects are contributing to reductions, and not perpetuating pollution by granting emitters *permits to pollute* through the purchase of offsets. Without additionality, there is a risk that offset credits could be issued for actions or projects that would have occurred anyway, resulting in no net reduction in atmospheric GHGs, or worse perpetuating GHG emitting activities through invalid *offset* credits. For this reason, large entities should apply offsets only to their hard-to-abate emissions, and claims of net-neutrality should be reviewed with serious scrutiny.

Offsets raise concern about granting polluting entities a "permit to pollute", with many climate scientists and advocacy groups rightfully calling offset regimes a major scam that worsens the climate crisis. This risk is exacerbated the further from home the offset projects are.[335]

5.6. Co-Benefits of Emission Reduction

In addition to the direct costs of inaction described above, there are indirect costs of inaction resulting from additional carbon dioxide being released into the atmosphere. The social cost of carbon (SCC) is one way to measure these costs and using the SCC in evaluating the efficacy of different policies can be a way to balance the costs of action with the costs of inaction to ensure costs are justified.

Localized Criteria Pollutants

While the Hawaiian Islands are generally fortunate to experience clean air regularly due to persistent trade winds, there are localized air quality challenges in certain regions not captured by standard air quality monitoring programs. Areas with localized pollutants include major transit corridors, industrial areas, and areas downwind of major power plants during low-wind days. Localized criteria pollutants identified by the EPA include diesel particulate matter (diesel PM) which is sourced from exhaust from diesel trucks, buses, ships, and other equipment. Diesel PM can reach deep into the lungs and can contribute to a range of health problems, particularly for individuals with pre-existing conditions. The health problems include heart and lung disease as well as lung cancer.[336] Individuals, for example, who opt for active transportation modes may be exposed to diesel particulate matter while commuting on major transit corridors.

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[335] West, T. A., Börner, J., Sills, E. O., & Kontoleon, A. (2020). Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *117*(39), 24188-24194.

[336] California Air Resources Board. (2022). *Summary: Diesel Particulate Matter Health Impacts.*

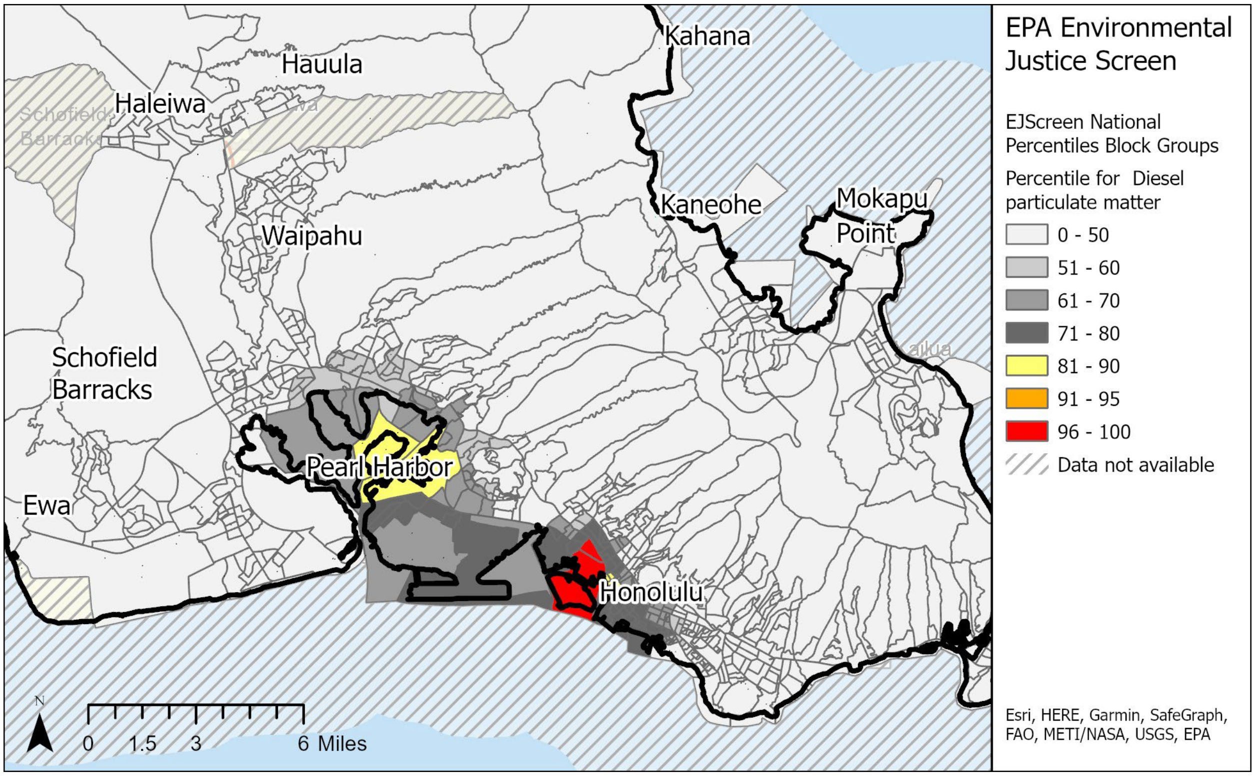

Figure 77 EPA's EJScreen National Percentiles for Diesel Particulate Matter. Percentiles are a way to see how residents compare to everyone else in the United States. U.S. percentile uses the U.S. population as the basis of comparison, Certain areas of O'ahu have modeled Diesel PM in the air higher than 95% of the US population. Diesel PM comes from EPA's AirToxScreen. The AirToxScreen is the Agency's ongoing, comprehensive evaluation of air toxics in the United States. This effort aims to prioritize air toxics, emission sources, and locations of interest for further study. It is important to remember that the air toxics data presented here provide broad estimates of health risks over geographic areas of the country, not definitive risks to specific individuals.[337]

Energy resilience

There is a misconception that decarbonization goals are at odds with resilience objectives. Through targeted actions this conception can not only be mitigated, but also resilience objectives can directly complement decarbonization, and vice versa. Through the following decarbonization activities, resilience is inherently improved.

Diversification of Energy Sources: Decarbonization involves transitioning to a more diverse and distributed energy mix, incorporating renewable sources like solar, wind, and hydro. This

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[337] US EPA Environmental Justice Mapping and Screening Tool, July 2023. US EJScreen Technical Documentation

diversification reduces reliance on a single energy source and enhances the resilience of the energy infrastructure against disruptions.

Decentralized Energy Systems: Distributed energy systems, such as microgrids, and residential solar and battery programs can be established as part of decarbonization efforts. These systems are more resilient to localized disruptions, providing a degree of energy independence during emergencies.

Flexibility in Energy Systems: Decarbonization involves the integration of flexible and adaptable technologies, such as energy storage and demand response. These technologies enable better management of energy supply and demand, enhancing the system's ability to adapt to changing conditions and unforeseen challenges, thereby serving both decarbonization and resilience purposes.

Resource Adequacy Analysis: Built into the modeling presented includes a resource adequacy assessment. This analysis can improve the build out of more resilient and efficient systems.

Community Engagement and Empowerment: Decarbonization efforts should involve community engagement and empowerment, fostering a sense of ownership and collaboration and much needed trust building. Strong community ties contribute to social resilience, as communities are better equipped to support each other during crises.

Better land management: While the development of utility scale energy projects is imperfect, development of these systems can be focused on abandoned agricultural land which may be overgrown with fire-prone invasive species. Using energy projects to manage otherwise mismanaged or abandoned land can improve island resilience.

Extreme weather events are occurring more frequently as a direct result of climate change. Mitigating climate change through decarbonization collectively results in a potential reduction in the frequency and intensity of extreme weather events, such as hurricanes, storms, and heatwaves. This, in turn, enhances resilience by lowering the risk of climate-related disasters – if everyone does their part. Hawaiʻi's decarbonization schedule adds us to the growing list of communities demanding climate-ready technologies and solutions.

APPENDIX A

Decarbonization Report: Synthesis of Outreach and Engagement

HAWAIʻI STATE ENERGY OFFICE

Hua Nani Partners
policy | strategy | advisory

Appendix A-1: Facilitated Stakeholder Meetings

Executive Summary

In November 2023, the Hawaiʻi State Energy Office (HSEO) conducted four targeted meetings with 59 participants[1] and 111 distinct invitees from across government, nonprofit, and private sectors to discuss the state's Decarbonization Report. The four meetings were facilitated by Hua Nani Partners and held on the topics of *Equity*, *Land Use and Transportation for Oʻahu*, *Land Use and Transportation for Neighbor Islands*, and *Decarbonization Tradeoffs*. HSEO sought feedback on the draft modeled decarbonization scenarios and prioritization of draft recommended measures. All meetings were offered in a hybrid in-person and virtual format to increase the opportunity for participation, except for the *Land Use and Transportation for Neighbor Islands* session, which was entirely virtual. This document summarizes the feedback received in the four convenings.

These convenings were a part of HSEO's stakeholder engagement process to collect input on the Decarbonization Report, which included the following:

- HSEO Decarbonization website launched on December 2, 2022, with open public comment form from June 2023 to November 17, 2023 (responses included in Appendix A-2)
- Individual stakeholder discussions with HSEO from June 2023 – December 2023; over twenty-five (25) meetings and five letters received (included in Appendix A-4)
- Thirteen combined meetings with sector-specific Priority Climate Action Plan (PCAP) groups June 2023 to October 2023
- Four (4) targeted convenings (working groups) with 59 distinct participants focused on Equity, Land Use and Transportation, Decarbonization Tradeoffs (feedback summarized in Appendix A-1).
- Two (2) public webinars with 100+ distinct participants total (over 200 invitees) on September 12, 2023, and November 14, 2023, including a separate feedback form at the November 14 webinar (responses included in Appendix A-3)
- Presentation to the Hawaiʻi Energy Equity Hui (EEH) on July 7, 2023. The EEH, established in 2020, is a statewide public-private collaborative network of individuals and organizations working towards an equitable clean energy transition.
- Presentation to Hawaiʻi Pacific University students on October 19, 2023.

HSEO also conducted an educational briefing on the modeled decarbonization pathways and draft report recommendations with a group of legislators and staffers representing nine legislators' offices in advance of finalizing this report.

Common Themes: Build on Existing Solutions and Incorporate Innovation, Equity, Education

While each of the stakeholder meetings had a different topical focus, certain common themes emerged across all sessions. Participants from all four meetings emphasized the need to incorporate equity more ambitiously in

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[1] Participant totals from each stakeholder meeting do not add up to 59 as multiple individuals attended more than one meeting.

both substance and process, to use the extensive existing work that has been done by Hawaiʻi communities and agencies, and to build upon these for future action, partnered with innovation. Participants also emphasized the need to build trust with communities to help them understand the incentives, challenges, and inevitable tradeoffs that come with the proposed Decarbonization Report. This section outlines the overall recommendations and identified challenges that emerged from these convenings.

Main Recommendations

Maximize existing solutions while also pursuing new opportunities. Most of the proven, effective decarbonization solutions need to be implemented for Hawaiʻi to be successful in achieving its decarbonization goals. We no longer have the luxury of time to select just a handful of solutions to reach our emissions reduction targets. It is critical that measures are carried out and sequenced correctly to not further burden low-income or asset-limited, income-constrained, employed (ALICE) households–in other words, most of Hawaiʻi's local working families.

Education and community engagement are essential to successful decarbonization. The importance of building community trust cannot be overstated. Behavioral change will inevitably be a part of successful decarbonization, and while financial incentives play a role in affecting human choice, people are also driven by trusted messengers, alignment with personal values, day-to-day priorities, and more. Equitably driving behavioral change will require fundamentally reworking relationships with communities – both by the government and the private sector. Further, regulatory requirements need to be simplified to include expeditious and meaningful community involvement at all points of project development. As government agencies and project developers turn to community members for input, it is important to address that stakeholder engagement fatigue is a growing issue. As a collective of public and private entities, we should implement creative solutions, combine outreach efforts, and appropriately compensate community members for their time.

Hawaiian Indigenous knowledge should help guide our energy transition. Hawaiian ancestral and Indigenous knowledge should play a critical role in our pathway to net negative emissions. Consider innovation in the context of Indigenous solutions, revitalizing the ahupuaʻa land management system, and centering Native Hawaiian voices.

Main Challenges and Potential Solutions

Participants repeatedly identified various challenges to implementing decarbonization solutions at scale to reach the state's emissions goals. The barriers are detailed below, each paired with potential solutions proposed or discussed by participants.

Lack of consistent and timely funding. Even with the influx of federal funding, one of the biggest barriers is the capital needed to implement clean energy and transportation projects at the speed and scale required for the energy transition, combined with the one-time nature of most of these funds.

- *Potential Solutions:* Implement new or reimagined sources of revenue that are more sustainable, such as a "polluter pays" or "feebate" structure, or consider redirecting existing sources of funds such as the barrel tax. State and local agencies should also coordinate more closely on applying for federal funding and leveraging these with existing funds.

Labor and resource constraints. Hawaiʻi's current workforce and available resources are severely deficient for the successful implementation of projects required to reach decarbonization targets.

- *Potential Solutions:* Encourage investment in Hawaiʻi's local workforce by using federal funds to partner with local universities in developing a workforce that is trained to perform jobs necessary for the energy transition, as well as to administer, implement, and monitor these funds. Support gathering of data to better understand decarbonization careers in Hawaiʻi.

Regulatory and statutory policy inflexibility at state and local levels. These issues range from the inflexibility of the regulatory/statutory system to keep up with technology, stemming from programs rigidly defined in statute, to project permits that take months or even years to be approved.

- *Potential Solutions:* Law-making, regulatory, and policymaking bodies should make a greater effort to incorporate flexibility into law, rulemaking, and policies to make space for emerging and evolving technologies and shifting market environments. Ensure regulatory bodies are adequately staffed to address these ongoing issues.

Community opposition to decarbonization projects. Participants expressed that there is already existing community opposition to decarbonization projects, for a wide variety of reasons, including historical lack of extensive community engagement by project developers, negative project impacts, and more. This opposition is likely to continue if communities are not appropriately and robustly engaged by the public and private sectors on this strategy and its associated measures.

- *Potential Solutions:* Recognize and openly discuss the tradeoffs, provide education and information transparently and in a timely fashion, and actively provide incentives to decarbonize (such as financing rooftop solar for low-income households and providing incentives for public transit, biking, and other modes of transportation). Require a certain level of meaningful community engagement for all state- and county-led projects, along with utility-scale energy projects. Consider community benefits packages as a tool to reconcile opposition and concern around new projects, with the stipulation that benefits should be designed mindfully and for longevity.

Risk of overburdening residents during the energy transition. The inevitable burdens of decarbonization (costs, behavioral changes, etc.) tend to fall disproportionately on residents who already bear the brunt of unaffordable costs of living partly because of the visitor industry.

- *Potential Solutions:* Hawaiʻi needs to ensure the visitor sector is included and equitably addressed in the state's plan to decarbonize. For example, the State can consider strategies such as vehicle miles traveled (VMT) reduction specifically targeted to visitors, along with redirecting the rental car surcharge to fund decarbonization measures.

Meeting Summaries

The following summarizes the discussions from each of the four meetings. Although each of the meetings was structured in a slightly different way, HSEO covered the background and context of Act 238, the existing policies and work completed to date, a high level review of the four modeled decarbonization scenarios, and the resulting critical pathways to decarbonization.

Equity

HSEO hosted the stakeholder meeting on *Equity* on Monday, November 6, 2023, 1:00 pm - 3:30 pm HST, with a total of 24 meeting participants[2]. This group discussed four of the pathways to decarbonization:

1. 100% reduction in fossil fuel combustion,
2. Improved efficiency & demand response technology adoption,
3. 20% reduction in statewide VMT, and
4. 100% zero-emission vehicle (ZEV) sales by 2035, and the equity challenges and opportunities associated with each pathway.

The following themes emerged from the *Equity* meeting.

Reshape the system to prioritize benefits for low-income individuals. A system for sharing benefits, community ownership models, and different business models needs to be developed. However, innovation is not the biggest need—implementation is, such as using tax credits from the Inflation Reduction Act for low-income families.

Rebuild trust with communities. Communities have felt they haven't been heard by government agencies and developers. In addition, there is a need for more transparency from the beginning to the end for energy projects and programs. Getting the appropriate information out to the wider community is both a challenge and an opportunity to pursue.

Community-level and culturally-appropriate responses in the transition are essential. The uniqueness of individual communities needs to be considered. Emphasis needs to be placed on education along with trusted partnerships and relationships. There is importance in building trust between communities and the government. To this end, the stakeholders would like to be kept posted on legislative packages proposed by HSEO to deal with these issues.

A holistic energy response is needed. There is a strong need for an integrated plan, as efficiency is not the whole solution for zero. For example, rooftop solar and demand response go together and are not an either-or situation.

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[2] This attendee count does not include HSEO staff or facilitators from Hua Nani Partners present at the meeting.

The transportation discussion emphasized Hawai‘i’s rural/urban needs, particularly for lower-income communities. On the ZEV side, several issues were discussed: equity for medium- and heavy-duty vehicle drivers and lack of EV charging for rural communities and the general population. On the VMT reduction side, the discussion centered around the need for reliable public transportation, that jobs need to be located close to home, along with the need for protected bike lanes, complete streets, and the development of active transportation networks. Participants also discussed the visitor industry’s impact on transportation.

Land Use and Transportation for Neighbor Islands

HSEO hosted the virtual stakeholder meeting on *Land Use and Transportation for Neighbor Islands* on Monday, November 13, 2023, 9:00 am - 11:30 am HST, with a total of 16 meeting participants. This group focused on the two transportation-focused decarbonization pathways, a 20% reduction in statewide VMT, and 100% ZEV sales by 2035, focusing on priority recommendations for each pathway and challenges associated with implementation. Participants discussed challenges to implementing existing policies, and how to build on work that has already been done in this space. The following themes emerged from the discussion.

There are challenges surrounding status quo development, funding, alignment, and enforcement of state goals. Participants outlined several challenges such as:

- The funding needs are great, even with the new federal monies. The need to collaborate for these federal funds is essential. Particularly, long-term financing strategies are needed to fund infrastructure and staff beyond the federal dollars.
- State agencies have entrenched interests–such as revenue from rental car fees–that conflict with unenforceable climate goals. The status quo for development patterns is difficult to surmount.
- Limited expertise in multimodal transportation engineering is also a challenge, as this contributes to the inadequate progress made on transportation goals and in upholding the inequitable status quo.

The State should play a bigger role in support of counties for Transit-Oriented Development (TOD) and Complete Streets. Participants agreed that the State can play a larger role in encouraging and supporting counties to strengthen Complete Streets and Transit-Oriented Development. Counties should be included in the land use scenario discussion because they face different land use issues, and there is a dire need for alignment of county and state zoning to help develop more mixed-use developments and commercial nodes to address VMT increases.

Equity in transportation must be addressed. Even though equity was not the focus of this group, it was discussed as being crucial to the transition. The current transportation system is inequitable and providing more travel choices, rather than being punitive to drivers, will help reduce this inequity. The strategies to reduce such inequity are reflected in VMT reduction accompanied by an increase in transportation choices–through TOD, Complete Streets, and related topics discussed by the hui, such as visitor-related transportation needs.

It’s critical to draw from existing work done thus far, particularly for VMT reduction. The group recognized that significant work has been done on the transportation issue of VMT reduction and encouraged the use of reports and their findings thus far, such as establishing a VMT goal, to move towards implementation.

Land Use and Transportation for Oʻahu

HSEO hosted the stakeholder meeting on *Land Use and Transportation for Oʻahu* on Thursday, November 16, 2023, 1:00 pm - 3:30 pm HST, with a total of 11 meeting participants. HSEO incorporated feedback from the earlier *Land Use and Transportation for Neighbor Islands* session and tailored this meeting to discuss and prioritize top-line recommendations from existing reports[3], and what is needed to implement known policy recommendations. Like the other Land Use and Transportation meeting, the discussion focused on the two transportation pathways, namely a 20% reduction in statewide VMT and 100% ZEV sales by 2035.

The group discussed challenges for transportation decarbonization including capital constraints (labor, dollars, resources) and the difficulty in establishing VMT goals, given there is no single entity that regulates VMT, unlike the renewable portfolio standard which is regulated by the utility. The group also discussed potential strategies for transportation decarbonization, including increasing revenue for the clean transportation transition through the barrel tax, and recognizing through policy that there should be a directional change in VMT even if a specific reduction is not articulated. Participants also emphasized the need to strengthen Complete Streets strategies (and overcoming obstacles such as permitting). HSEO presented the group with eight priority recommendations for VMT reduction and ZEV adoption based on existing reports and work done thus far, asking participants to rank actions for the state to prioritize in the next 1-3 years.

Participants ranked the following eight actions to be prioritized in the next 1-3 years to reach a 20% reduction in statewide VMT:

1. Encourage complete streets, infill development, and land-use mixing
2. Prioritize investments in public transit
3. Require evaluation of land use and VMT impacts for all state and county projects (e.g. capital improvement projects & new housing developments)
4. Prioritize development, improvement, and maintenance of active transportation infrastructure
5. Parking reform (e.g., increased parking costs, bike parking)
6. Adopt a statewide VMT reduction target for LDVs
7. Commuter benefits and incentivizing telework
8. Implement an aggressive road usage surcharge

There was a lengthy discussion on setting a statewide VMT target through legislation; some participants voiced it's not worth the time and resources to pass such a bill at the legislature, and others advocated for the importance of measuring progress towards an established goal. The group also explained the low ranking of an

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[3] The reports taken into consideration for this discussion were *Estimating Policy Effects on Reduced Vehicle Travel in Hawaiʻi* (SSTI, Smart Growth America, and Rhodium Group for Transcending Oil, 2019); *ICCT Hawaiʻi Clean Energy Initiative Transportation Energy Analysis* (HSEO, 2015); *Roadway Expansion and Vehicles Miles Traveled Report* (RMI for Hawaiʻi Climate Commission, 2022; *Investing in Transportation Choices: Recommendations for Safe, Sustainable, Affordable and Reliable Mobility* (Hawaiʻi Climate Commission, 2023); and *Drivers of VMT and Priority Reduction Strategies* (SSTI and Smart Growth America for the Hawaiʻi Climate Commission, 2021).

aggressive road usage surcharge by highlighting the need to implement other VMT reduction strategies first to provide individuals with options for alternative modes of transportation before placing a fee on driving.

Participants ranked the following eight actions to be prioritized in the next 1-3 years to achieve 100% ZEV sales by 2035:

1. State investment in EV charging infrastructure
2. Conversion of county and rental fleets[4]
3. Update HRS §291-71 to require more charging stations for larger lots, and decrease the minimum parking threshold of 100 vehicles (e.g. require 1 station per 50 stalls)
4. State-issued rebates for EVs
5. Establish a program to ensure charging stations that received public funding, or are mandated per HRS §291-71, are maintained and operational
6. Expand rebates for e-bikes
7. Light duty vehicle buyback program ("cash for clunkers"), potentially focused on low-income groups
8. Fuel switching for medium- and heavy-duty vehicles

Although not included in the original list of measures to rank, participants advocated for the inclusion of EV-ready new construction in the list of priority actions.

Decarbonization Tradeoffs

HSEO hosted the stakeholder meeting on *Decarbonization Tradeoffs* on Friday, November 17, 9:00 am-11:30 am HST, with a total of 20 meeting participants. The group discussed tradeoffs associated with behavioral change – one of the most cost-effective mechanisms to achieve decarbonization – and effective land use. The themes across discussions from the Decarbonization Tradeoffs session reflected the need for a holistic approach to addressing decarbonization challenges, emphasizing the interconnectedness of emission reduction goals, equity considerations, renewable energy strategies, community engagement, and the role of government in creating a supportive regulatory environment. The following specific themes emerged from the discussions.

Engage in meaningful stakeholder engagement and relationship building. The group emphasized the importance of procedural equity in addition to equitable outcomes and operationalizing trust-building without extending project timelines. The group also discussed ways to ensure that projects benefit communities and promote equity, including considering community benefits packages and their role in fostering positive relationships between projects and communities. In cases where community opposition is overwhelming, economic benefits are no enough to warrant projects being approved and developed.

Consider bold and creative solutions. The group discussed creative decarbonization solutions such as shutting down roads or freeways for periods of time; conducting sweeping education campaigns, such as on energy efficiency measures; community ownership of projects; etc.; and innovative tools such as Hawaiʻi Green Growth's Mālama Implementation Tool–a place-based project assessment tool.

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[4] State vehicles are mandated to be 100% ZEV for LDVs by 2045 (HRS §103D-412 and HRS §196-9).

Behavioral change driven by education, limited by economic factors. The group discussed the importance of achieving behavioral change equitably, particularly in the transition to EVs, and considering the role of education in driving equitable behavioral change. With limited time, there is a higher risk of behavioral change being inequitable. For many struggling families in Hawaiʻi, money limitations are a reality, and cheaper solutions that save them money are realistically more appealing.

Government working as a partner without getting in the way. Participants expressed that the legislature could do more to encourage more efficient public-private partnerships by not being too prescriptive with policy, but using it to encourage the use of existing tools. We can look at our past successes (i.e. adoption of rooftop solar largely due to the confluence of federal and state tax credits that spurred commercial boom), and attempt to replicate those conditions. Modeling this success will be more difficult for transportation, as it's inherently a less regulated sector with over one million individual actors. The government does, however, play a primary role in the infrastructure creation, maintenance, and alteration for transportation networks.

Conclusion

Participants across all four sessions voiced the critical nature of equitable process and outcomes, incorporating robust community engagement strategies, strengthening public-private partnerships, improving supportive regulatory environments for expedited project planning and implementation, and maximizing both proven and innovative solutions to successfully reach the State's decarbonization goals.

According to meeting participants, some of the greatest barriers to the State's successful, equitable decarbonization are largely the inverse of these tenets: lack of financial, workforce, and resource capital; community opposition; risk of overburdening communities which are already struggling; and policy inflexibility. The feedback from these four meetings shaped this report and its associated recommendations.

Appendix A-2: General Online Survey Responses

The following is a record of online survey responses received from June through November 2023. A total of 18 individuals completed the form. HSEO asked the following questions in the survey:

- Given the thirteen requirements of Act 238, what should be a primary focus of the Decarbonization Strategy?
- What are your biggest concerns regarding climate mitigation actions?
- Are there outstanding questions that the Decarbonization Strategy should answer?
- What are the most important components of climate pollutant mitigation?
- What are the biggest barriers to meaningful climate pollution reduction?
- Additional Comments: Please feel free to include comments on scenario assumptions and past presentations here.

Responses are included below grouped by these questions. Respondents did not have to answer every question. Comments are attributed anonymously, to an organization, or to an individual, depending on the respondent's indicated preference. These responses have only been altered to correct spelling and grammatical errors, and are otherwise the verbatim responses received from the form.

Given the thirteen requirements of Act 238, what should be a primary focus of the Decarbonization Strategy?

Anonymous Respondent: #3. Include land use and transportation planning measures aimed at reducing emissions from the transportation sector

Anonymous Respondent: #8, 10 & 12. Environmental Justice - how this affects people, especially some of the hardest hit who often have minimal resources to respond. And understanding where the major impacts are and what actions can be taken to make informed decisions.

Anonymous Respondent: Include land use and transportation planning measures aimed at reducing emissions from the transportation sector. Our small state has been built on a car centric model. Improvements to walkability, bicycling infrastructure and micro mobility, followed by public transit, should be prioritized over personal auto use.

Anonymous Respondent: Getting people out of cars and onto clean transport means.

Anonymous Respondent: The examination of contributions from each carbon emitting source, how each source can be reduced, and entities responsible for reduction is the most important requirement of ACT 238.

Anonymous Respondent: I'm not sure I know which requirements these are and it wasn't really listed that way in the PPT.

Anonymous Respondent: Mitigation

Anonymous Respondent: Implement Ocean Thermal Energy Conversion (OTEC) technology on a commercial scale.

Anonymous Respondent: Transportation

Anonymous Respondent: Fast tracking progress in the sectors with the highest emissions: electricity and transportation.

Sustainable Energy Hawaii: Long term systems' sustainability and energy transition capacity, modeling competitive supply-chain conditions, geopolitics and resulting affordability for economic stability while keeping appropriately ahead of the curve with corresponding global decarbonization efforts. This means focusing on baseload systems that are less reliant on CRM than intermittent systems, have better capacity factors and a more environmentally supportive footprint.

Sean Newsum, Airlines for America: Airlines for America® (A4A), the principal trade and service organization of the U.S. airline industry, appreciates the opportunity to provide input into the Hawaii State Energy Office's (HSEO) Act 238 Decarbonization Study. We applaud the State of Hawaii's leadership in establishing long term economy-wide decarbonization targets and conducting analysis on the viability of various decarbonization pathways. We appreciate the HSEO's efforts to share an overview of its proposed approach to the decarbonization analysis, the assumptions therein, the embedded decarbonization sectoral targets, and solicit feedback from the community.

Within Requirement 9 of the Decarbonization Strategy, which specifies to determine the most cost-effective pathway, and Requirement 10 which specifies to rank recommendations based on level of impact, cost and east of implementation, we recommend to ensure 'economic impact' is incorporated in the analysis of these requirements and the list of scenario evaluation criteria. For example, policies aimed at air traffic demand reduction, and thus visitor demand reduction, would likely have a negative impact on the economic activity of the state and those impacts should be considered in the evaluation.

The initial Decarbonization Strategy for aviation focuses on state actions to encourage electrification and adoption of alternative fuels. And further, to determine the most cost-effective pathways to decarbonization. Sustainable Aviation Fuel (SAF) is the most cost-effective pathway to decarbonization for aviation, and state actions in the form of incentive policies to accelerate the availability of affordable SAF for air transport service providers serving Hawai'i are the most critical action in meeting the objectives of the Decarbonization Strategy.

Joe Kent (Grassroot Institute of Hawaii): 11. Make recommendations on whether the goals established pursuant to HRS §225P-5 should be adjusted. The current goals are not practically achievable without increasing costs beyond what residents can sustain.

Leah Laramee (Hawaiʻi State Climate Change Mitigation and Adaptation Commission): Holistic and multi beneficial actions such as nature-based solutions mixed use community building. Reducing VMT and solutions that reduce the cost of living in the state.

Jayne LeFors (Individual): The primary focus should be transitioning away from a tourism-based economy and towards a self-sustaining economy that provides the majority of our food resources within the state. We can't ignore the fact that every year millions of people travel here by jets that spew tons of CO2 into the atmosphere. We also need to reduce the amount of goods, mainly food, that must be sent here by ships and planes that emit tons of CO2. Food security and food production should be high on the list of priorities for our state.

What are your biggest concerns regarding climate mitigation actions?

Anonymous Respondent: GHG emissions is a global pollutant.

Anonymous Respondent: This is a new set of challenges. How do we pilot ideas and try new things in a way that allows for failure, and accelerates successes?

Anonymous Respondent: Focus on a big shiny "thing" to solve our problems, unless the citizens have the appetite for nuclear power, we're going to need to distribute our efforts AND make some people unhappy. Lightweight electric vehicles and public transit over internal combustion vehicles. smaller, possibly slower roadways, people over cars, housing density, better zoning... There is very little political will to be forward looking.

Anonymous Respondent: It will involve radical shifts in the economy and people will resist.

Anonymous Respondent: The state is not doing enough to prepare for sea level rise and expected increased storm activity. 1)The inundation of our installed water distribution and sewage collection system by rising ground water will make it extremely difficult to repair water main breaks and will cause greater infiltration into our sewage collection pipes which will increase sewage treatment quantities. 2)Coastal roadways (Kaʻaʻawa, Hauʻula and Sunset Beach area) need to be moved inland now. 3) We need hurricane hardened state and county buildings where those without shelter or in substandard shelters (the majority of Oahu!) can seek refuge during a strong hurricane (Cat 3 or larger).

*Anonymous Respondent: T*hat we are going to rely on technology adoption versus technologies that exist now but require resources (like building sidewalks, or energy efficiency).

Anonymous Respondent: They are done in a rigid manner that does not allow State to adopt to new technologies and challenges.

Anonymous Respondent: A lack of public willingness to spend the money required.

Anonymous Respondent: Not having the workforce to implement. Public opposition – e.g. so hard to build a pedestrian bridge or bike lanes

Anonymous Respondent: We talk more than we implement. We don’t do what we say. We are always looking for magic options that don’t exist.

Sustainable Energy Hawaii: That the rest of the world is not doing their part. Hawaii may not be balancing local economic stability with energy system resilience while giving emissions the dominant say in action choices.

Sean Newsum (Airlines for America): The Decarbonization Strategy can only be met through a strong public-private partnership between the government and aviation stakeholders, including airlines, but also, critically including fuel producers. Hawai'i state government has a critical role to play in incentivizing and supporting the availability of affordable SAF from fuel producers.

A4A and our members are committed to limiting and further reducing our industry's greenhouse gas ("GHG") emissions. On March 30, 2021, A4A, together with our member carriers, pledged to work across the aviation industry and with government leaders in a positive partnership to achieve net-zero carbon emissions by 2050 ("2050 NZC Goal"). This pledge continues our longstanding commitment to embrace our responsibility to address climate change and reduce commercial aviation's GHG emissions footprint. Our 2050 NZC Goal parallels the Administration's goal of achieving net-zero GHG emissions in the aviation sector by 2050, included in its Aviation Climate Action Plan announced November 9, 2021 ("Aviation CAP").

The U.S. airline industry and the Administration also share the conviction that SAF will be critical to meeting our ambitious climate goals. The Administration's Aviation CAP agrees with every credible analysis in concluding that SAF "will be critical to the long-term decarbonization of aviation" and "to aviation's ability to meet the net-zero goal." This is the core impetus for the Administration's policy – manifested in the SAF Grand Challenge – to make 3 billion gallons of cost-competitive SAF available to U.S. aircraft operators in 2030. On September 9, 2021, in harmony with the Biden Administration's announcement of the SAF Grand Challenge, A4A and our members increased the previous 2 billion gallon A4A SAF goal by an additional 50 percent, establishing the 2030 SAF Goal.

In addition to sharing these goals, the Administration and the government are united in the view that they can only be met through a strong public-private partnership between the government and aviation stakeholders, including airlines. As summarized in its Aviation CAP, the USG has committed to working through a range of policy instruments, including the SAF Grand Challenge with industry to rapidly scale up SAF production with the goal of meeting the fuel needs of U.S. aviation by 2050." Similarly, A4A has welcomed its "whole of government approach" and committed to working in partnership with government to meet its 2050 NZC Goal and 2030 SAF Goal.

A4A and our members are proud of our strong environmental record. We have been keenly focused on fuel efficiency and GHG emissions savings for many years. As a result, U.S. airlines have improved their fuel efficiency over 135 percent between 1978 and 2021, saving over 5.5 billion metric tons of carbon dioxide (CO2), which is equivalent to taking more than 28 million cars off the road every year for 40 years. Our industry supports more than 10 million jobs nationally and 5 percent of GDP while contributing just 2 percent of our nation's GHG emissions (ref. U.S. EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020). This record is not happenstance but the result of our long standing, strong commitment to addressing climate change. For the past several decades, U.S. airlines have dramatically improved fuel efficiency and reduced GHG emissions by investing billions in fuel-saving aircraft and engines, innovative technologies like winglets (which improve aerodynamics) and cutting-edge route-optimization software. These investments have backed ambitious climate commitments. Since 2009, we have been active participants in a global aviation coalition committed to achieving ambitious climate goals. Today, we are focused on making the investments necessary to achieve our 2050 NZC Goal and 2030 SAF Goal.

Joe Kent (Grassroot Institute of Hawaii): 1. Most of the projected progress seems to rely on switching to sustainable aviation fuel (SAF) which currently costs more than two times the price of U.S. jet fuel, and that could significantly increase the price of air travel.

2. There may be lots of public pushback if lawmakers attempt to achieve a rapid reduction in nearly all gasoline cars.

3. Hawaii is not an ideal place to switch its entire fleet of EV cars because of the end-of-life cycle issues with lithium batteries, which are costly, difficult and hazardous to ship.

4. Reducing vehicle miles traveled is not an equitable policy, since those on lower incomes may need to travel more in order to get to work.

5. Limiting flights to Hawaii would hurt our tourism industry, which is the primary driver of our economy.

6. It would be extremely difficult to build solar on all the ideal places on Oahu, and even doing so wouldn't be enough to power the island.

7. Solar farms compete somewhat with agricultural farms, which presumably would be needed to "sink" carbon.

8. Materials for green energy may rise in price significantly as more government mandates around the world increase demand for EVs and biofuels. So the switch to cleaner energy could be even more expensive in the future.

9. HECO's grid plan is projected to cost billions of dollars, and with lawsuits on top of that, the electricity costs for ratepayers will likely rise, even under the reference scenario.

10. HECO's grid plan lists biofuels as its main source of firm power, which are twice as expensive as oil.

Leah Laramee (Hawaiʻi State Climate Change Mitigation and Adaptation Commission): That we are behind schedule! more funding needs to be dedicated to comprehensive and cohesive actions.

Jayne LeFors (Individual): I'm concerned we're doing too little too late. We need to ramp up solar production on every rooftop, both residential and commercial structures. We need to build solar structures over every parking lot. This is being stifled by HECO as they drag their feet by reducing incentives and making the buyback period increase. We also need hundreds more EV charging stations built across the state as soon as possible. Look to California for their example - when I visit there I see every parking lot has row upon row of charging stations, while here in Hawaii you might see just one or two chargers in major shopping centers.

Are there outstanding questions that the Decarbonization Strategy should answer?

Anonymous Respondent: How and who? What are the obligations and how will can the state support businesses and individuals to make the necessary changes. The Green Bonds program is a great example from the EU, that has motivated companies to perform better and come up with creative solutions so that they can access lower cost funding.

Anonymous Respondent: What is the commitment to supporting the best options available " today"? Affordable carbon capture and storage will always be 15 years away, we can't wait. Are we really going to pay for carbon capture at the point of production, higher electricity rates are not going to fly with the electrification of everything, we cannot allow this plan to be a boondoggle for HECO!

Anonymous Respondent: How can the economics of each high-impact measure be restructured to pay for itself?

Anonymous Respondent: The pathways to reduce statewide carbon emissions from vehicles, trucks, buses and airplanes is my major concern for reducing carbon emission in Hawaii. With regard to private vehicles it appears we are going the wrong way, as the number of large gasoline consuming trucks and SUV's on our roads today compared to the early 1990's is much greater. How can the State or County governments most effectively influence the general population and specific businesses to move to more energy efficient transportation alternatives?

Anonymous Respondent: It should way the costs of decarbonization against the benefits. There is very little upside to carbonization given Hawaii's size if other jurisdiction do not also join in.

Anonymous Respondent: Since OTEC technology was proven in the 1970's and 1980's, what more is needed to bring it to commercial reality?

Sustainable Energy Hawaii: How is public policy encouraging a development environment through a critical analysis of current regulatory hurdles that currently discourage the level of investment needed to transition the broader energy system to include the replacement of liquid transportation fuels

Stephanie Chang (Stephanie Chang Design Ink): In all of this valuable modeling and scenario building, I encourage you to be honest about the role of people, of human choice in all of this. Community residents choosing to adopt energy efficient appliances, community residents choosing to purchase an EV, community residents choosing a renewable energy project to be built and sited in their communities, and others including the need for community residents to decrease consumption and waste etc. etc.

Can we quantify the role of this individual choice by residents within the big picture of decarbonization? How will people choosing to do (or not do) the above actions affect total Greenhouse gases for Hawaii? We should be asking this; it is an important aspect of the equation, no? If the report is capturing what is needed for Hawaiʻi to successfully decarbonize, the report needs to acknowledge the role of people's actions as it will affect decarbonization. Even if it cannot be quantified, it can still be acknowledged, and I would argue, centered. It matters in the report to acknowledge it, and even more ideal if quantified because it helps all of us understand its degree of importance. We know the tools to influence behavior — effective storytelling, engagement, outreach, education — but HOW important are they??? Please help us understand. That this figures in your report also matters because it signals where organizations' and agencies' focus should go. It allows organizations' funding allocation to match the degree to which this aspect affects our state's goals.

There are many things that drive human choice. Yes, offering financial incentives is one piece (as could be regulatory aspects) but it is not the only driver. Feeling trust for the messenger is a part of it; feeling like one understands the Why. Feeling like this choice also aligns with our personal values is another. Decarbonization may see most effective result if it's aligned and connected with what communities care about and are asking for: ability to contribute and shape infrastructure (social and physical) to reflect their values. All of these things require a degree of intention and effort to carry out. It will not happen "on its own" naturally and without investment; it will not happen with business as usual.

Sean Newsum (Airlines for America): How can Hawai'i government best contribute to enabling SAF availability from fuel producers for flights serving Hawai'i?

A4A and our members strongly support tax incentives – in particular the US federal government SAF Blenders Tax Credit (BTC) – needed to catalyze SAF production. The Biden Administration also strongly advocated for the enactment of these incentives and we are thankful for the critical support the Administration provided to ensure enactment of the SAF-BTC and Clean Fuels Production Credit (CFPC) – as well as other tax incentives like the Clean Hydrogen Credit – that will provide support vital to successfully engendering exponential growth in domestic SAF production through 2030.

While the national SAF Grand Challenge will provide necessary support to the Hawai'i decarbonization strategy, to fully achieve the strategic objective defined by HSEO for cost-effective decarbonization pathways, state level policies for Hawaii that complement federal incentives must be adopted. Illinois, Minnesota, and Washington have each adopted producer or purchaser tax credits within the past year to encourage the adoption of SAF in their states. We encourage the State of Hawaii to consider a similar approach.

Joe Kent (Grassroot Institute of Hawaii): By what means is the state assumed to achieve significant reductions projected in each scenario?

Jayne LeFors (Individual): How can we create a Green Economy that doesn't depend on tourism and instead promotes self-sustainability in our island home that isn't reliant on outside imports of food and other goods.

What are the most important components of climate pollutant mitigation?

Anonymous Respondent: Cutting emissions from power plants and cars.

Anonymous Respondent: Lets focus on the unnecessary emissions of high impact GHGs. Many of the hotels have waste water treatment facilities that simply off gas the methane... they don't even burn it to reduce the climate impacts. This should be illegal.

Anonymous Respondent: Transit and Regulation improvements. Our transit model needs to move to a low carbon plan with walking, biking, public transit as top priority, then deliveries, then cars.

Regulations need to support more efficient vehicles (smaller), and development/zoning changes to allow greater density in the places where people need to live and work (IN TOWN)

Anonymous Respondent: Focus on CO2 mitigation--most other pollutants will ride in tandem.

Anonymous Respondent: The single simplest means to reduce climate pollution is to reduce consumption of products leading to pollutants, i.e. large gasoline and diesel vehicles, large energy consuming systems at homes (A.C. systems, second refrigerators, non-efficient refrigerators, gas or electric water heaters vs heat pumps or solar hot water systems). We need to focus on making all energy use as efficient as possible within the state. If one compares energy efficiency in Europe to that of the US, we are far behind. How can the state government influence or mandate actions to reduce consumption and energy efficiency statewide?

*Anonymous Respondent: A*ddress the biggest emitters that don't appear to be reducing - those in transportation

Anonymous Respondent: Market based measures.

Anonymous Respondent: Public understanding and acceptance of the best way to achieve this goal, from an engineering and a political point of view.

Anonymous Respondent: RE land availability or openness to undersea cables; VMT reduction and electrification

Anonymous Respondent: Retiring fossil fuel plants.

Sustainable Energy Hawaii: Developing energy systems with the capacity and durability to resist global competition 20 year from now.

*Sean Newsum (Airlines for America): T*he aviation sector has recognized that the preponderance of climate mitigation will necessarily have to come from a rapid and widespread transition to alternative fuels, commonly known as Sustainable Aviation Fuel (SAF). While electrification of aircraft is a subject of significant interest for Research & Development, near to medium term deployment of this technology is expected to occur for applications in Urban Air Mobility or Advanced Air Mobility – short range operations with less than 10 passengers. On a national level, the US government in its US Aviation Climate Action Plan has also recognized that aviation climate mitigation, while including incorporation of advanced and future aircraft technology, will rely on SAF tor the majority of CO2 emissions mitigation in the 2050 timeframe. While there may be opportunities to consider and pursue alternative propulsion technologies (battery electric, hydrogen fuel cell electric, and hydrogen combustion) for inter-Island air traffic in the 2040's, decarbonization of air traffic from Hawaii to mainland US destinations should be assumed to occur through the widespread adoption of SAF production and availability by fuel suppliers to US carriers operating from Hawaii. Therefore, HSEO should focus its efforts for aviation on strategies and policy to encourage the production and availability of SAF for flights departing from Hawaii airports.

While SAF production, availability, and use has been growing rapidly in recent years, SAF remains a nascent market relative to conventional jet fuel whose market has been established for several decades, but also relative to other renewable fuels such as Ethanol, Biodiesel, and Renewable Diesel which have become established and mature markets over the past 15-20 years. As a new emerging product competing in the established conventional jet fuel and renewable fuels markets, SAF requires support from governments to become established, to scale up production, and benefit from economies of scale to accelerate growth. The US government, through the Inflation Reduction Act (IRA), has provided for a new SAF Blenders Tax Credit (BTC) and Clean Fuels Production Credit (CFPC) which will provide new incentives to potential SAF producers and reduce the competitive disadvantage that SAF faces today. Some individual states have adopted policies to complement the available federal incentives to further reduce the competitive advantage faced by SAF.

To fully achieve the strategic objective defined by HSEO for cost-effective decarbonization pathways, state level policies for Hawaii that complement federal incentives must be adopted. Illinois, Minnesota, and Washington have each adopted producer or purchaser tax credits within the past year to encourage the adoption of SAF in their states. We encourage the State of Hawaii to consider a similar approach.

Joe Kent (Grassroot Institute of Hawaii): It's most important to maintain a voluntary approach to any effort, rather than a coercive approach.

Leah Laramee (Hawaiʻi State Climate Change Mitigation and Adaptation Commission): Equity, ensuring actions don't curtail future actions, and moving quickly!

Jayne LeFors (Individual): Ending the use of fossil fuels as soon as possible.

What are the biggest barriers to meaningful climate pollution reduction?

Anonymous Respondent: Politics and policies.

Anonymous Respondent: Money, lifestyle changes and the infrastructure needed to change in a manner that isn't a sacrifice to people. Great public transportation can be such a useful and beneficial option for all parts of our communities, and people don't want to give up the freedom of driving or flying for an inconvenient, unpleasant, or unreliable alternative. Air traffic will have to continue.. can that full a huge push towards native reforestation?

Anonymous Respondent: Political will, a failure of vision, leadership structure of the state senate and legislative, they can't pass anything meaningful and wanted by the public because they are paternalistic and seem to be controlled by major business interests. I assume it's that or just plain corruption.

Anonymous Respondent: Near-total dependence on tourism, near total-dependence on single-driver automobiles.

Anonymous Respondent: Public ignorance and financial barriers erected by our competitive economic system that does not place a dollar value on our environment.

Anonymous Respondent: Political will and investment - we've known how to deal with these issues for the past decade, we've just not been able to implement the policies effectively.

Anonymous Respondent: It is other countries and jurisdictions. It is not Hawaii.

Anonymous Respondent: Politics and short term thinking

Anonymous Respondent: Funding; Labor (this includes having a competitive labor market, good compensation and benefits - we compete nationally for labor); Over regulation (don't let perfect be the enemy of the good); community acceptance

Anonymous Respondent: Community pushback.

Sustainable Energy Hawaii: Regulation, finance and public buy-in. They are inseparable.

Sean Newsum (Airlines for America): For aviation, the most important component of climate pollutant reduction is rapidly expanding production and availability of affordable, cost-effective SAF to air transport carriers serving Hawai'i.

Joe Kent (Grassroot Institute of Hawaii): The costs of achieving these goals has not yet been calculated, yet are likely to be in the billions of dollars. These costs will fall mostly on local residents.

Also, the end-of-life cycle issues with electric batteries at best threaten Hawaii's clean environment, and at worst have health and safety risks associated.

Leah Laramee (Hawaiʻi State Climate Change Mitigation and Adaptation Commission): Funding and capacity.

Jayne LeFors (Individual): Government subsidies for the fossil fuel industry and continued permitting of fossil fuel extraction projects. Politicians who have sold out as their re-election campaigns are being funded by fossil fuel corporations. Lack of urgency as we strive to maintain our consumerism-based economy rather than reducing consumption.

Additional Comments: Please feel free to include comments on scenario assumptions and past presentations here.

Anonymous Respondent: Ground source heat pumps (GSHP) are a great way to decarbonize HVAC and water heating demands. It increases the thermal efficiency from 1 for traditional air source heat pumps to 4 to 5 for GSHP. They can be installed within foundational structures such as pile foundations (energy piles), slabs and walls, tunnel lining, pavement, etc. (i.e.; any structural element in contact with the ground). They have been installed and used throughout Europe but there is growth in the U.S. Please consider this technology as a contributor to the mitigation strategy.

Anonymous Respondent: Have you seen Kenya's new national tree planting holiday... what would it take for the state nurseries and schools/offices to do that together in the public sector, and the private sector to step up and fund a complementary effort.

Anonymous Respondent: I'm glad the forum exists to review the strategy, I want forward progress.

Anonymous Respondent: Begin with rapid up ramp on fossil fuel taxes (inc. jet fuel) up to $2.00/gallon with income going to free bus rides and jitney shuttle services for all. Provide roaming guards on buses to encourage school children on buses. Double rebates for Energy Star appliances and EV's and

EV charging stations and subsidize small homes and apartments. Supply low-income families with very heavily subsidized Energy Star appliances, free ceiling fans and up to $10,000 and financing toward the purchase of >30 mpg cars with clunker trade in.

Anonymous Respondent: There was very little on behavioral approaches - much of the phrasing appeared to be more about tech adoptions. I'm not sure I agree with the VMT estimates for Oahu when HDOT estimates increases across all counties in their annual budget documents measures of effectiveness. It is clear that some forms of pricing will need to be introduced - I think it will also be important then to talk about the benefits of those actions past climate or decarb benefits. Like if we make walking and biking safer, we should see reductions in traffic fatalities and other cardiovascular or asthma issues in adults and kids, etc.

Anonymous Respondent: Thanks for all the work you did! It was a quick turnaround! Please find and update this study regularly to ensure we are on track and have recent data.

Stephanie Chang (Stephanie Chang Design Ink): Thank you for this report. And thank you so much for asking for feedback from the community about this report. It speaks volumes. Would be a dream, an aspiration, for community members to see themselves in this report. Maybe that's for a future time, where efforts to "bridge build" and translate this report will be particularly useful for engaging and involving community residents.

Sean Newsum (Airlines for America): Regarding the HSEO scenarios for aviation (reference Appendix, p. 31 of September 12th, HSEO Webinar presentation).

Scenario 2: High Electrification

- Fuel efficiency improvements in aviation: 50% of the reference efficiency forecast from the Annual Energy Outlook (less efficiency than forecasted for the mainland given the relatively newer fleet of airplanes in Hawaiʻi)"
- "10% SAF blend by 2030, 40% SAF blend by 2045"
- "Increase in electric inter-island aviation, for applicable flights only, by 2045 (start ramping up in 2040)"

Comment: Scenario 2 adds SAF availability and use targets for 2030 and 2045. The 2030 target is consistent with the commitments of several A4A member airlines and similar to the national SAF Grand Challenge target when considered proportionally. A4A and its member airlines have not established SAF targets for 2045, but A4A and its members have committed to "net zero" carbon emissions by 2050 and support the ambitious goal of the U.S. government's SAF Grand Challenge of "supplying sufficient SAF to meet 100% of aviation fuel demand by 2050", which supports and aligns with the United States 2021 Climate Action Plan. While a 40% SAF blend by 2045 is highly ambitious, our overarching goal for 2050 is arguably more so and it would be preferable for Hawai'i to align with overall U.S. targets to the extent possible. Technological readiness for electric power aviation necessary for inter-island aviation is still immature and it is unclear whether technology will mature sufficiently by 2040 to meet the ambition of the HSEO Decarbonization Strategy.

Scenario 3: High Electrification plus additional demand reductions

- “Fuel efficiency improvements in aviation: 100% of the reference efficiency forecast from the Annual Energy Outlook”
- “10% SAF blend by 2030, 40% SAF blend by 2045”
- “Increase average length of stay to reduce flight miles while maintaining tourist activity”
- “Increase in electric inter-island aviation, for applicable flights only, by 2045 (start ramping up in 2040)”

Comment: Scenario 3 adds air travel demand reductions, while assuming to maintain tourist activity. The view of A4A and its member airlines is that demand reduction as a policy objective is inappropriate and could have negative, unintended consequences. The specific assumption to reduce flight miles through policies to increase average length of stay is impractical and unreasonable. Average length of stay for visitors to Hawaii had been declining prior to the COVID-19 pandemic. Average length of stay is a metric that is influenced by many external economic factors (including hotel costs which have been increasing in Hawaii in recent years) and it is not easily influenced through policy. Policy measures aimed at air travel demand reduction could have adverse and unintended consequences of reducing overall economic activity. The focus of Hawai’i’s decarbonization strategy should be to reduce carbon emissions in the most cost-effective manner without impacting economic activity.

Scenario 4: 50% by 2030 Achievement

- “Fuel efficiency improvements in aviation: 100% of the reference efficiency forecast from the Annual Energy Outlook”
- “15% SAF blend by 2030, 40% SAF blend by 2045”
- “Increase average length of stay to reduce flight miles while maintaining tourist activity”

Comment: Scenario 4 increases the SAF blend objective for 2030 from 10% SAF blend to a 15% SAF blend objective. In addition to our comments regarding Scenario 3 and the increasing length of stay scenario, we note that the existing 10% SAF blend target is highly ambitious as it stands, and increasing the blend target to 15% can only be achieved with very aggressive Hawai’i government incentives designed to drive greater SAF availability in Hawai’i.

Leah Laramee (Hawaiʻi State Climate Change Mitigation and Adaptation Commission): Mahalo for your work!

Paul Bernstein (Individual): I'm concerned with how the cost estimates that were displayed in the November presentation will be used. These costs fail to reflect the total cost of the pathways. The costs reflected in Scenario 2 illustrate my point as they are negative. If this were true, then it suggests many people are making decisions against their interests now, but that's untrue. People are using their car because it is more efficient for them than other modes of transport. A VMT reduction will come at a cost in both money and time. I fully agree that we need to reduce our VMT, but we need to recognize that to do so means spending money to make public transit, walking, cycling, and other non-vehicle modes of travel more attractive from a cost, time, and safety standpoint. Therefore, when estimating the cost of transport, I recommend accounting for the full cost and not simply the fuel costs involved in the different pathways.

Appendix A-3: Online Survey Responses from November 14 Webinar

During the November 14, 2023 webinar, HSEO and E3 presented the draft technical modeling results and issued a slightly different survey to attendees. HSEO asked the following questions via this survey:

- Based on the results presented, what types of carbon mitigation policies would you recommend the state prioritize?
- Given the presentation today and draft results - what are the recommendations you think should be prioritized for the report to the state legislature?

A total of 31 attendees responded to the survey. All responses were anonymous, and similar to the other survey, the respondents did not have to answer every question. The verbatim survey responses are included below, altered only to correct spelling and grammatical errors, and grouped by question.

Based on the results presented, what types of carbon mitigation policies would you recommend the state prioritize?

The ones with total savings that include societal benefits of decarbonization

VMT reduction and mode shift

Carbon pricing

Those that also advance resiliency/adaptation

Scenario 2 (because it's the net-savings pathway). Heavy mode-shift to public transit, walking, biking.

Zero energy buildings.

Transportation Policies: Encourage the adoption of electric vehicles, improve public transportation, and invest in infrastructure for walking and biking to reduce carbon emissions from transportation.

Greater focus on fuel switching versus electrification of ground transportation

Transportation modal-switch, building neighborhoods and transportation infrastructure that encourage people to walk, bicycle, and catch transit

Carbon cashback - both efficient and helps low- and middle-income families

Import substitution; Conversion of internal combustion engine vs only new sales of ZEV passenger vehicles

Mitigation policies:

- Carbon accounting by total greenhouse gas lifecycle, not just point-source or emissions within Hawaii.

- Multi-sector improvements, such as policies that support local food production as a method of decarbonization, and including displacement of imported meat, dairy, eggs, and proteins as well as fruits and vegetables
- Apply “electrification of everything” policy to the specific sectors and uses where that makes sense, such as light passenger vehicles. Do not allow that electrification enthusiasm to prioritize “solutions” that are less efficient and more costly than other measures, such as fuel switching
- Fuel switching policy that makes it easier to design, permit, install, operate, and switch to locally-produced renewable fuels for hotels, restaurants, heavy, marine, and air transportation

Agricultural and (Re)Forestation activities that incorporate large scale carbon sequestration for carbon credits that does not remove land from ag production capacity

They all seem necessary, but their implementation all look very daunting if community / public buy-in on the solution isn't secured. These are dramatic changes that impact everyone and at very least impacts the already expensive cost of living in Hawaii.

Legislature needs to pass legislation requiring building energy efficiency requirements with strict deadlines, beginning with state and county owned buildings.

Policies that require/incentive deep energy retrofits to existing buildings.

Energy efficiency, VMT reduction & mode shift

I would de-emphasize policy on adoption of electric vehicles and EV charging for light passenger vehicles. All of the major automakers have announced electric models, and in some cases (like Volkswagen), non-electrical options are not even manufactured any more. The State of Hawaii does not need to invest precious resources to get car buyers to switch to electrical.

More emphasis on fuel switching for ground transportation

On the opposite end of better complete streets to contribute to transportation, for farther out communities looking at equivalent activities and supports to not penalize the needs for high private vehicle usage, but helps to find good alternatives.

Tie the decarbonization plan to a climate adaptation/resiliency plan. These need to be integrated.

Prioritize landscape restoration: removal and eradication of invasive species, and replacement with native and less fire-prone species, on conservation and Class C/D agricultural lands. This will be a priority after the Maui fires anyway, it might as well also help support decarbonization efforts. Wildfire is also a GHG polluter.

Given the presentation today and draft results - what are the recommendations you think should be prioritized for the report to the state legislature?

Same as above [The ones with total savings that include societal benefits of decarb]

VMT reduction and mode shift

Deep changes to transportation infrastructure to incentivize transit, walking, biking

Strongly recommend shifting to a consumption based inventory model to more accurately reflect HI's emissions.

BEV transition, mode shift, support for clean energy transition so costs not all passed to customer

Consider additional consumption based emissions inventory (like Oregon's) for Hawaii

To facilitate mode shift, heavy investment in safe and protected bike/ped/trail NETWORKS in areas with vulnerable users and where there is a high percentage of trips within a 3 mile distance

Carbon Pricing Framework: Recommend the development and implementation of a carbon pricing mechanism, such as a carbon tax or cap-and-trade system, to incentivize businesses to reduce carbon emissions.

- Apply "electrification of everything" policy to the specific sectors and uses where that makes sense, such as light passenger vehicles. Do not allow that electrification enthusiasm to prioritize "solutions" that are less efficient and more costly than other measures, such as fuel switching
- Fuel switching policy that makes it easier to design, permit, install, operate, and switch to locally-produced renewable fuels for hotels, restaurants, heavy, marine, and air transportation

Ban on internal combustion engine vehicle sales

Without meaningful carbon pricing, policy interventions risk being somewhat arbitrary and can only calibrate to the 'relative pain' of each individual sector without connectivity to the broader goal. Every sector will tend to say 'we can't do this - what about the emissions of another sector. Aren't they more impactful?

Appendix A-4: Letters from Stakeholders

The pages that follow are a record of the five letters received providing input on the draft Decarbonization Report from the Hawaiʻi State Office of Planning and Development, Hawaiian Airlines, Island Energy Services, Carbon Cashback, and Par Hawaii.

STATE OF HAWAIʻI OFFICE OF PLANNING & SUSTAINABLE DEVELOPMENT

STATEWIDE SUSTAINABILITY BRANCH

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September 12, 2023

Ms. Monique Schafer
Decarbonization Program Manager
Hawaiʻi State Energy Office
Via email to: monique.m.schafer@hawaii.gov

Aloha Monique,

Mahalo for hosting today's Decarbonization Stakeholder Outreach Meeting, in accordance with Act 238, Session Laws of Hawaiʻi 2022.

The Statewide Sustainability Branch, as authorized by Hawaiʻi Revised Statutes §225M-8, is the state entity required to develop, organize, and promote policies and programs that assist in the meeting of Hawaiʻi's numerous sustainability and climate policies and goals, as well as is required identify, evaluate, and make recommendations regarding proposed legislation, regulatory changes, or policy modifications to the Governor, the Legislature, government agencies, private entities, and other bodies for the purpose of encouraging activities that best sustain, protect, and enhance the quality of the environment, economy, and community for the present and future benefit of the people of Hawaiʻi.

To support your agency's work to achieve the mandates set forth in Act 238, the Office of Planning and Sustainable Development's Statewide Sustainability Branch would like to share the following state plans, information, and energy and greenhouse gas emissions statutory targets for consideration, inclusion, and alignment with your efforts.

State of Hawaiʻi Plans and Studies:

- **Hawaiʻi 2050 Sustainability Plan**: Pursuant to Hawaiʻi Revised Statutes §226-65, the Hawaiʻi 2050 Sustainability Plan legally serves as the State of Hawaiʻi's combined climate and sustainability strategic action plan. The Hawaiʻi 2050 Sustainability Plan was recently published in 2021, and consolidated the U.N. Sustainable Development Goals, over 150 state plans and laws, multiple county climate and sustainability plans and general plans, and the voluntary Aloha+ Challenge. The plan determined during the 2020-2030 "Decade of Action" that eight (8) focus Areas should be achieved: Promote a Sustainable Economic Recovery, Reduce Greenhouse Gas Emissions, Improve Climate Resilience, Advance Sustainable Communities, Advance Equity, Institutionalize Sustainability, Preserve the Natural Environment, and Perpetuate

Traditional Ecological Knowledge and Values. These eight (8) foci identify 38 strategies, and 262 recommended actions.

The Statewide Sustainability Branch requests that the State's Decarbonization Study align with and include the State's official climate and sustainability strategic action plan's recommendations. The Hawaiʻi 2050 Sustainability Plan is available online at: https://hawaii2050.hawaii.gov, please contact me should you have any questions.

- **Hawaiʻi Statewide Transportation Plan**: Pursuant to Hawaiʻi Revised Statutes Chapter 279A, the Hawaiʻi Statewide Transportation Plan (HSTP) is required to be updated every ten (10) years as a framework to be used in the planning of the statewide transportation system and provide an outlook for 20-25 years. The Department of Transportation recently began their HSTP update in 2022 and published a draft version of their plan, to provide guidance for Hawaiʻi's transportation system through 2045 as an overarching policy document that guides the system-level and master plans of the three primary modes of transportation. The HSTP is available online at: https://hidot.hawaii.gov/administration/files/2022/12/HSTP_Exec_Summ_2022_compressed.pdf, and https://hidot.hawaii.gov/administration/files/2022/12/HawaiiStatewideTransPlan_Draft_compressed.pdf.

- **Hawaiʻi Greenhouse Gas Emissions Report for 2005, 2018, 2019 Final Report published April 2023:** Pursuant to Hawaiʻi Revised Statutes Chapter 342B, Part VI, the Hawaiʻi Department of Health is responsible for the tracking of greenhouse gas emissions to determine the State's progress in the reduction of greenhouse gas emissions. This most recent emissions report was published in April 2023 and presents the updated greenhouse gas emissions estimates for 1990, 2007, 2010, 2015, 2016, and 2017; as well as developed emissions estimates for 2005, 2018, and 2019; and emissions projections for 2020, 2025, 2030, 2035, 2040, and 2045. This updated Hawaiʻi Greenhouse Gas Emissions Report is available online at: https://health.hawaii.gov/cab/files/2023/05/2005-2018-2019-Inventory_Final-Report_rev2.pdf.

- **Feasibility and Implications of Establishing a Carbon Offset Program for the State of Hawaiʻi:** Pursuant to Act 16, Session Laws of Hawaiʻi 2018, the Office of Planning and Sustainable Development, in partnership with the State Greenhouse Gas Sequestration Task Force, investigated the feasibility of establishing both a state-program administered and state-offset project developer scenarios for a potential Carbon Offset Program for the State of Hawaiʻi. This study found that it would be unlikely that the State of Hawaii would generate significant revenue through the production of offsets, and that any trading of offset credits purchased within Hawaiʻi would be limited by the state's Zero Emissions Clean Economy target. This report is available online at: https://files.hawaii.gov/dbedt/op/sustainability/feasibility_and_implications_of_establishing_a_carbon_offset_program_for_the_state_of_hawaii_finalweb.pdf.

State of Hawaiʻi Climate and Sustainability Statutory Targets

As you are aware, there are over 20 climate and sustainability statutory targets enacted by the State of Hawaiʻi. The following statutory targets provided below are specifically energy-related or related to the state's greenhouse gas emissions:

2030 Statutory Targets:

1. **Energy-Efficiency Portfolio Standards Target:** Requires the PUC to establish the Energy-Efficiency Portfolio Standards (EEPS) target requiring that **4,300** gigawatt hours (GWh) of electricity use statewide be reduced **by 2030**.
   (Hawaiʻi Revised Statutes §269-96)

2. **Renewable Portfolio Standard Target:** Requires each electric utility company that sells electricity to establish a renewable portfolio standard (RPS) of **40%** of its net electricity generation **by 12/31/2030**.
   (Hawaiʻi Revised Statutes §269-92)

3. **Greenhouse Gas Emission Limit:** Establishing a statewide Greenhouse Gas Emissions Limit target to be **50%** below the level of statewide greenhouse gas emissions in 2005, to be achieved **no later than 2030**.
   (Hawaiʻi Revised Statutes §225P-5)

4. **State Fleet ZEV Transition:** Requires the State to transition **all** light-duty motor vehicles that are passenger cars in the State's fleet to be zero-emission vehicles **by 12/31/2030**.
   (Act 74, Session Laws of Hawaiʻi 2021, codified as HRS §§ 225P-7, 264-20.7, and 196-9 (c) (11), as amended.)

2035 Statutory Targets:

1. **Hawaiʻi Department of Education Net-Zero Energy Target**: Requires the Hawaiʻi Department of Education to become **net-zero** in energy use, producing as much renewable energy as it consumes across all public schools **by 01/01/2035**.
   (Hawaiʻi Revised Statutes §320A-1510)

2. **University of Hawaiʻi Net-Zero Energy Target:** Requires the UH to become **net-zero** in energy use, producing as much renewable energy as it consumes across all campuses **by 01/01/2035**.
   (Hawaiʻi Revised Statutes §304A-119)

3. **State Fleet ZEV Transition:** Requires the State to transition **all** light-duty motor vehicles in the State's fleet to be zero-emission vehicles **by 12/31/2035**.
   (Act 74, Session Laws of Hawaiʻi 2021, codified as HRS §§ 225P-7, 264-20.7, and 196-9 (c) (11), as amended.)

2040 Statutory Target:

1. **Renewable Portfolio Standard Target:** Requires each electric utility company that sells electricity to establish a renewable portfolio standard (RPS) **70%** of its net electricity generation **by 12/31/2040.**
(Hawaiʻi Revised Statutes §269-92)

2045 Statutory Targets:

1. **Renewable Portfolio Standard Target:** Requires each electric utility company that sells electricity to establish a renewable portfolio standard (RPS) **100%** of its net electricity generation by **12/31/2045**.
(Hawaiʻi Revised Statutes §269-92)

2. **Zero Emissions Clean Economy Target:** Requires the State to sequester more atmospheric carbon and greenhouse gases than emitted within the state as quickly as practicable, but no later than **2045**.
(Hawaiʻi Revised Statutes §225P-5)

Please let me know if I can be of further assistance, in support of the Hawaiʻi State Energy Office's statewide and economy-wide decarbonization study. Please feel free to contact me at Danielle.m.bass@hawaii.gov.

Mahalo!

Danielle M. M. Bass
State Sustainability Coordinator
Office of Planning and Sustainable Development
State of Hawaiʻi

November 17, 2023

Mr. Mark Glick
Chief Energy Officer
Hawaii State Energy Office
235 S. Beretania Street, 5th Floor
Honolulu, HI 96813

Subject: Hawaii State Energy Office Decarbonization Study

Dear Mr. Glick,

Hawaiian Airlines greatly appreciates the opportunity to provide input into the Hawaii State Energy Office's (HSEO) Act 238 Decarbonization Study. We applaud the State of Hawaii's leadership in establishing long term economy-wide decarbonization targets and conducting analysis on the viability of various decarbonization pathways. We appreciate HSEO's efforts to share an overview of its proposed approach to the decarbonization analysis and solicit feedback from the community.

The U.S. airline industry (represented by the trade organization Airlines for America (A4A) and its member carriers, including Hawaiian Airlines) is committed to limiting and further reducing greenhouse gas ("GHG") emissions. On March 30, 2021, A4A member carriers pledged to work across the aviation industry and with government leaders to achieve net-zero carbon emissions by 2050 ("2050 NZC Goal"). This pledge continues A4A carriers' longstanding commitment to address climate change and reduce commercial aviation's GHG emissions footprint. A4A's 2050 NZC Goal parallels the Biden Administration's goal of achieving net-zero GHG emissions in the aviation sector by 2050, included in its Aviation Climate Action Plan announced November 9, 2021 ("Aviation CAP").

The U.S. airline industry and the Administration also share the conviction that sustainable aviation fuel (SAF) will be critical to meeting the industry's ambitious climate goals. The Administration's Aviation CAP agrees with every credible analysis in concluding that SAF "will be critical to the long-term decarbonization of aviation" and "to aviation's ability to meet the net-zero goal." This is the core impetus for the Administration's policy – manifested in the SAF Grand Challenge – to make 3 billion gallons of cost-competitive SAF available to U.S. aircraft operators in 2030. On September 9, 2021, in harmony with the Biden Administration's announcement of the SAF Grand Challenge, A4A and its members pledged to work with government leaders and other stakeholders to make 3 billion gallons of cost-competitive SAF available to U.S. aircraft operators in 2030, thereby increasing its prior 2030 SAF Goal by 50 percent.

While electrification of aircraft is a subject of significant interest for Research & Development, near to medium term deployment of this technology is expected to occur for applications in Urban Air Mobility or Advanced Air Mobility – short range operations with

less than 10 passengers. On a national level, the U.S. government in its U.S. Aviation Climate Action Plan has also recognized that, while incorporation of advanced and future aircraft technology is important, the sector will rely on SAF for the majority of CO2 emissions mitigation in the 2050 timeframe. While there may be opportunities to consider and pursue alternative propulsion technologies (such as battery electric, hydrogen fuel cell electric, or hydrogen combustion) for inter-island flights in the 2040's (subject to the availability of sufficient renewable power generation capacity), decarbonization of flights by U.S. carriers from Hawaii to transpacific destinations and within the state should be assumed to occur through the widespread adoption of SAF production and availability by fuel producers and suppliers. Therefore, we recommend that HSEO focus its aviation decarbonization efforts on strategies and policies to encourage the production and availability of cost-competitive SAF for flights departing from Hawaii airports.
Aviation decarbonization can only be met through a strong public-private partnership between the government and aviation stakeholders, including airlines and also fuel producers. Hawaii state government has a critical role to play in incentivizing and supporting the availability of commercially viable SAF from fuel producers. SAF is a nascent industry and the cost of production of SAF is currently 2 to 5 times that of conventional jet fuel. The SAF industry needs government incentives to drive adoption of SAF and get to scale.

Hawaiian Airlines strongly support tax incentives – in particular the U.S. federal government SAF Blenders Tax Credit (SAF-BTC) – needed to catalyze SAF production and adoption. The Biden Administration also strongly advocated for the enactment of these incentives and we are thankful for the critical support the Administration provided to ensure enactment of the SAF-BTC and Clean Fuels Production Credit (CFPC) – as well as other tax incentives like the Clean Hydrogen Credit – that will provide support vital to successfully engendering exponential growth in domestic SAF production through 2030. While the national SAF Grand Challenge will provide necessary support to the Hawaii decarbonization strategy, to fully achieve the strategic objective defined by HSEO for cost-effective decarbonization pathways, state level policies for Hawaii that complement federal incentives must be adopted. Illinois, Minnesota, and Washington have each adopted producer or purchaser tax credits within the past year to encourage the adoption of SAF in their states. Given the scarcity of supply of SAF, Hawaii will need incentives that are competitive with other U.S. states in order to attract supply of SAF to Hawaii. We believe state-level tax credits will be the most effective mechanism to advance the use of SAF in Hawaii and contribute to Hawaii's decarbonization goals.

In addition, we have reviewed the presentations from the Sept 12, 2023 and Nov 14, 2023 webinars and have the following comments:

- <u>GHG inventory: Sept 12 presentation, Pg 11</u>: We understand that the state's GHG inventory does not include upstream emissions for fuels produced outside of Hawaii. We are concerned that this leads to a bias against the local production of renewable fuels. We believe Hawaii will need a combination of both locally produced SAF as well as imported SAF in order to meet aviation demand and decarbonize the aviation sector. We believe the opportunity for local production of SAF is important because it provides additional assurance of supply for Hawaii's economy, and contributes to sustainable economic development for the state. We believe it's important to consider the positive contributions that a local SAF economy can create, rather than only the GHG reduction impact, when considering policies to advance aviation decarbonization.

- Evaluation criteria: Sept 12 presentation, Pg 22: We recommend to add 'economic impact' to the list of scenario evaluation criteria. For example, policies aimed at aviation demand reduction would likely have a negative impact on the economic activity of the state and those impacts should be considered in the evaluation.
- Scenario assumptions: Sept 12 presentation, Pg 31: Scenarios 3 and 4 include an assumption to 'increase the average length of stay to reduce flight miles while maintaining tourist activity.' We do not view this as a realistic assumption, especially considering the significant increase in hotel costs in Hawaii over the past several years, with total trip cost being a primary driver of length of stay. Average length of stay for visitors to Hawaii had been declining in the years prior to the COVID-19 pandemic. Average length of stay is a metric that is influenced by many external economic and structural factors and not easily influenced by policy. Policy measures aimed at achieving air travel demand reduction could have the adverse and unintended impact of reducing overall economic activity within the state. The focus of Hawaii's decarbonization strategy should be to reduce carbon emissions in the most cost-effective manner while supporting economic activity.
- Scenario assumptions: Nov 14 presentation, Pg 34: Scenario S2 includes an assumption to reduce flight miles by 10% by 2030. Similar to our comments on the Sept 12 presentation, we recommend to add 'economic impact' to the evaluation criteria for these scenarios. Policies aimed at air travel demand reductions reduction could have the adverse and unintended impact of reducing overall economic activity within the state, and those impacts should be included in the evaluation. The focus of Hawaii's decarbonization strategy should be to reduce carbon emissions in the most cost-effective manner while supporting economic activity.

For more than 94 years, Hawaiian Airlines has been providing air transportation to Hawaii residents and visitors. As Hawaii's airline, we are committed to climate action to secure the future of our island home. Thank you for the opportunity to provide feedback to this important study.

Sincerely,

Avi Mannis
EVP, Chief Marketing Officer
Hawaiian Airlines

Jon Mauer
President and CEO

Island Energy Services, LLC
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JonMauer@islandenergyservices.com

November 2, 2023

Mark Glick
Chief Energy Officer
mark.b.glick@hawaii.gov

Hawai'i State Energy Office
Leiopapa A Kamehameha, State Office Tower
235 S Beretania St. #502, Honolulu, HI 96813

Cc: Monique Shafer
Decarbonization Program Manager
monique.m.schafer@hawaii.gov

Dear Mark,

Thank you for the opportunity to comment on Strategies to Decarbonize Hawai'i: Webinar on HSEO's Act 238 Study.

Island Energy Services Downstream, LLC (IES) is supportive of the State's goals to be carbon neutral by 2045 and is eager to play a major role in enabling a carbon neutral Hawai'i. We are well aware of the challenges ahead of us to achieve these goals.

Based in Kapolei, IES is a Hawai'i-based fuels logistics and marketing business providing premier fuel products for the State of Hawai'i. Our company has over 280 local employees and reliably serves retail, industrial, aviation, military, and utility customers throughout the state through a network of key storage and distribution assets comprised of fuels terminals and pipelines. IES is uniquely positioned to provide the services needed to import, store, and distribute renewable products throughout Hawai'i to assist in decarbonizing the State.

Please find our comments on Decarbonize Hawai'i: Webinar on HSEO's Act 238 Study in the attached. We look forward to having more detailed discussion on these topics in the near future.

Best Regards,

Jon Mauer

Jon Mauer
President and CEO
Island Energy Services, LLC

Strategies to Decarbonize Hawai'i: Webinar on HSEO's Act 238 Study.
Island Energy Services' Comments, November 2, 2023

Act 238's Goal of 50% of 2005 by 2030

As discussed in E3's April 2023 Report Hawai'i Pathways to New Zero - An Initial Assessment of Decarbonization Scenarios, Act 238's goal of achieving 50% of 2005 carbon emissions by 2030 appears un-attainable even in the most aggressive scenarios. The transportation and electrical sectors both have high technical, infrastructure, supply, and behavioral hurdles to overcome in a very short timeframe. We would like to see a more pragmatic approach that sets reachable goals for 2030 that can be a foundation for Hawai'i's ultimate 2045 net zero goal.

Decarbonization Policies and Regulations

As discussed in E3's April 2023 Report Hawai'i Pathways to New Zero - An Initial Assessment of Decarbonization Scenarios, "additional policies and regulations are needed to ensure the deployment of decarbonization strategies". Part of these additional polices and regulations should be a form of "Carbon Pricing" to provide the proper commercial incentives for decarbonization across all sectors, including the electrical sector.

Carbon pricing is needed to put Hawai'i on a level playing field with other states and countries that have or will have carbon pricing programs. To date, LCFS programs have been the most popular form of carbon pricing. LCFS programs have been established in California, Oregon, and Washington, as well as British Columbia. LCFS bills have been considered in New Mexico, Minnesota, Illinois, Michigan, and New York. Hawai'i will be in direct competition with the U.S. West Coast states and British Columbia for renewable fuels and without a carbon pricing or similar LCFS program, Hawai'i will be at a distinct commercial disadvantage to attract renewable fuels.

In-State Biofuels vs. Imports

Producing in-state biofuels will likely be very limited. E3's April 2023 Report Hawai'i Pathways to New Zero - An Initial Assessment of Decarbonization Scenarios discusses "Decarbonized fuels could be locally produced in the State of Hawaiʻi from a variety of biogenic feedstocks. The two general categories of feedstocks are 1) biomass residues from agricultural, forestry, and municipal waste; and 2) dedicated energy crops."

Reliance on dedicated in-state energy crops will require a tremendous amount of land. For example, energy grass is a higher yielding crop that can produce 7.5 barrels of biodiesel per acre annually.[1] In order to produce 10,000 barrels per day of biofuel (or less than 10% of Hawai'i's current fossil fuel demand), nearly 500,000 acres of land is required. For reference, Oahu totals 386,000 acres. Hawai'i will need to import substantial amounts of renewable fuel to meet their goals. Production of in-state biofuels is only a small part of the solution.

Life Cycle Approach to Carbon Intensity

The Pathway's approach for renewable fuels required for 2030 and 2045 goals do not take into account a Carbon Intensity (CI) lifecycle approach for these fuels including the actual CI of the fuel (the assumption is that all renewable fuels have a CI index of zero), and the manufacturing and transportation impacts.

For reference, CI lifecycle approaches form the basis for most of the tax credits established by the federal IRA and the LCFS programs in CA, OR, and WA.

Hawai'i's reliance on renewable fuels will be substantial, especially for aviation and power generation. Imports will make up the bulk of these renewable fuels as in-state renewable fuel production is extremely limited due to the amount of land required for renewable fuel production. Consideration should be given to consider the "life cycle" CI for all renewable fuel consumption and the ultimate impact on Hawai'i's decarbonization strategy.

Inflation Reduction Act

The recently enacted federal Inflation Reduction Act (IRA) includes the sunsetting of the Biomass-Based Diesel Blenders Tax Credit (BTC) at the end of 2024 and replaces it with the Section 45Z Clean Fuel Production Tax Credit (CFPC) defined in Section 13704 of the IRA. This new policy will have significant impacts on both Sustainable Aviation Fuel (SAF) and biomass-based diesels and other fuels. Stillwater Associates have summarized the impacts, and their findings and conclusions can be found here:

https://stillwaterassociates.com/inflation-reduction-act-sustainable-aviation-fuel-credit-carbon-intensity-matters/

https://stillwaterassociates.com/so-long-btc-hello-cfpc/

Of particular interest to us, and to Hawai'i, is the Act's requirement that: "The credit can only be earned for production of fuels in the United States". This has strong implications for Hawai'i and significantly limits Hawai'i's supply of imported renewable fuels including SAF and renewable fuels for power generation. Due to Jones Act shipping requirements and general supply and demand balances on the U.S. West Coast, the bulk of Hawai'i' liquid energy imports come from northeast Asia. Market forces on the U.S. West Coast and costly Jones Act shipping rates will likely prohibit any significant volumes of renewable fuels reaching Hawai'i. For example, large quantities of renewable fuels, including SAF, are and will be produced by Neste in Singapore. Hawai'i is a natural market for these fuels. But as written, the IRA will create a substantial economic barrier and prevent any of these fuels from reaching Hawai'i.

Hawai'i state delegation/representation, suppliers, and other stakeholders should consider lobbying for some form of Hawai'i exemption. For example, the IRA does have exemption language for critical minerals used in electric vehicles that allow "critical minerals …extracted, processed, and/or recycled domestically or in a country the U.S. has a free trade agreement with". The state might also, on its own, consider establishing a credit to offset the barrier of imports not qualifying for IRA credits.

[1] Energycane produces more biodiesel than soybean at a lower cost, by Marianne Stein, July 8, 2021, University of Illinois, Institute for Genomic Biology

Carbon Cashback

Aloha Hawaii State Energy Office:

Mahalo for opportunity to submit comments on the decarbonization study. I am submitting these comments on behalf of Carbon Cashback Hawai'i. The remainder of the document makes the case for including carbon cashback in the set of policies Hawai'I should implement to reduce its greenhouse gas emissions.

Mahalo nui loa,
Dr. Paul Bernstein
www.carboncashbackhawaii.org

To help compare some of the common policies considered to address greenhouse gas emissions and to help rank recommendations that are likely to arise in the decarbonization study, Carbon Cashback Hawai'I has created the color-coded table below that qualitatively evaluates different policies across a number of metrics that the decarbonization study is tasked with considering. Dark green indicates the best policy; and red, the worst. A glance at the table suggests that a policy that places a fee on carbon emissions and returns the revenues to residents (Carbon fee w/ dividends to residents, or carbon cashback) scores well for every metric, and outperforms every other policy for the metrics as a whole. It is the most cost-effective policy and provides the greatest benefits to low- and moderate-income households. This is not to say that carbon fee with dividends can or should serve as the *sole* policy to achieve decarbonization, but rather that it is almost certainly part of "the most cost-effective and equitable pathway to decarbonization" to be identified under Act 238 (2022), and it performs well in terms of all the other criteria to be considered under the Act.

Table: Comparison of Policies to Reduce Emissions from Fossil Fuels

	Metrics								
	Overall Measure	Impacts on Economy			Effects Emission Reductions				Jobs
		Households	Government		Sectors				
Policies	Cost-Effectiveness (highest to lowest)	Benefits Disadvantaged\Low *ncome* Communities Most	Administrative Cost (Ease of Implementation)	Effect on Government Budget	Ground Transportation	Air Travel and Shipping	Electricity	Carbon Capture and Sequestration	Accelerates Green Jobs & Tech
Carbon fee w/ dividends to residents	🟩	🟩	🟢	Neutral	🟩	🟩	🟩	🟢 *	🟩
Carbon fee w/o dividends	🟩	🟥	🟩	Increases	🟩	🟩	🟩	🟢 *	🟩
Efficiency standards - Buildings	🟨	🟨	🟥	Neutral			▨		🟨
Efficiency standards - Appliances	🟨	🟧	🟨	Neutral			▨		🟨
Mandates (e.g., no gas water heaters)	🟧	🟨	🟥	Neutral			🟨	🟨 *	🟨
Subsidies w/ Income Thresholds	🟥	🟢	🟥	Decreases	🟨		🟨		🟨
Subsidies w/o income thresholds	🟧	🟥	🟧	Decreases	🟧		▨	🟨 *	🟨
VMT Tax	🟨	🟥	🟢	Increases	🟨				🟥

* Credits could be given for sequestration. In which case these policies would have a positive impact on carbon sequestration.

Legend

🟩 **Best**
🟢
🟨 **Moderate**
🟧
🟥 **Worst**

Cost-Effectiveness is a measure of the cost per ton of emissions abated. The carbon pricing policies offer the best cost-effectiveness because they address emissions throughout the economy, which means they address emissions from existing and future technologies. Mandates and efficiency standards address emissions from new technologies and often limit choices and are sector specific. Subsidies are sector specific, address only new technology, and suffer from the free rider problem -- the government pays people or companies to do something that they would have done without the money thus leading to inefficiencies.[1]

Benefits Disadvantaged Communities. Carbon pricing with return of revenues to people is the clear winner as this policy provides a mechanism to make most low- and moderate-income households whole.[2] The policy is progressive since it returns the revenues to individuals in equal shares. Efficiency standards raise costs making capital more expensive and harder for low-income households to purchase. Mandates often create the same problem. The VMT tax and carbon pricing with no return of revenues to people are the worst policies and most regressive since lower income households spend a greater share of their income on energy and travel. Subsidies without income limits generally benefit only the higher income households. Subsidies with income thresholds are better but the poor cost-effectiveness in California's implementation suggests that few lower income households can take advantage of the subsidies and clearly the least wealthy would still be unable to make use of the subsidies.

Administrative Cost (Ease of Implementation): No new administrative infrastructure is needed to implement carbon pricing with dividends as this policy can be implemented by making use of two existing State tax frameworks: for the pricing, the existing Environmental Response, Energy, and Food Security Tax of Chapter 243-3.5, Hawaii Revised Statutes ("barrel tax") (i.e., increasing the tax rate to specified levels), and for the dividends, the Income Tax Law of Chapter 235 of Hawaii Revised Statutes (i.e., providing a new refundable tax credit). A VMT tax could be relatively easy to implement and require little new administrative cost if it were combined with the existing vehicle inspection program that already records a vehicle's odometer reading. Then regulators could asses the VMT tax payment and require this be paid in order to register a vehicle. The ease of implementing these pricing mechanisms contrasts with the regulatory policies such as efficiency standards, mandates, and subsidies. These programs would require new oversight measures and infrastructure to differing degrees. Subsidies would require new income tax forms and verification that purchases qualified for the subsidy. The burden would be worse if there were income thresholds as this policy would require more oversights to ensure no cheating. Mandates generally require new rules and regulations to be put in place coupled with sometimes very bureaucratic oversight. The same drawbacks apply to efficiency standards. The appliance standards would likely be the worst because they would need to be combined with a subsidy program to induce consumers to purchase more efficient appliances as the State probably cannot realistically restrict the sale of appliances that fail to meet a given standard.

Effect on Government Budget: Carbon fees with dividends, efficiency standards, and mandates have negligible impacts on the government's budget. In contrast, subsidies are a drain on the budget and

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[1] California Climate Investments, '2023 Mid-Year Data Update," (May 2023).

[2] University of Hawai'i Economic Research Organization, "Carbon Pricing Assessment for Hawaiʻi: Economic and Greenhouse Gas Impacts" (April 2021) and University of Hawaiʻi Economic Research Organization, "Hawaiʻi Carbon Pricing Study: Additional Scenarios & Administrative Considerations," (Dec 2021).

require either additional funds to be raised (i.e., taxes increased) or cut backs in current government services. The VMT tax and carbon fees without dividends increases the government budges but does so in a regressive manner thus further financially challenging low- and moderate-income households.

Ground Transportation: Of the policies that affect emissions from ground transportation, pricing carbon and therefore placing a fee on fossil-based transportation fuels is the best policy for the following reasons. First, it addresses all CO2 emissions from both existing and new vehicles. Subsidies only address emissions from new vehicles.[3] Second, it addresses emissions directly unlike a VMT tax, which addresses a proxy for emissions namely miles traveled. The simplest VMT tax treats all vehicles the same and so makes no distinction as to the true on-road efficiency of each vehicle. As a state (that is in compliance with the Clean Air Act) for which the EPA has not granted an exemption like California, Hawaii cannot implement mandates addressing ground transportation such as requiring improved fuel efficiency or a certain share of new vehicles to be electric.

Air Travel and Shipping: Apart from carbon pricing, the state probably has few options to reduce emissions from air travel and shipping in a cost-effective manner.

Electricity: Carbon pricing offers a comprehensive way to address all emission from the electric sector. This policy contrasts with efficiency standards, mandates, and subsidies which would address electricity usage from particular sectors, such as subsidies for residential PV systems would only address residential electricity usage.

Carbon Capture and Sequestration: The carbon pricing policies could be expanded from a simple policy that makes use of the barrel tax to one that also provides credits for activities that verifiably sequester carbon. Doing so would require oversight to measure the amount of carbon sequestered. An entity that sequestered carbon would be given a credit equal to the product of the carbon fee and the amount of carbon sequestered. Given some of the difficulties to verify and measure the amount of carbon sequestered, mandates that require better practices, for example in the agriculture sector, could offer a better method. These mandates would be a new standalone policy whereas carbon pricing could include carbon capture and sequestration.

Accelerates Green Jobs & Tech: Since carbon pricing affects emissions throughout the economy, it would accelerate green jobs and green technology throughout the economy and do it where it made the most economic sense.[4] Subsidies and mandates would also effect an increase in green jobs and technology, but it would do so in a more narrowly focused manner and would be picking the sectors where these jobs would be created, which could lead to these jobs not being created where they are most needed. A VMT tax would likely do nothing for green jobs and technology.

Businesses (this metric does not appear in the above table)**:** Carbon fees will increase costs to businesses based on the carbon intensity of their operations. But a great advantage of carbon pricing is that it places no restrictions how a company chooses to reduce its emissions. Unlike mandates, which limit a company's set of options and unlike subsidies and efficiency standards, which pick winners and losers, the carbon fee allows each company to reduce emissions in the most cost-effective manner for it.

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[3] https://www.rff.org/publications/explainers/carbon-pricing-202-pricing-carbon-transportation-sector/

[4] https://www.rff.org/publications/reports/waiting-for-clarity-how-a-price-on-carbon-can-inspire-investment/

Summary: Carbon fee with dividends returned to residents is not the only policy Hawaii needs to reduce its greenhouse gas emissions, but it is the single most effective policy for it addresses all carbon emissions, strengthens other greenhouse gas abatement policies such as the RPS and efficiency standards, financially benefits most low- and moderate-income households (hence promotes climate justice), is progressive, requires virtually no new administrative infrastructure, allows businesses to most cost-effectively reduce their emissions, has proven to be successful in British Columbia[5] (partly leading to all of Canada adopting carbon pricing), and is endorsed by over 3,600 economists.[6]

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[5] https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-economy/carbon-tax

[6] https://clcouncil.org/economists-statement/

Par Hawaii

1. Regarding the key value item "Reduce combustion-based electricity generation (including biofuels)", we offer the following comments:
    - While this is a laudable long-term objective, we believe this objective will hinder, rather than help, Hawaii's path to decarbonization. The reason for this is that the electric grid, particularly on Oahu, is heavily reliant on synchronous generators that are powered by liquid fuels. Synchronous generators provide grid stability and firm generation, and this cannot be replicated economically with intermittent renewables (solar and wind) paired with batteries. Therefore, liquid fuels will be an important part of the generation mix for many years, if not decades. We believe that an important part of decarbonizing Hawaii's economy is through fuel switching from petroleum-based fuels to renewable diesel, biodiesel and other fuels that have life-cycle emissions well below fossil fuels.
    - Further, we suggest that the reduction in combustion-based electricity generation should be a secondary consideration, since Hawaii meets the national ambient air quality standards.
    - We believe it is important that Hawaiian Electric is consulted on this item, if they have not already been consulted.

2. We believe there is a significant opportunity to rejuvenate Hawaii's agricultural sector, and reduce wildfire risk, through the production of oil-based crops to be used to produce biofuels for transportation or power generation. The Hawaii Natural Energy Institute of the University of Hawaii has done a substantial amount of work on the feasibility of oil-yielding crops. Additionally, Par Hawaii has entered into a partnership with Pono Pacific, a local land and agricultural management company, to develop oil-yielding crops in Hawaii.

    https://www.hnei.hawaii.edu/
    https://www.parhawaii.com/pono-pacific-forms-partnership-with-par-hawaii/

3. Electrification is unlikely to be a feasible solution for the trucking and aviation sectors in the foreseeable future. Therefore, the decarbonization of transportation and aviation will require liquid biofuels. This will require additional state level incentives such as an expansion of the renewable fuels tax credit and/or a low carbon fuel standard. States on the US West Coast and elsewhere have incentives – ranging from approximately $1-2 per gallon – for low carbon fuels. Fuels will flow to where they can achieve the highest value for producers. Hawaii will need to be competitive with the incentives available in other states in order to attract renewable fuels.

4. Par Hawaii is proceeding with a $90 million project to convert a unit at the Kapolei refinery to the production of renewable diesel and sustainable aviation fuel. This unit will have a capacity of approximately 60 million gallons per year and will begin production of fuel in Q2 of 2025. As noted above, these fuels are expected to be exported to the US West Coast, unless State policy includes financial incentives for those fuels to be consumed in Hawaii.

5. We would encourage research into the potential for geologic sequestration of CO2 in the form of mineralization, similar to the Carbfix project in Iceland. The University of Hawaii is conducting research into the potential for this approach in Hawaii.

    https://www.carbfix.com/

Appendix B – PATHWAYS Inputs

Hawaiʻi State Energy Office and

Energy and Environmental Economics, Inc.

Appendix B-1: PATHWAYS Input and Assumption Sources

[1]Building Inputs and assumptions for energy demands, baseline stock, costs, and efficiency can be found in Table 1.

Table 1 Residential and commercial building assumption references

Description	Reference
Calibration of sectoral electricity demand input data (GWh)	Historical 2019 electricity consumption from EIA Form EIA-861M detailed data.[1] Breakdown by island was informed by historical 2019 data provided by Hawaiian Electric. Sectoral breakdown was informed by the Hawai'i PUC's market potential study.[2]
Calibration of sectoral fuel input data (MMBtu)	Energy Information Administration, State Energy Data System[3]
Reference technology shares of electric devices (percent of stock)	Base year stock shares were informed by the EIA Residential Energy Consumption Survey (RECS)[4], the 2018 Commercial Buildings Energy Consumption Survey (CBECS)[5], as well as the Hawai'i PUC's market potential study.[6] Stock shares and service demands were calibrated to align 2019 energy demands with recorded historical data.
Technology costs	U.S. Energy Information Association, Updated Buildings Sector Appliance and Equipment Costs and Efficiencies, 2023, Appendix A[7]
Technology efficiencies	- Cooking: ACEEE, Induction Cooking Technology Design and Assessment, 2014[8] - Heat pumps: NREL, Electrification Futures Study Technology Data, 2021[9] - All other end uses: U.S. Energy Information Association, Updated Buildings Sector Appliance and Equipment Costs and Efficiencies, 2023, Appendix A[10]

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[1] https://www.eia.gov/electricity/data/eia861m/

[2] https://puc.hawaii.gov/wp-content/uploads/2021/02/Hawaii-2020-Market-Potential-Study-Final-Report.pdf

[3] https://www.eia.gov/state/seds/seds-data-complete.php?sid=US

[4] https://www.eia.gov/consumption/residential/

[5] https://www.eia.gov/consumption/commercial/

[6] https://puc.hawaii.gov/wp-content/uploads/2021/02/Hawaii-2020-Market-Potential-Study-Final-Report.pdf

[7] https://www.eia.gov/analysis/studies/buildings/equipcosts/

[8] https://www.aceee.org/files/proceedings/2014/data/papers/9-702.pdf

[9] https://www.nrel.gov/docs/fy21osti/79094.pdf

[10] https://www.eia.gov/analysis/studies/buildings/equipcosts/

Transportation

Inputs and assumptions for energy demands, costs, and efficiency can be found in Table 2 for transportation. The transportation sector's service demands and baseline stocks were benchmarked to emissions from the Inventory, electric demand from Hawaiian Electric, and liquid fuel demands from SEDS.

Table 2 Transportation assumption references

Description	Reference
Calibration of sectoral fuel input data (MMBtu)	Energy Information Administration, State Energy Data System, 2021.[11]
Technology costs	International Council on Clean Transportation, 2022.[12] California Air Resources Board, Appendix G: Total Cost of Ownership Discussion Document, 2022.[13]
Technology efficiencies	- AEO, Table 41, 2019.[14] - NHTSA, CAFE Central Analysis, 2022.[15] - Argonne National Laboratory, Light Duty Electric Drive Vehicles Monthly Sales Updates[16] , 2020 - Bureau of Transportation Statistics, Table VM-1, 2021[17]

Macroeconomic Assumptions

PATHWAYS uses macroeconomic assumptions to model population growth, and therefore energy demand and emissions, in future years. Assumptions for macroeconomic inputs can be found in Table 3. Absent the measures seen in the Reference and mitigation cases, energy demands and emissions grow over time based on macroeconomic indicators.

Table 3 Macroeconomic assumption references

Sector	Description	Reference
Population	Baseline	DBEDT, Table 1.05, 1.06, 2019.[18]
	Growth	DBEDT, 2045 Long Range Projections, 2018.[19]
Households	Baseline	DBEDT, Table 1.05, 1.06, 2019.[20]

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[11] https://www.eia.gov/state/seds/seds-data-complete.php?sid=US
[12] https://theicct.org/wp-content/uploads/2022/10/ev-cost-benefits-2035-oct22.pdf
[13] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appg.pdf
[14] https://www.eia.gov/outlooks/aeo/
[15] https://www.nhtsa.gov/file-downloads?p=nhtsa/downloads/CAFE/2022-FR-LD-2024-2026/Central%20Analysis/
[16] https://www.anl.gov/esia/light-duty-electric-drive-vehicles-monthly-sales-updates
[17] https://www.fhwa.dot.gov/policyinformation/statistics.cfm
[18] https://dbedt.hawaii.gov/economic/databook/2019-individual/
[19] https://dbedt.hawaii.gov/economic/economic-forecast/2045-long-range-forecast/
[20] https://dbedt.hawaii.gov/economic/databook/2019-individual/

Sector	Description	Reference
	Growth	DBEDT, 2045 Long Range Projections, 2018.[21]
Commercial Square Footage	Baseline	AEG, Market Potential Study, 2020.[22]
	Growth	EIA, AEO Table 22, 2023.[23]

Fuel Assumptions

Fuel price and emissions intensity assumptions can be found in Table 4. Hawai‘i-specific fossil fuel price trajectories were developed starting with Hawai‘i fuel prices in 2019 from EIA SEDS and applying the fuel price trends from AEO 2023 to project these prices through 2045. Renewable fuel price trajectories were developed using the E3 Biofuel Optimization tool. In E3's PATHWAYS modeling, biofuels are included as a decarbonization option to replace fossil fuel use. E3 explicitly models the feedstock availability, conversion processes, and final fuel allocation of advanced biofuels, which E3 characterizes as biofuels that can be blended up to 100% without requiring any changes for equipment that currently consumes fossil fuels. These advanced biofuels are distinct from conventional biofuels like ethanol and biodiesel, which cannot be used at a 100% blend level with most existing vehicles. Biomass feedstock supply curves used to determine biofuel availability come from the 2016 Department of Energy Billion Ton Report (BTR).[24] The BTR provides supply curves on the amount of biomass feedstock available at various price thresholds out to 2040, and E3 aggregated 40 of these individual feedstocks into 5 broader categories for the scenario screening process:

1. Cellulosic Energy Crops
2. Woody Energy Crops
3. Purpose-Grown Forests
4. Wastes
5. Residues

After the biomass feedstock supply curves are screened based on geographic allocation and feedstock category, they are passed to a biofuels optimization tool that also takes in biofuel conversion costs and efficiencies, remaining fossil fuel demand in the economy after electrification and energy efficiency measures, and the counterfactual fossil fuel costs and emissions intensities. The biofuels optimization tool will convert feedstocks from the BTR to final fuels, either RNG or renewable liquid fuels, based on the lowest possible cost of decarbonization by calculating which fuel pathways have the lowest incremental cost and greatest incremental GHG savings when compared to their counterfactual fossil fuels. For this

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[21] https://dbedt.hawaii.gov/economic/economic-forecast/2045-long-range-forecast/
[22] https://puc.hawaii.gov/wp-content/uploads/2021/02/Hawaii-2020-Market-Potential-Study-Final-Report.pdf
[23] https://www.eia.gov/outlooks/aeo/
[24] https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

study, renewable prices were developed assuming that only available feedstocks were from wastes and residues within the continental United States. The optimization was performed based on a projection of future renewable fuel demand for the all of the states in the US Climate Alliance, and assuming national average fossil fuel price trajectories. This approach was taken because of the large demand for renewable fuels in Hawaiʻi, which would likely require the procurement of out-of-state imported fuels. A cost-adder was applied to the national renewable fuel price trajectories based on the difference in Hawaiʻi fuel prices relative to national fuel prices today. This cost-adder was meant to reflect the added cost of importing fuels.

Table 4 Fuel assumption references

Sector	Description
Fossil fuel price trajectories	EIA, AEO Table 3, 2023.[25] EIA SEDS[26]
Fuel emissions intensity	EPA, Emissions Factors for Greenhouse Gas Inventories, 2022.[27]

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[25] https://www.eia.gov/outlooks/aeo/

[26] https://www.eia.gov/state/seds/

[27] https://www.epa.gov/climateleadership/ghg-emission-factors-hub

Appendix B-2: PATHWAYS Costing Inputs and Assumptions

Building Investment and Transportation Investment

Each device type in PATHWAYS is assigned an upfront capital cost based on the sources listed in Table 4, which is then levelized over the lifetime of the device. A financing rate of 5% (real) was used to annualize incremental equipment costs. The useful life of each type of equipment is shown below in Table 5.

Table 5 Financing lifetime assumptions

Sector	Subsector	Lifetime (Years)
Residential	Central Air Conditioning	17
	Clothes Drying	13
	Clothes Washing	11
	Cooking	14
	Dishwashing	15
	Freezing	22
	General Service Lighting	1
	Reflector Lighting	1
	Linear Fluorescent Lighting	1
	Exterior Lighting	1
	Refrigeration	17
	Room Air Conditioning	10
	Multi Family Space Heating	22
	Single Family Space Heating	21
	Water Heating	13
Commercial	Space Heating	24
	Air Conditioning	18
	Water Heating	12
	Ventilation	18
	Cooking	11
	General Service Lighting	1
	Linear Fluorescent Lighting	1
	HID Lighting	1
	Refrigeration	10
Transportation	Light Duty Cars	15
	Light Duty Trucks	16
	Light Medium Duty Trucks	16
	Medium Duty Trucks	20
	Heavy Duty Trucks	20
	Buses	20

Building Energy Efficiency

Energy efficiency costs were developed using the energy efficiency supply curves developed for the Hawaiian Electric IGP.[28] Supply curves were based on the scenarios from the Hawai'i PUC market potential study.**[29]**

Industry Investment

Industrial decarbonization focuses on the conversion of the Par Refinery. As such, the costs of industrial decarbonization are reflected in the costs to convert Par to the production of biofuels. In mid-2023, Par Pacific announced that it was planning to begin the conversion of one of the refinery units to the production of sustainable aviation fuel, citing the price of conversion as under $1.50 per gallon based on projected annual operating capacity.[30] This value is assumed for both phases of refinery conversion to biofuels.

Fossil Fuels and Low Carbon Fuels

A detailed description of the methodology used to develop fuel prices is given in Appendix B-1.

AFOLU

Cost for natural and working lands are derived from measures included the 2020 Conservation International and State of Hawai'i Office of Planning report "Reversing Climate Change".[31] Using the "First Cost per Acre", projected acres across the state, and total emissions abated, an annual $/tCO$_2$ sequestered is calculated for each measure. Costs for agricultural emissions mitigation measures come from the EPA Non-CO$_2$ Report.[32] All agriculture measures valued at $200/tCO$_2$e or less are included in this study.

Other Non-Energy Mitigation

Costs for waste and HFC emissions mitigation come from the EPA Non-CO$_2$ Report.[33] All waste and HFC measures valued at $200/tCO$_2$e or less are included in this study.

NETs

Negative emissions technologies were costed based on assumptions for all-electric direct air capture (DAC). Costs were developed based on Fasihi et al. (2019), McQueen et al. (2021), and National Academies of Sciences, Engineering, and Medicine (2019).[34,35,36] The electricity supply for DAC is assumed to be off-grid solar + storage, which is costed at the same value of grid electricity for simplicity.

Device O&M

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[28] https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning/stakeholder-and-community-engagement/key-stakeholder-documents

[29] https://puc.hawaii.gov/wp-content/uploads/2021/02/Hawaii-2020-Market-Potential-Study-Final-Report.pdf

[30] https://www.parpacific.com/press-releases/par-pacific-announces-significant-investment-hawaii-renewable-fuels-production

[31] https://planning.hawaii.gov/wp-content/uploads/Conservation-International-FINAL-Report_GHG-4.30.2020.pdf

[32] https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases

[33] https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases

[34] https://www.sciencedirect.com/science/article/pii/S0959652619307772

[35] https://nap.nationalacademies.org/read/25259/chapter/19#493

[36] https://iopscience.iop.org/article/10.1088/2516-1083/abf1ce/pdf

Annual maintenance costs for light duty vehicles are sourced from the International Council on Clean Transportation's 2022 "Assessment of Light-Duty Electric Vehicle Costs and Consumer Benefits in the United States in the 2022–2035 Time Frame" report.[37] Annual maintenance costs for medium- and heavy-duty vehicles come from analyses done by the California Air Resource Board preceding the Advanced Clean Trucks regulation.[38] Residential and commercial building device operations and maintenance costs are calculated with the same methodologies as upfront building device costs.[39,40,41]

Costs Not Modeled

Costs for VMT reductions and flight mile reductions were not modeled. Policy driven VMT reductions, as seen in S2, come from a variety of measures including land use mixing, increasing direct parking costs, improving transit access, and increasing mileage-based pricing measures. The bulk of the reductions in vehicle miles traveled come from measures like road mileage pricing and parking cost increases, which would net out from a total resource cost perspective because the revenues are used to fund other measures. The flight mile reductions were modeled as a sustainable tourism measure with a one-day increase in the average length of tourist stay in Hawaiʻi. This measure was not explicitly costed. For more information about policy recommendations to achieve these emissions reductions see **Section 2.3 - Transportation.**

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[37] https://theicct.org/publication/ev-cost-benefits-2035-oct22/

[38] https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appg.pdf

[39] https://www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf.

[40] https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf

[41] https://www.cityofpaloalto.org/files/assets/public/v/1/development-services/advisory-groups/electrification-task-force/palo-alto-electrification-study-11162016.pdf

Appendix C – Electric Sector Inputs and Assumptions and Island Specific Results

Electric Sector Additional Inputs and Results by Island

National Renewable Energy Laboratory and Hawaiʻi State Energy Office

Table of Contents

Appendix C-1: Electric Sector Inputs and Assumptions

Aviation Demands by Year

Aviation electricity demand data were broken out across all islands on which Mokulele Airlines operates. The island-specific demand breakdown was derived from BTS data presented in Chapter 2. Table presents the island-specific demand breakdowns attributed to electrification of inter-island flight.

Table C-1. Aviation demand by year and island (GWh).

Aviation Demand by Year (GWh)				
Island	**2030**	**2035**	**2040**	**2045**
Hawaiʻi	0	0.7	1.5	2.2
Lānaʻi	0	0.5	1.0	1.6
Maui	0	1.4	2.8	4.1
Molokaʻi	0	1.1	2.2	3.2
Oʻahu	0	1.3	2.6	3.9
Total	**0**	**5**	**10**	**15**

Solar and Wind Resource Technical Potential

For Oʻahu, Hawaiʻi Island, Maui, Molokaʻi, and Lānaʻi, solar and land-based wind resource technical potential are sourced from 2023 Hawaiian Electric IGP Base scenario assumptions. The 2023 Hawaiian Electric IGP Base scenario uses the Alt-1 land exclusions outlined in the 2021 update of the NREL technical potential report.[1] The capacity expansion analysis used representative weather year technical potential profiles published in the Hawaiian Electric IGP workbooks.[2]

A solar resource technical potential study has not been performed for Kauaʻi, so the System Advisor Model (SAM) was used to generate solar resource technical potential profiles for new-

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[1] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company*. National Renewable Energy Laboratory.

[2] The solar and wind technical potential profiles used in this study are provided in Excel workbooks at this website: https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning/power-supply-improvement-plan. For Oʻahu, Hawaiʻi Island, Maui, Molokaʻi, and Lānaʻi, Hawaiian Electric published four workbooks with inputs to their IRP processes under the heading "March 31, 2022 – Hawaiian Electric Response to Order No. 38253 Approving Inputs and Assumptions with Modifications (PDF)." The solar and wind technical potential profiles are sourced from the workbooks associated with each island entitled "Workbook 2."

build solar.[3] The SAM inputs used typical meteorological year resource data for the Kapaʻa grid cell and the same solar technology configuration used in the 2021 NREL report.[4] As no technically feasible land area study has been performed, no solar capacity constraints were imposed on Kauaʻi. Land-based wind was not considered for capacity expansion due to the shearwater and endangered seabird populations that nest on Kauaʻi (the last island with an absence of mongoose).[5] Technical potential profiles for existing solar plants were generated using SAM with site-specific configurations.

The resource adequacy (RA) multi-weather year analysis was performed with weather year data from 2014 and 2018. The 2014 weather year represented a year with low solar resource, and the 2018 weather year represented a year with low wind resource from the available 2000–2019 weather year data. Solar and wind weather-year-specific resource data were sourced from the Alt-1 scenario in the 2021 NREL technical potential report. For Kauaʻi, 2014 and 2018 solar weather year data were generated using the same approach used to generate technical potential profiles for new-build solar on Kauaʻi. Distributed solar 2014 and 2018 resource data were also generated with SAM, using data from the area on each island with the largest population and assuming a rooftop-mounted panel with a 20-degree tilt.

Appendix C-2 Results by Island

Island-Specific Results – Oʻahu

This appendix discusses the Oʻahu-specific electric sector modeling results.

New-Build Capacity Results

Figure C-1 presents the technologies and capacities procured by the Oʻahu capacity expansion model from 2030 to 2045. In 2030, the model principally procured solar, land-based wind, and storage. See the "Large-Scale versus Distributed Solar Capacity Expansion Results" section below for a discussion about the scale of solar technologies procured in the model. Starting in 2035, offshore wind becomes available, and the model procures between 262 MW (S2) and 347 MW (S1) of offshore wind. In 2040, the model procured incrementally more land-based wind, and significantly more solar and storage. Ultimately, in 2045, the model principally procures more solar, storage, and biomass, and the existing thermal fleet that remains in operation transitions from burning fossil fuels to biodiesel. When the thermal generation fleet transitions to burning biodiesel, the existing thermal units become more expensive to operate, and the biomass generation, which is also a dispatchable resource, becomes more cost-competitive. Oʻahu capacity expansion results meet resource adequacy industry standards (2.4 event-hr/8760) across all scenarios and weather years.

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[3] System Advisor Model Version 2022.11.29 (SAM 2022.11.21). National Renewable Energy Laboratory. Golden, CO.

[4] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company*. National Renewable Energy Laboratory.

[5] KIUC (2023) Save our Shearwaters

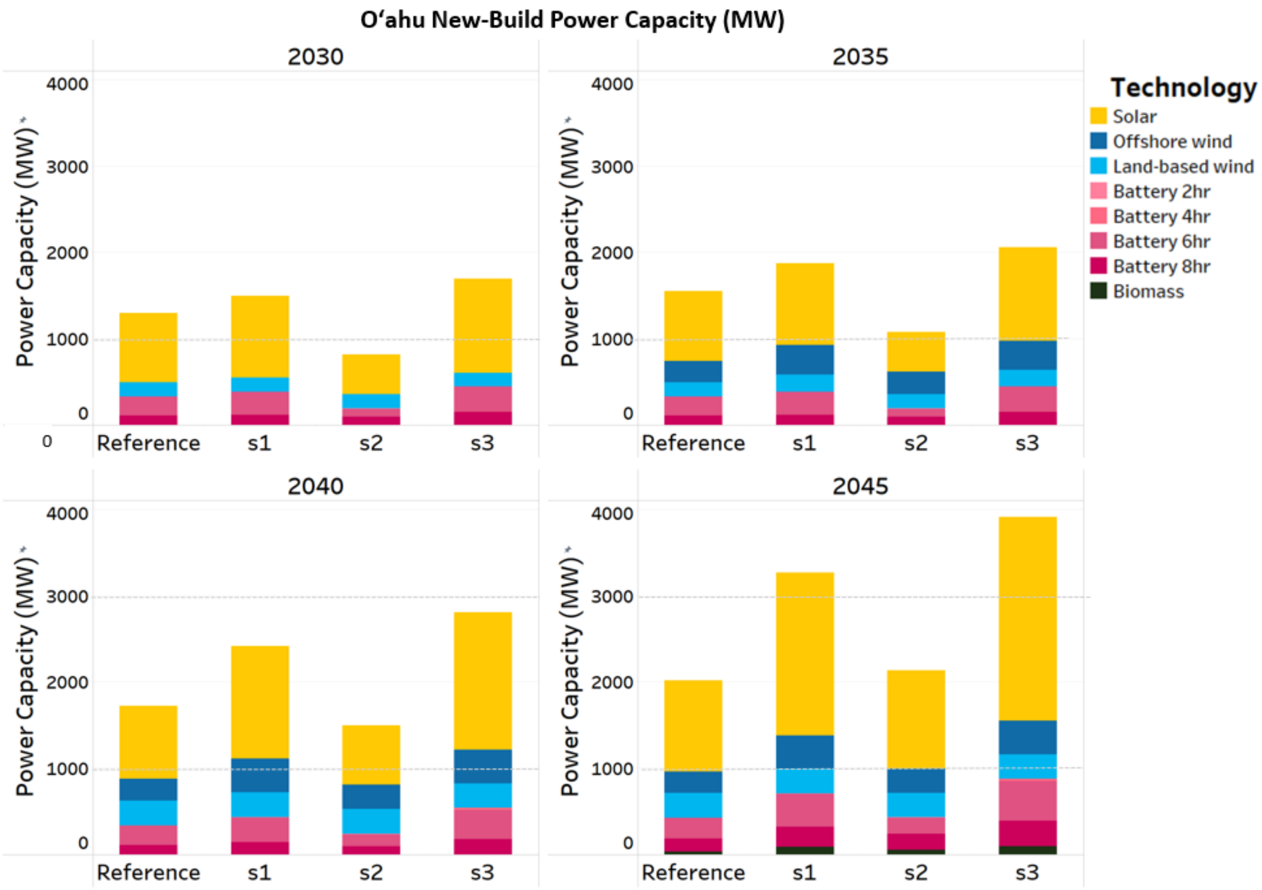

Figure C-1. Cumulative new capacity procured across all scenarios and simulation years.

The Oʻahu model selected a mix of solar, storage, land-based wind, offshore wind, and biomass generation technologies across all scenarios. The Reference scenario has the smallest amount of new capacity build-out by 2045, while S3 sees the largest amount of new capacity build-out by 2045. The greatest differences in capacity build-out across scenarios are in the solar and storage capacities, with S3 procuring 2,350 MW and 4,920 MWh of solar and storage capacity, respectively, and Reference procuring 1,050 MW and 2,630 MWh of solar and storage capacity, respectively, by 2045. All scenarios procure biomass as a flexible generation source in 2045 (37 MW in the Reference scenario and 98 MW in the S3 scenario).

Figure C-2 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and procured generation and storage on the system. Generation retired prior to each snapshot year does not appear in these capacities. The 2030 capacities represent the midterm system with the majority of the planned and programmed RFP and CBRE generation capacities installed. The 2045 system capacities represent the technology mix that achieves the 100% RPS for each scenario.

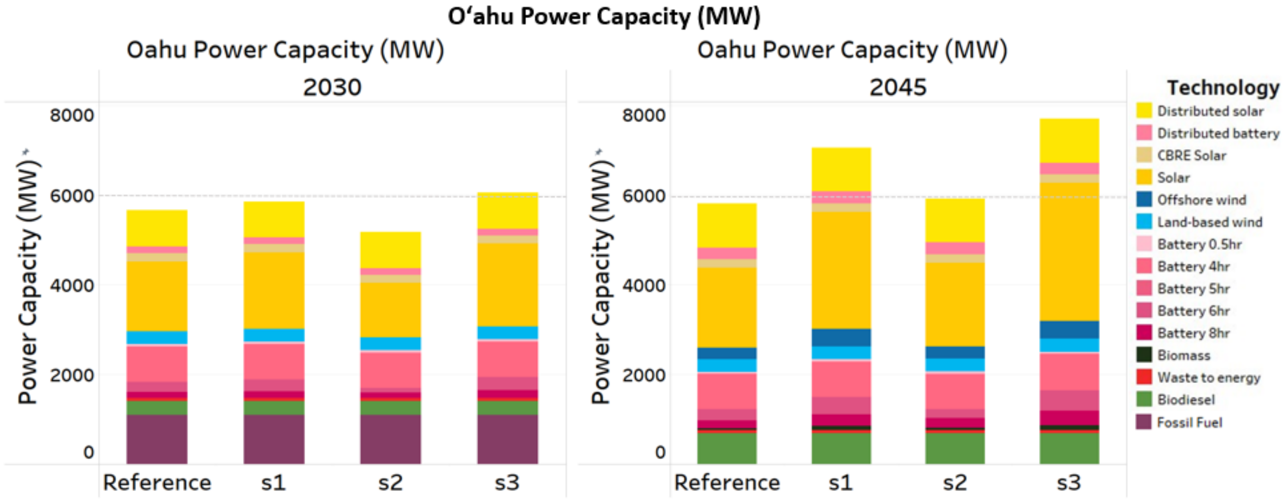

Figure C-2. O‘ahu total system capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Large-Scale Versus Distributed Solar Capacity Expansion Results

Distributed solar was represented in two ways in the model, both as a capacity expansion option and as a planned resource based on the customer adoption projections sourced from the Hawaiian Electric IGP Base scenario capacity expansion model inputs. The distributed solar referenced in Figure C-2 represents the projected customer adopted distributed solar. The “Solar” technology in the new-build capacity charts (Figure C-1) represents a mix of capacity expanded large-scale and distributed solar.

The capacity expansion solar technologies are not broken out by their respective large-scale and distributed solar breakdowns, as the model is likely underestimating the cost of the capacity expansion distributed solar option. The cost of capacity expansion distributed solar in the model represented a cost to procure the solar component of a paired solar rooftop and storage system, while the cost of distributed storage represented the cost to procure the storage component of a paired rooftop solar and storage system. Paired solar and storage systems can be less expensive than the sum of the costs of standalone solar and storage systems of equivalent capacities. However, while the model did procure the rooftop solar technology component, the model did not procure any capacity of the distributed storage component. The model did not procure the distributed storage capacity expansion option, as the distributed solar in the model could send electricity to the grid to charge the less-expensive, large-scale storage. Without representing the combined cost of procuring distributed storage with the distributed solar, the model likely underrepresents the cost to build distributed solar.

A deeper analysis of distributed solar costs is needed to assess the cost-competitiveness of large-scale solar versus distributed solar and present a projection of procurement capacity breakdown between the two technology types. Beyond cost considerations, future work should consider how evolving land use constraints may contribute to the feasibility of distributed solar and storage versus large-scale generation. For example, the Hawaiian Electric IGP report[6] explored scenarios with land use limitations that led to distributed solar and storage procurement in 2045 and 2050. Likewise, for the system to utilize distributed solar production at high penetration levels with minimal curtailment, distribution system upgrades, distributed storage, and/or advanced operation of the distribution system are needed, so future studies should consider the cost and production tradeoffs among diminishing production from incremental distributed solar deployment, distribution system upgrade costs, advanced distribution system operation, and distributed storage costs. Whether through utility procurement or customer-side adoption, distributed solar and storage will play an important role in meeting Hawaiʻi's decarbonization goals and associated electricity demands and warrants further future study.

Offshore Wind

By 2045, all scenarios selected between 250 and 390 MW of offshore wind capacity.[7] The majority of this capacity is procured in 2035, when the cost inputs still reflect pre-IRA ITC incentives. After 2035, the model only procures incrementally more offshore wind, in part due to the input cost assumption that the ITC incentives will phase out for offshore wind after 2035, making the technology less cost-competitive in later years than in 2035. As shown in Figure C-3, offshore wind contributes a large portion (~15%) of the total Oʻahu generation once procured in 2035. Offshore wind adds value to the renewable mix by supporting the system's need for generation during the night and cloudy hours when solar cannot generate additional electricity.

Because this modeling effort and the Hawaiian Electric IGP[8] present offshore wind as a significant contributor to Oʻahu generation, future work should consider a more detailed cost and technical potential analysis. Additionally, the cost and technical potential data used in this study (and in the Hawaiian Electric IGP report) were generated using preliminary and simplified assumptions and should be refined for more accurate offshore wind technology representation moving forward.

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[6] Hawaiian Electric 2023. Integrated Grid Plan (full report).

[7] The offshore wind technology costs represent the costs to procure a 400MW sized wind plant, which was likely the minimum size for an offshore wind plant to be financially viable under current market conditions.

[8] Hawaiian Electric 2023. Integrated Grid Plan (full report).

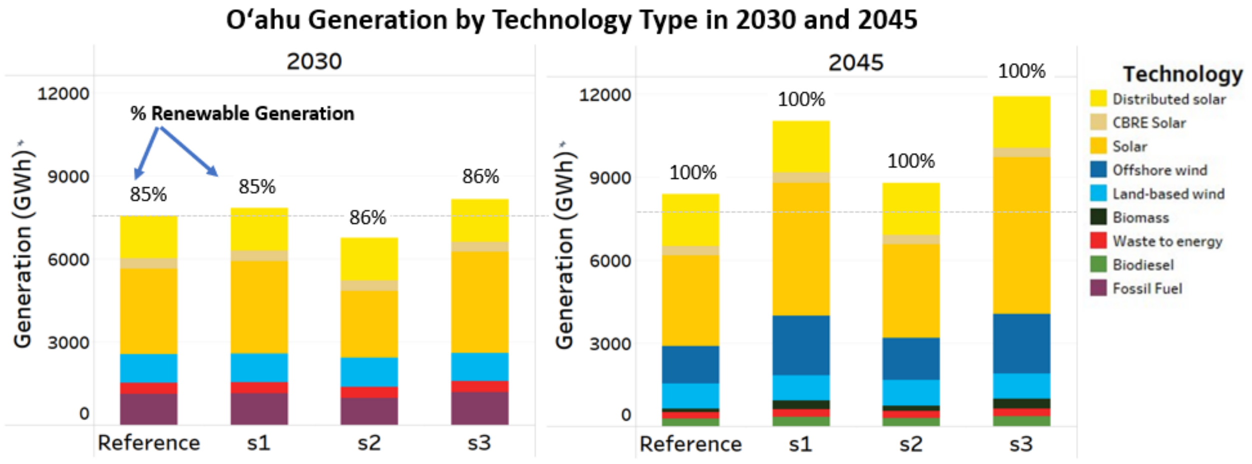

Figure C-3. Oʻahu electricity generation by technology type in 2030 and 2045.

Land-Based Wind

New-build land-based wind on Oʻahu has a relatively high average capacity factor (0.46) as compared to new-build solar options (0.24 average capacity factor) on Oʻahu. Additionally, like offshore wind, land-based wind often generates electricity during hours when solar cannot generate electricity (during the night and cloudy days). Due to the relatively high average capacity factor, competitive cost, and ability to provide generation during times when the sun is not shining, the model elects to build the maximum amount of land-based wind capacity available on Oʻahu across all scenarios. As existing wind plant PPA contracts retire, the model chooses to renew them. Historically, some land-based wind plants have been subject to community opposition on Oʻahu. Future land-based wind development should align with the equitable procurement practices described in Chapter 1.

Land-Use Impacts

Table C-2 details the total land available for solar and wind development on Oʻahu as defined in the Alt-1 scenarios of the 2021 NREL solar and wind technical potential report.[9] The land use availability presented in this chart and the land impact results presented in Table C-2 were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report (Grue et al., 2021).[10]

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[9] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[10] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

Table C-2. Total technically feasible land on Oʻahu for land-based wind and solar generation facilities.

Oʻahu Total Land Area (acres)	Total Technically Feasible Land(acres)	
	Solar	Wind
383,000	24,700	13,400[11]

Table C-3 presents the estimated percent of technically feasible land required for planned and model-selected capacities of solar and land-based wind in each scenario by 2045. The percentages of technically feasible land use results in Table C-3 incorporate the planned and targeted stage two and three RFP capacities as well as the planned and targeted phase two Tranche 1 and LMI CBRE selected project capacities. The land use impacts associated with each scenario directly correlate with the final 2045 gigawatt-hour demands for each scenario — as shown in Table C-3, the greatest land use impacts are associated with S3, the scenario with the highest 2045 gigawatt-hour demands, while the smallest land use impacts are associated with the Reference scenarios, the scenario with the lowest 2045 gigawatt-hour demands. In S3, the new and planned solar build-outs use up to 86% of land available for solar development, while in the Reference scenario, the new-build capacity expansion results and planned solar build-outs use up to 52% of land available for solar development. These results represent the estimated land use impacts if all capacity expansion solar procured by the model is large-scale solar. These land use impacts do not include any impacts associated with the distributed solar customer adoption forecasts.

Table C-3. Percent of technically feasible land on Oʻahu estimated for planned and selected capacities of solar and land-based wind in each scenario by 2045.

Scenario	Solar & Wind Breakdown	Technically Feasible Land Used (%)	Oʻahu Annual Demand in 2045 (GWh)
Reference Estimated Land Use	Solar	52	7,670
	Wind	100	
S1 Total Estimated Land Use	Solar	74	10,000
	Wind	100	
S2 Total Estimated Land Use	Solar	54	8,090
	Wind	100	
S3 Total Estimated Land Use	**Solar**	86	**10,800**
	Wind	100	

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[11] The Alt-1 scenarios developed by Grue et al. (2021) did not exclude land with existing land-based wind developments from the total developable land capacity value. The developable land area for land-based wind referenced in this table is smaller than the value provided in Alt-1 scenarios to reflect only the remaining undeveloped land-based wind area.

and show the solar and wind land use impacts separately because the technically feasible land for solar and wind have a significant degree of overlap. This overlapping land availability indicates that new solar and wind facilities may share the same land areas, and total land use findings for solar and wind may not be a one-to-one sum of acres needed for solar and acres needed for land-based wind. This study did not include a site-specific capacity expansion analysis of solar or wind build-out. For a more detailed description of the renewable zones included in this study, refer to the Hawaiian Electric IGP report.[12]

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Oʻahu model indicates that the most cost-effective resource portfolios generate more electricity from renewables than required by the RPS. Figure C-4 shows all scenarios achieve > 80% renewable generation by 2030 and >90% renewable generation by 2040. This result indicates that building and operating renewable resources and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045. All scenarios experience a slight decrease in the proportions of renewable energy generation between 2035 and 2040. This decrease occurs because the model finds running a slightly larger proportion of fossil fuels more cost-effective than procuring additional storage to meet the growing demand during time periods with low variable renewable generation.

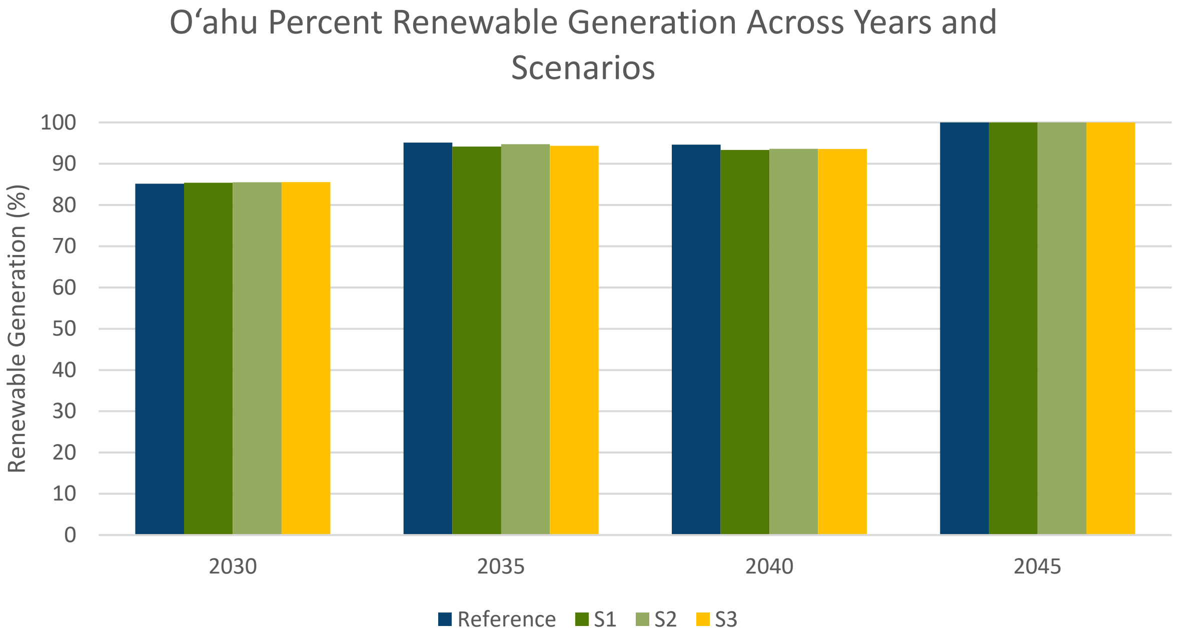

Figure C-4. Oʻahu percent renewable generation across year across scenarios.

Figure C-5, Figure C-6, and Figure C-7 show the relative electric sector total costs, total demands, and unit cost of electricity across all simulation years and scenarios. The total costs

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[12] Hawaiian Electric 2023. Integrated Grid Plan (full report).

presented in Figure C-5 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the Electric Power, Statewide Electric Sector Results (Chapter 4, Section 4.6), these costs only represent the costs associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit cost of electricity in Figure C-7 provides a basis for comparison of the unit cost of electricity supply, not a utility rate.

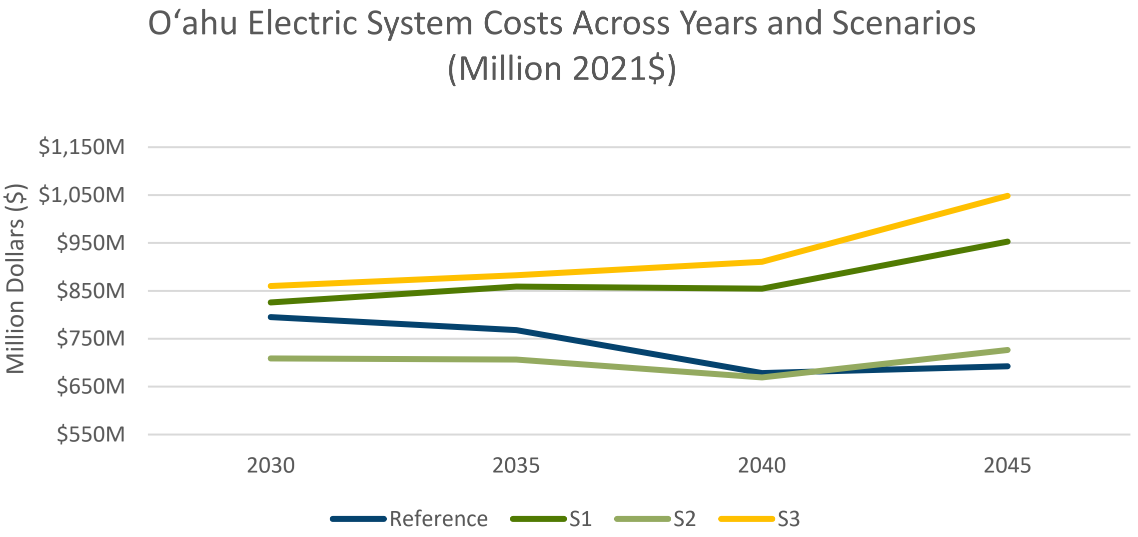

Figure C-5. O‘ahu annual electricity supply costs across model simulation years and scenarios (in million 2021$).

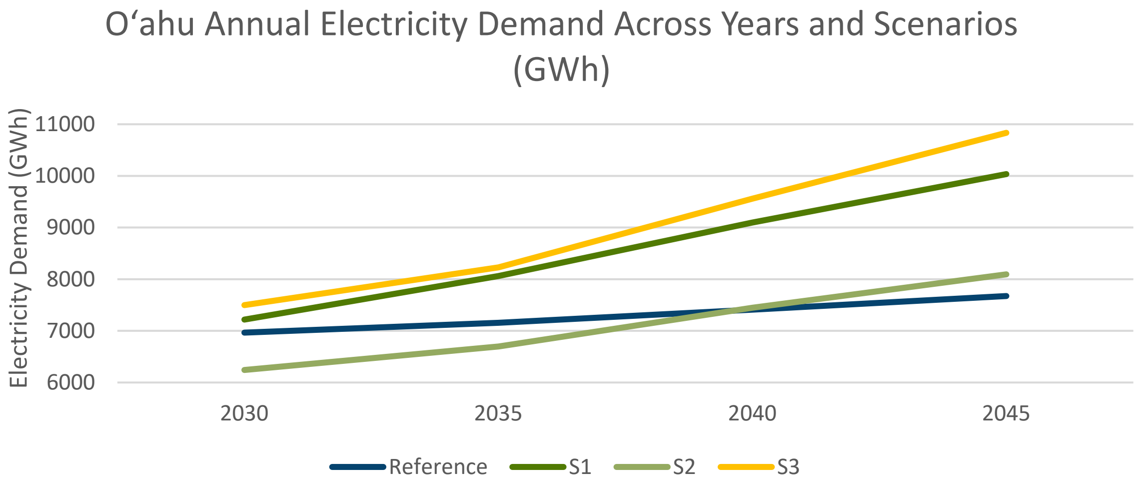

Figure C-6. O‘ahu annual electricity demands (GWh) across scenarios and years.

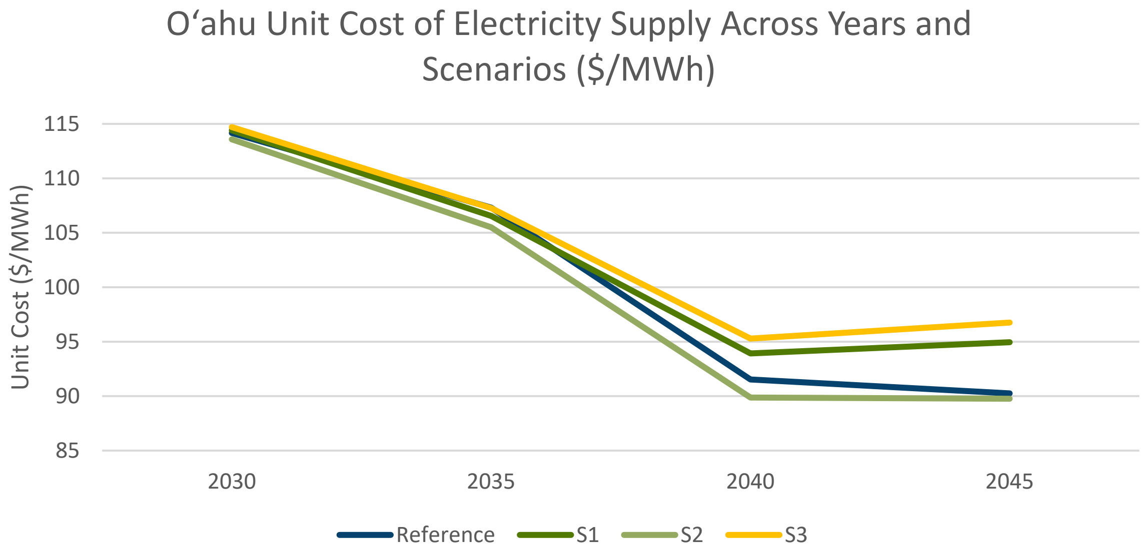

Figure C-7. O‘ahu unit cost of electricity supply ($/MWh) across years and scenarios.

Figure C-5 shows that the annual electricity supply costs for scenarios S1 and S3 grow from 2030 to 2040, while the Reference and S2 costs decline during this period. However, due to the increasing demands, Figure C-7 demonstrates that the unit cost of electricity ($/MWh) declines over the 2030–2040 period. By 2045, the unit cost of electricity reductions realized between 2030 and 2040 have slowed for the Reference and S2 scenarios, while the unit cost of electricity has increased slightly for the S1 and S3 scenarios. This slowing or reversing of the unit cost of electricity reductions between 2040 and 2045 demonstrates the costliness to transition from a system operating with 93-95% to a system operating with 100% renewable geneation.

In this analysis, the relative costliness to achieve 100% renewable generation as compared to 93–95% renewable generation is largely due to the need to transition to the more expensive dispatchable renewable generation options in order to reach 100% renewable energy generation. On O‘ahu, these options include biodiesel and biomass generation. When the model transitions the remaining fossil fuel generating units from relatively less expensive fossil fuels to biodiesel, it builds new generation to meet the increased load, Figure C-8, while occasionally running the converted, biofuel generating units. Although a kilowatt-hour of electricity from biofuel generators is expensive relative to solar and storage generators, the model finds that these dispatchable technologies are more cost effective than achieving the same level of dispatchability with additional variable renewable energy and storage.[13] The technology types that will be available and the technology cost reductions that will be achieved

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[13] The capacity expansion model only represented the hourly needs of the system. In systems with high penetrations of variable renewable generation resources, the needs for intra-hour flexibility would be even greater than the needs for hourly flexibility. Engage does not represent the intra-hourly needs of the system or sub-hourly dispatch costs.

by 2045 are highly uncertain, and the technology types and costs used in this study should be reevaluated over time.

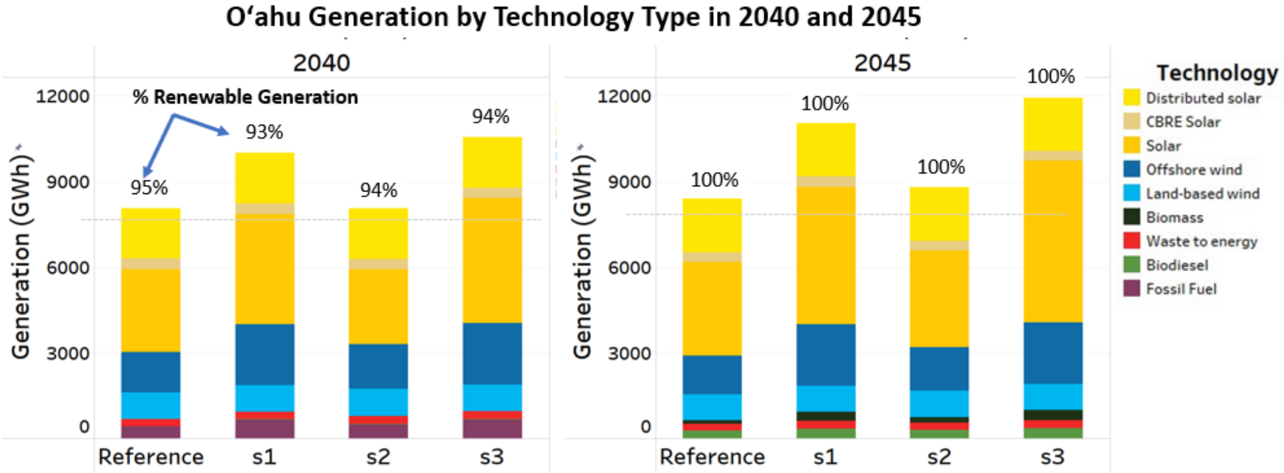

Figure C-8. O‘ahu generation (GWh) by technology type across scenarios to achieve 100% RPS in 2045 from 93-95% RPS in 2040.

Island-Specific Results – Maui

This section discusses the Maui-specific electric sector modeling results.

New-Build Capacity Results

Figure C-9 presents the cumulative new-build capacity results from the capacity expansion analysis. The model procures new land-based wind in each year, with the exception of S2 in 2030. The model also procures additional solar resources between 2035 and 2045, again with the exception of S2 in 2035. Ultimately, in 2045, the model procures storage and additional biodiesel capacity to meet the 100% renewable generation requirement. From 2030 to 2040, the model procures 20–50 MW, relatively little new solar and wind in each snapshot year but jumps to procuring 2 times as much generation and storage capacity between 2040 and 2045. The system does not find a need to procure large quantities of new generation in early years, as the planned procurements prior to 2030 are sufficient to meet the load, Figure C-10. Maui capacity expansion results meet resource adequacy industry standards (2.4 event-hr/8760) across all scenarios and weather years.

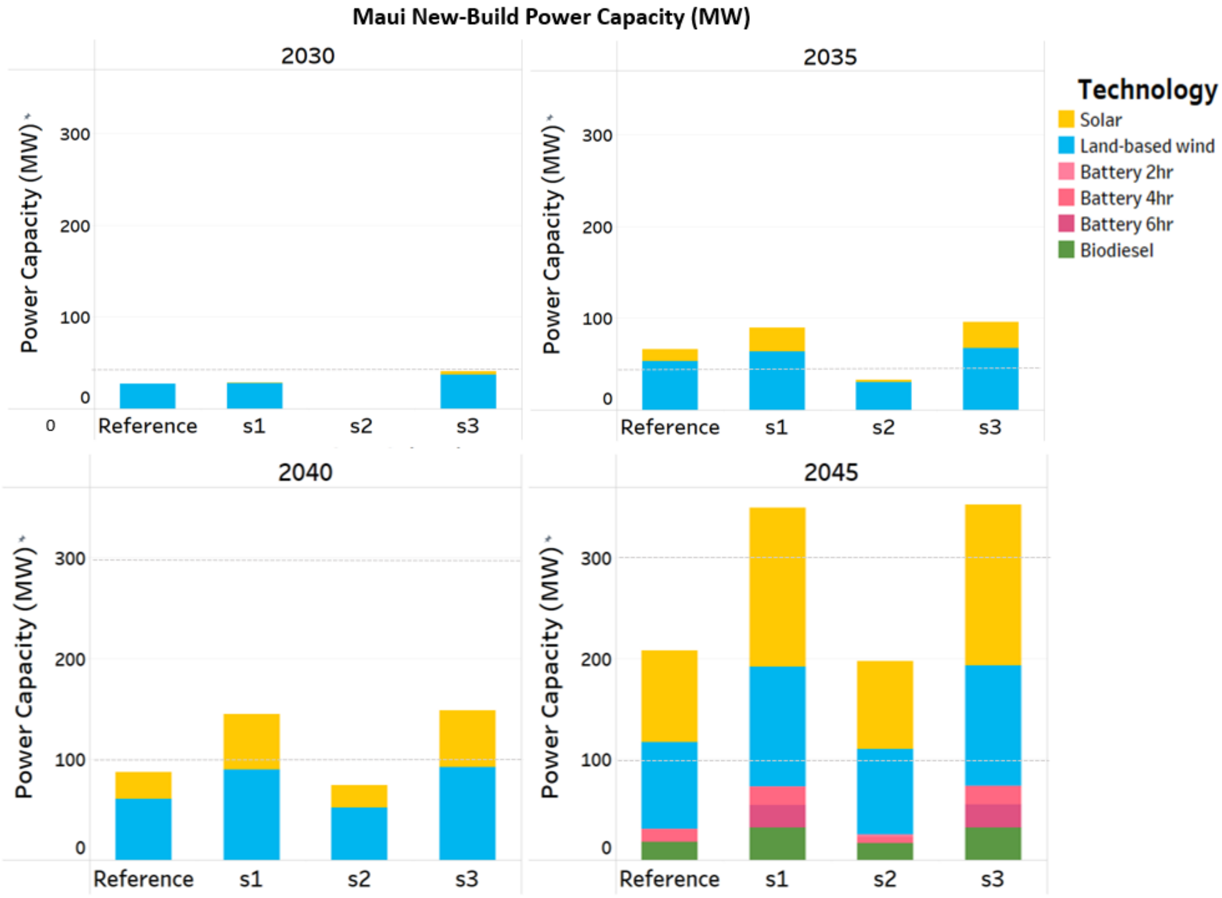

Figure C-9. Maui cumulative new capacity procured across all scenarios and simulation years.

Figure C-10 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and model procured generation and storage on the system. Generation retired prior to each snapshot year does not appear in these capacities. The 2030 capacities represent the midterm system with most of the planned and programmed RFP and CBRE generation capacities installed. The 2045 system capacities represent the technology mix that achieves the 100% RPS for each scenario. The Maui planned procurements across RFP and CBRE projects add 1,480 MWh of battery energy storage prior to 2030. Due to these large additions of storage prior to the model run years, the model does not find building additional storage necessary until 2045. Additionally, the model procures new biodiesel generation in 2045, in addition to the conversion of the remaining fossil generation units.

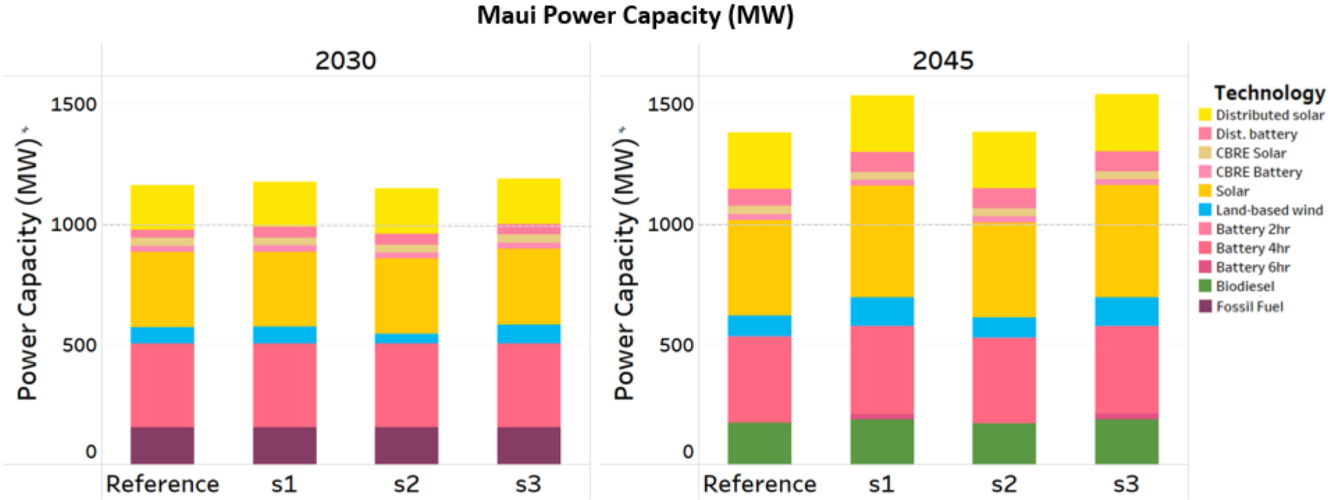

Figure C-10. Maui total system capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Land Use Impacts

Table C-4 outlines the total land available for solar and wind development on Maui as defined in the Alt-1 scenarios of the 2021 NREL solar and wind technical potential report (Grue et al., 2021). The land use availability and results were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report (Grue et al., 2021).[14]

Table C-4. Total technically feasible land on Maui for land-based wind and solar generation facilities.

Maui Total Land Area (acres)	**Total Technically Feasible Land[15] (acres)**	
	Solar	Wind
465,000	89,000	63,300[16]

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[14] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[15] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

The Alt-1 scenarios developed by Grue et al. (2021) did not exclude land with existing land-based wind developments from the total developable land capacity value. The developable land area for land-based wind referenced in this table is smaller than the value provided in Alt-1 scenarios to reflect only the remaining undeveloped land-based wind area. Table C-5 presents the percent of technically feasible land required for planned and model-selected capacities of solar and land-based wind in each scenario by 2045. The percent of technically feasible land use results in Table C-5 include the planned and targeted capacities in the stage two and three RFP as well as the implemented and targeted CBRE. The land use impacts do not vary dramatically across scenarios. The estimated land use impacts fall within 3.5–4% for solar and within 11–16% for wind across scenarios.

Table C-5. Percent of technically feasible land on Maui estimated for planned and selected capacities of solar and land-based wind in each scenario by 2045.

Scenario	Solar & Wind Breakdown	Technically Feasible Land Used (%)	Maui Annual Demand in 2045 (GWh)
Reference Land Use	Solar	3.5	1,350
	Wind	11	
S1 Total Land Use	Solar	4.0	1,570
	Wind	15	
S2 Total Land Use	Solar	3.5	1,340
	Wind	11	
S3 Total Land Use	Solar	4.0	1,580
	Wind	16	

and show the solar and land-based wind land use impacts separately because the technically feasible land for solar and wind have a significant degree of overlap. This overlapping land availability indicates that new solar and land-based wind facilities may share the same land areas, and total land use findings for solar and wind may not be a one-to-one sum of acres needed for solar and acres needed for land-based wind. This study did not include a site-specific capacity expansion analysis of solar or wind build-out. For a more detailed description of the renewable zones included in this study, refer to the Hawaiian Electric IGP report.[17]

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Maui model finds that the most cost-effective resource portfolios generate more electricity from renewables than outlined in the RPS. These results

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[17] Hawaiian Electric 2023. Integrated Grid Plan (full report). https://hawaiipowered.com/igpreport/03_IGP-Report.pdf

indicate that building and operating renewable resources and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045. Figure C-11 shows all scenarios achieve more than 93% renewable generation by 2030. The percent renewable generation declines between 2030 and 2035 as the load grows with minimal new renewable procurement. During this period, the model finds that meeting a slightly larger proportion of the load with fossil fuels is more cost-effective than procuring additional generation and storage to meet demand during periods of low variable renewable generation.

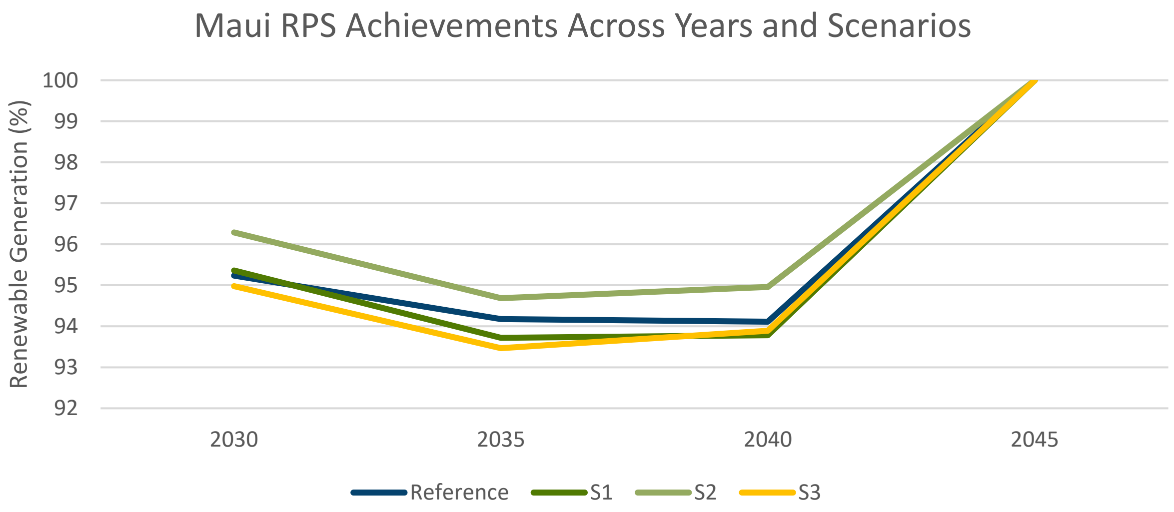

Figure C-11. Maui percent renewable generation across years and scenarios.

Figure C-12, Figure C-13, and Figure C-14 show the electric sector electricity supply costs, total demands, and unit cost of electricity supply per megawatt-hour across all simulation years and scenarios. The total costs presented in Figure C-12 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the Electric Power, Statewide Electric Sector Results (Chapter 4.6), these costs only represent the costs associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit cost of electricity supply in Figure C-14 provides a basis for comparison of the relative cost of energy, not a utility rate.

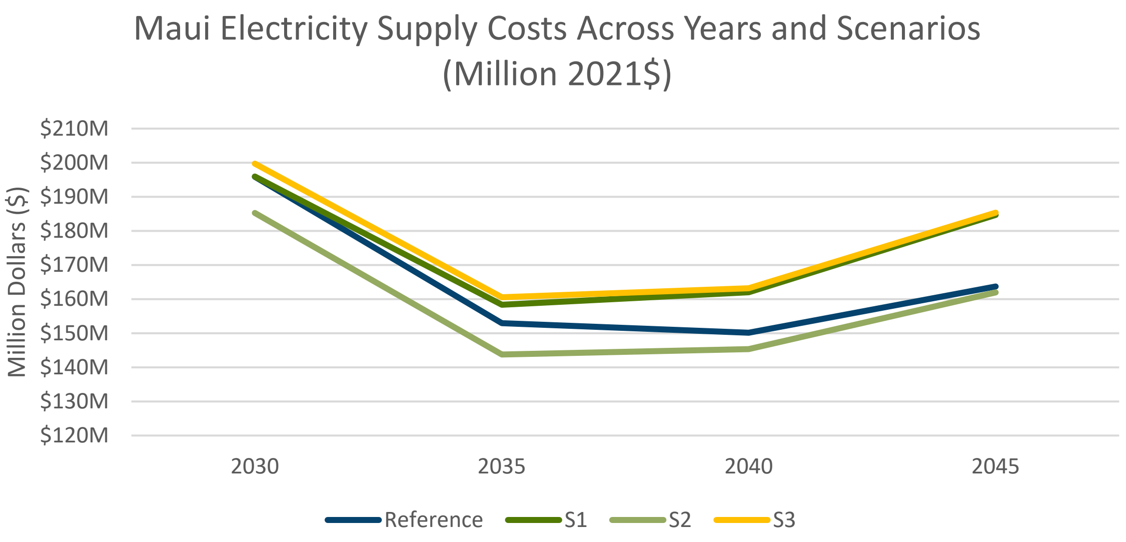

Figure C-12. Maui annual electricity supply costs across model simulation years and scenarios (in million 2021$).

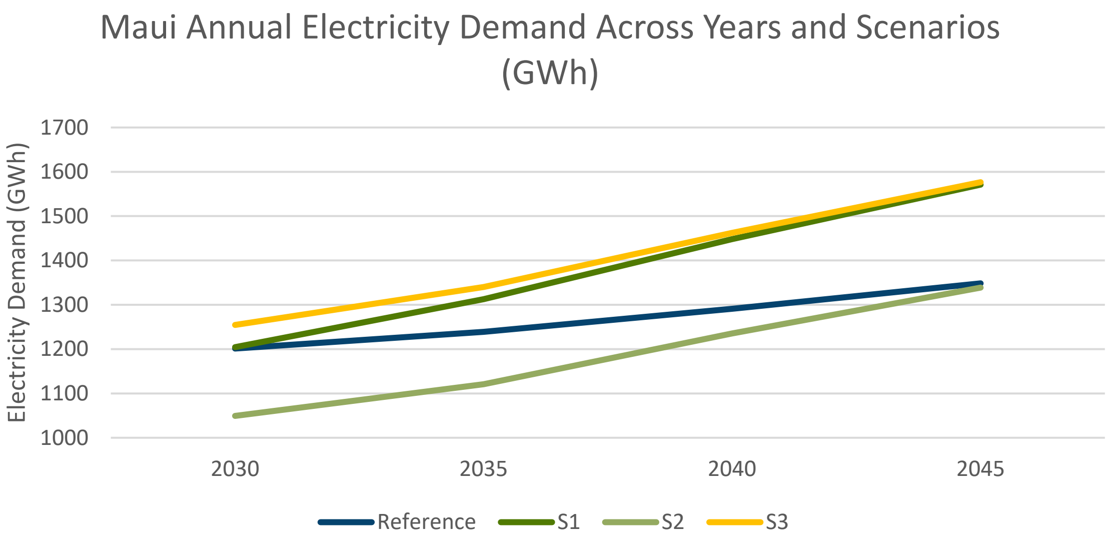

Figure C-13. Maui annual electricity demands (GWh) across scenarios and years.

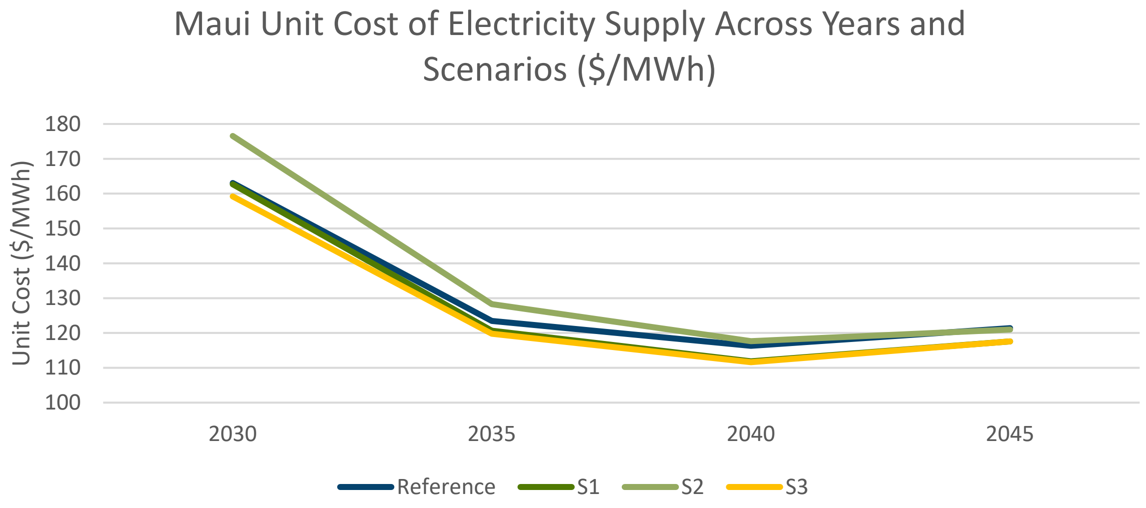

Figure C-14. Maui unit cost of electricity supply ($/MWh) across years and scenarios.

Figure C-12, Figure C-13, and Figure C-14 present the system costs and demands in model simulation years from 2030 to 2045. Figure C-12 shows total system costs declining between 2030 and 2035, largely due to the expiration of two wind PPA contracts, and new capacity being built at lower cost. Average electricity supply costs per megawatt-hour of generation decline through 2040, but experience a slight uptick in 2045. This increase in the unit cost of electricity between 2040 and 2045 is because of the costliness to transition from a system operating with 94% renewable generation to a system operating with 100% renewable geneation.

In this model, the relative costliness to achieve 100% renewable generation as compared to 95-96% renewable generation is primarily due to the transition to the more expensive renewable fuel source, biodiesel. When the model transitions remaining fossil fuel generating units from relatively less expensive fossil fuels to biodiesel, it builds new generation to meet the increased load (Figure C-15) while occasionally running the converted, biofuel generating units. Although a kilowatt-hour of electricity from biofuel generators is expensive relative to solar and storage generators, the model finds that these dispatchable technologies are more cost effective than achieving the same level of dispatchability with additional variable renewable energy and storage.[18] The technology types that will be available and the technology cost reductions that will be achieved by 2045 highly uncertain, and the technology types and costs used in this study should be reevaluated over time.

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[18] The capacity expansion model only represented the hourly needs of the system. In systems with high penetrations of variable renewable generation resources, the needs for intra-hour flexibility would be even greater than the needs for hourly flexibility. Engage does not represent the intra-hourly needs of the system or sub-hourly dispatch costs.

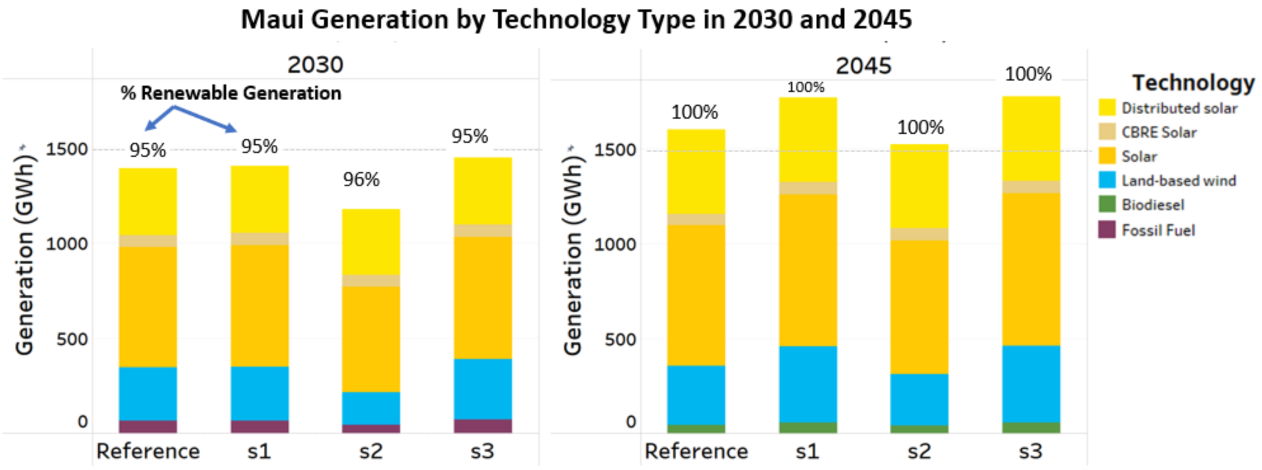

Figure C-15. Maui generation (GWh) by technology type across scenarios to achieve 95-96% renewable generation in 2030 and 100% in 2045.

Island-Specific Results – Hawaiʻi Island

This section discusses the Hawaii-specific electric sector modeling results.

New-Build Capacity Results

Figure C-16 presents the cumulative technologies and capacities procured by the Hawaiʻi capacity expansion model from 2030 to 2045. Across all scenarios, the model procures a mix of land-based wind, solar, and geothermal resources. All scenarios procure most of their new-build capacity from land-based wind as land-based wind is the most cost-effective technology, particularly prior to 2040. The Reference and S1 scenarios begin procuring geothermal by 2040, while the S1 and S3 scenarios begin procuring geothermal as early as 2035.

In scenarios S1 and S3, the capacity expansion model results did not meet resource adequacy industry standards (2.4 event-hr/8760) in the low solar (2018) weather year. The resource adequacy firm capacity analysis found that the S1 and S3 2040 capacity expansion systems needed an additional 4 MW of firm capacity in order to meet the 2.4 event-hr/8760 target under unplanned outage events and low solar resource weather years. The technology types that will be available to provide firm, dispatchable capacity in 2040 are uncertain, and this firm capacity need could likely be substituted for geothermal or other cost-effective dispatchable technologies.

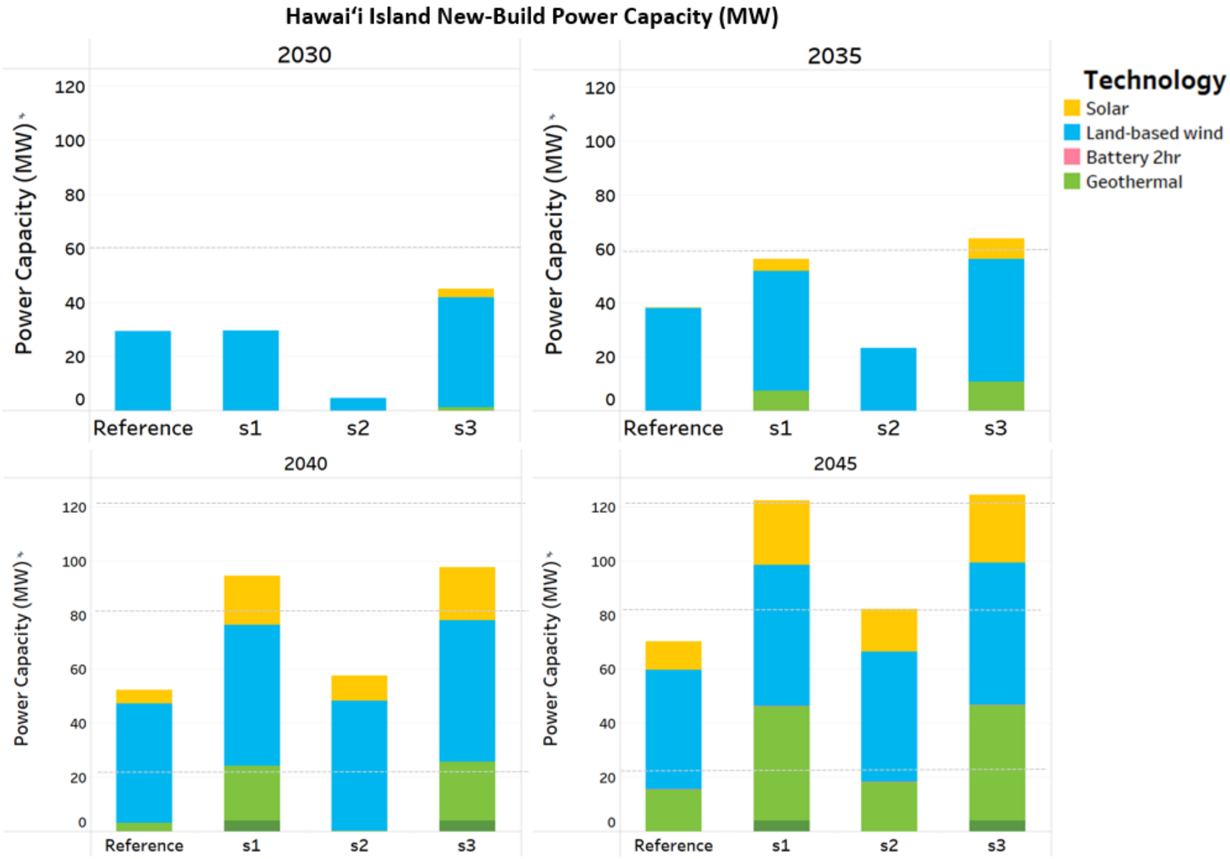

Figure C-16. Hawaiʻi Island cumulative new capacity procured across all scenarios and simulation years.

Figure C-17 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and procured generation and storage on the system. Generation retired prior to each snapshot year do not appear in these capacities. The 2030 capacities represent a midterm system with the majority of the planned and programmed RFP and CBRE generation capacities installed. The 2045 system capacities represent the technology mix that achieves a 100% RPS for each scenario. In 2045, all fossil fuel generation that is not scheduled to retire transitions to running on biodiesel.

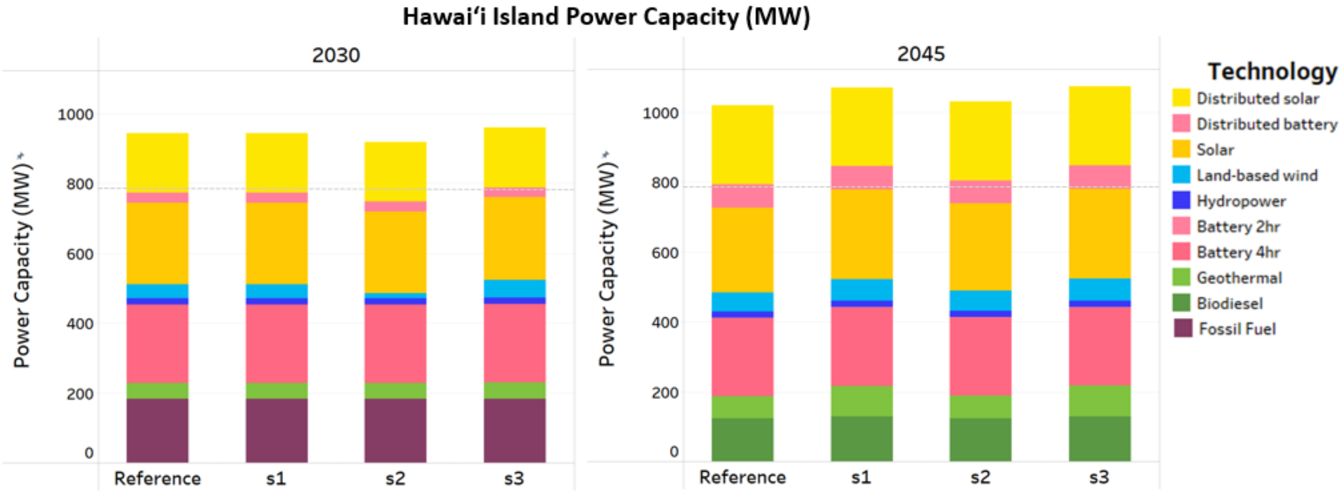

Figure C-17. Hawaiʻi Island total system capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Land-Based Wind

Across all scenarios, the Hawaiʻi Island model procures a significant amount of wind. The greatest wind resource potential in Hawaiʻi Island is highly concentrated at three different areas around the island: the northernmost point, the southernmost point, and a mid-way point along the southern coast.[19] Aside from these three areas of high technical potential, the rest of the island has a relatively low wind resource potential. The wind resource in the Hawaiʻi Island model represents these areas with high wind resource potential.

Land Use Impacts

Table C-6 outlines the total land available for solar and wind development on Hawaiʻi Island as defined in the Alt-1 scenarios of the 2021 NREL solar and wind technical potential report (Grue et al., 2021). The land use availability and results were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report (Grue et al., 2021).[20]

Table C-6. Total technically feasible land on Hawaiʻi Island for land-based wind and solar generation facilities.

Hawaiʻi Island Total Land Area (acres)	Total Technically Feasible Land[21] (acres)	
	Solar	Wind
2,580,000	495,000	415,000

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[19] AWS True Wind (2019) Wind Power Density of Hawaii Island at 50 Meters

[20] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[21] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

Table C-7 presents the percent of technically feasible land required for planned and model selected capacities of solar and land-based wind in each scenario by 2045. The percent of technically feasible land use results in Table C-7 include the planned and targeted stage two and three RFP capacities as well as the planned and targeted phase one and two CBRE capacities. All scenarios estimate solar and land-based wind development to require less than or equal to 0.34% and 1% of technically feasible land, respectively. Scenarios S3 and S1 see the highest electricity demands, and thus require the largest build-out of renewables and associated land impacts.

Table C-7. Hawaiʻi Island estimated percent of technically feasible land required for planned and selected capacities of solar and land-based wind in each scenario by 2045.

Scenario	Solar & Wind Breakdown	Technically Feasible Land Used (%)[22]	Hawaiʻi Annual Demand in 2045 (GWh)
Reference Land Use	Solar	0.32	1,420
	Wind	0.87	
S1 Total Land Use	Solar	0.34	1,690
	Wind	1.0	
S2 Total Land Use	Solar	0.33	1,460
	Wind	0.95	
S3 Total Land Use	Solar	0.34	1,690
	Wind	1.0	

Table C-6 and Table C-7 show the solar and wind land use impacts separately because the technically feasible land for solar and wind have a degree of overlap. This overlapping land availability indicates that new solar and wind facilities may share the same land areas, and total land use findings for solar and wind may not be a one-to-one sum of acres needed for solar and acres needed for land-based wind. This study did not include a site-specific capacity expansion analysis of solar or wind build-out. For a more detailed description of the renewable zones included in this study, refer to the Hawaiian Electric IGP report.[23]

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[22] To represent the upper end of potential solar land use impacts, the percent of available land used for solar values assumes all new-build solar capacity selected by the model is large-scale solar.

[23] Hawaiian Electric 2023. Integrated Grid Plan (full report).

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Hawaiʻi Island model finds that the most cost-effective resource portfolios lead to greater proportions of renewable energy generation than outlined in the RPS requirements. Figure C-18 shows all scenarios achieve more than 98% renewable generation between 2030 and 2040. This result indicates that building and operating renewable resources and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045. All scenarios see a slight decrease in the proportions of renewable energy generation between 2035 and 2040. This decrease occurs because the model finds that running a slightly larger proportion of fossil fuels is more cost-effective than procuring additional storage to meet demand during select periods of low variable renewable generation.

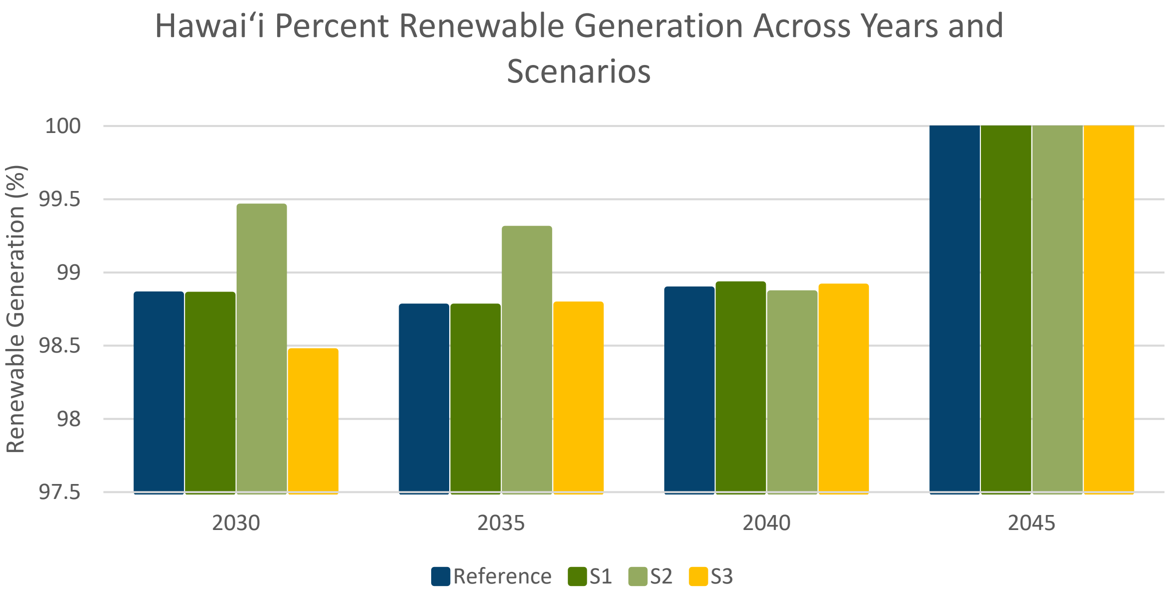

Figure C-18. Hawaiʻi Island percent renewable generation across yeas and scenarios.

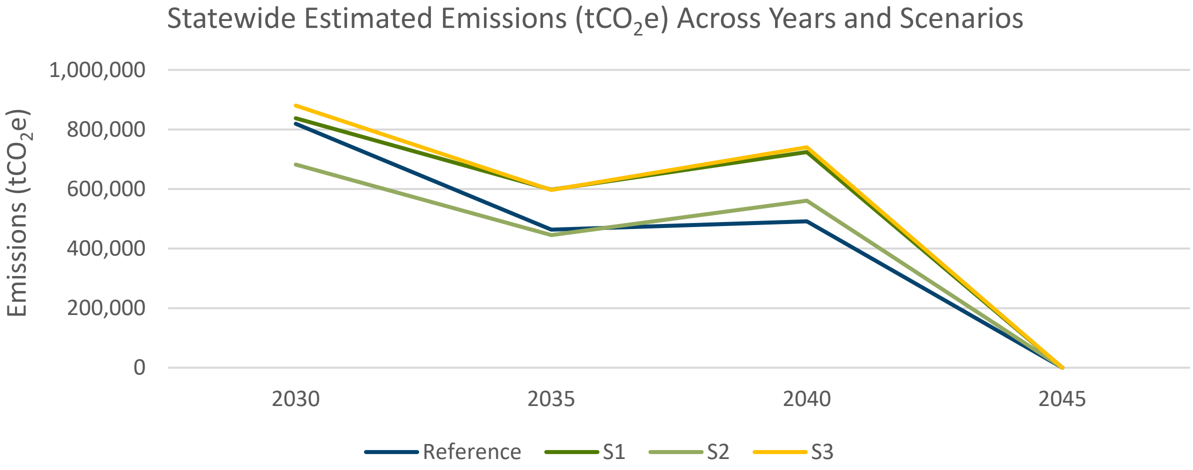

Figure 1. Statewide estimated metric tons of CO2e emissions.

Figure C-19, Figure C-20, and Figure C-21 show the electric sector electricity supply costs, total demands, and unit cost of electricity supply per megawatt-hour across all simulation years and scenarios. The total costs presented in Figure 36 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the Statewide Electric Sector Results section, these costs only represent the costs associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit cost of electricity supply in Figure C-21 provides a basis for comparison of the relative cost of energy, not a utility rate.

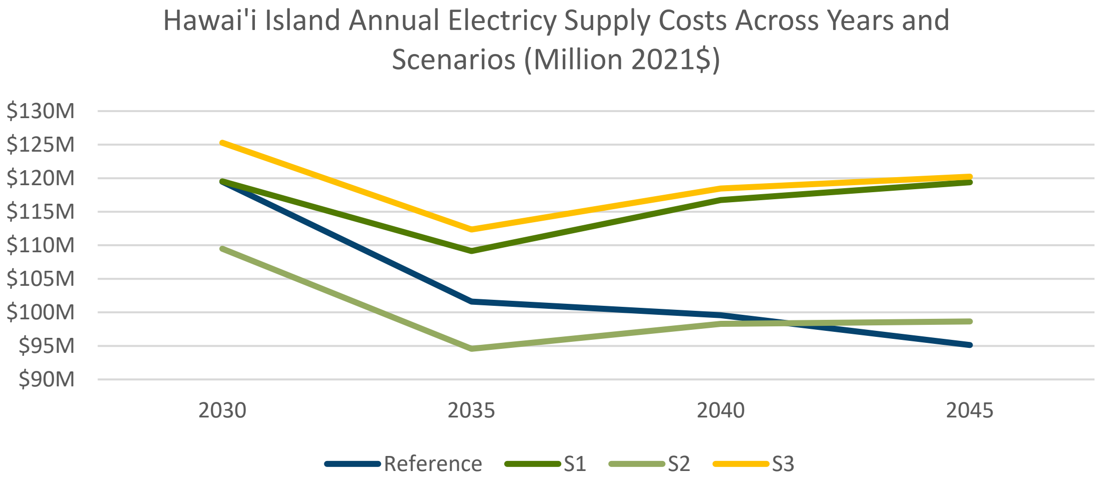

Figure C-19. Hawaiʻi Island annual electricity supply costs across model simulation years and scenarios (in million 2021$).

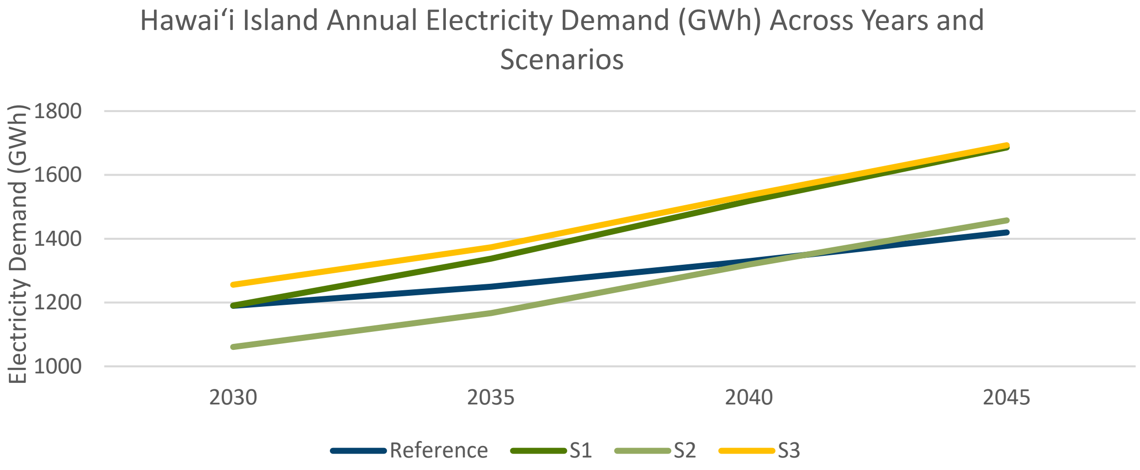

Figure C-20. Hawai‘i Island annual electricity demands (GWh) across scenarios and years.

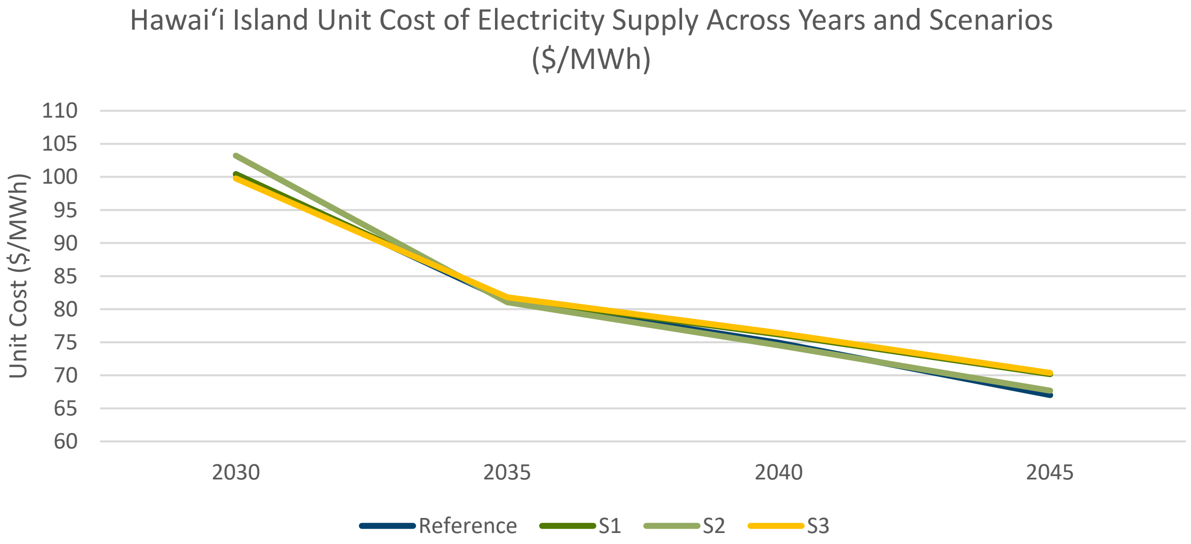

Figure C-21. Hawai‘i Island unit cost of electricity supply ($/MWh) across years and scenarios.

Figure C-19 presents the total system costs across simulation years. Total system costs largely represent the fixed costs associated with the existing utility-owned genertion fleet and the PPA costs associated with renewable energy generation. The system costs decrease from 2030 to 2035 primarily because the Hamakua fossil fuel plant is scheduled to retire, and the fixed costs associated with that generator are removed from the total costs. S1, S2, and S3 costs grow between 2035 and 2040 as the model procures greater proportions of renewable energy generation, while the Reference scenario cost continues to decline from 2034 to 2045. Reference scenario costs decline because small procurements of new renewable generation do not outwiegh the fossil fuel costs that are displaced by that new renewable generation.

Figure C-21 shows the unit cost of electricity supply decreasing across all years. Maui and Oʻahu largely see average electricity supply prices either stabilize or grow between 2040 and 2045; however, Hawaiʻi Island unit costs slow while still continuing to decline. The primary reason these costs continue to decline is because the geothermal technology in 2045 is relatively less expensive in meeting the system's dispatchable generation needs than biofuel generation. Figure C-22 illustrates how the Hawaiʻi Island model generates a small proportion of total generation from biofuel generation in 2045 (e.g., 0.5% in S1), while geothermal acts as baseload, generating 28% (in S1) of 2045 generation. The technology types that will be available and the technology cost reductions that will be achieved by 2045 are highly uncertain, so costs used in this study should be reevaluated over time.

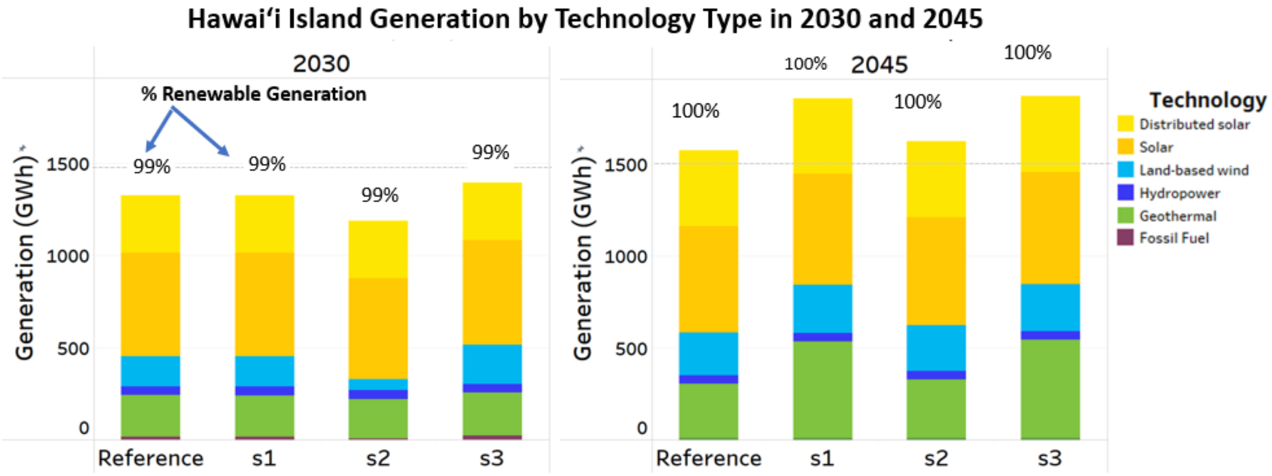

Figure C-22. Hawaiʻi Island generation (GWh) by technology type across scenarios to achieve 99% renewable generation in 2030 and 100% in 2045.

Island-Specific Results – Kauaʻi

This section discusses the Kauaʻi-specific electric sector modeling results.

New-Build Capacity Results

Figure C-23 presents the cumulative technologies and capacities procured by the Kauaʻi capacity expansion model from 2030 to 2045. The Kauaʻi model exclusively procures solar and storage technology from 2030 to 2045. Wind is not an available resource on Kauaʻi due to the shearwater and endangered seabird populations that nest on Kauaʻi (the last island with an absence of mongoose).[24] In 2030, the model procures 65–100 MW of solar and 19–105 MWh of storage (S2 procures the least new capacity while S3 procures the largest new capacity). By 2045, the model procures 164–210 MW of solar, and 116–216 MWh of battery energy storage (Reference procures the least new capacity while S3 procures the largest new capacity). Kauaʻi capacity expansion results meet resource adequacy industry standards (2.4 event-hr/8760) across all scenarios and weather years.

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[24] KIUC (2023) Save our Shearwaters

Because a detailed solar resource technical potential study has not been performed on Kauaʻi, the capacities of solar necessary to meet demand could increase or decrease depending on the resource potential of the areas that are feasible for solar development. The solar resource technical potential used in the Kauaʻi model had an average solar capacity factor of 0.22.

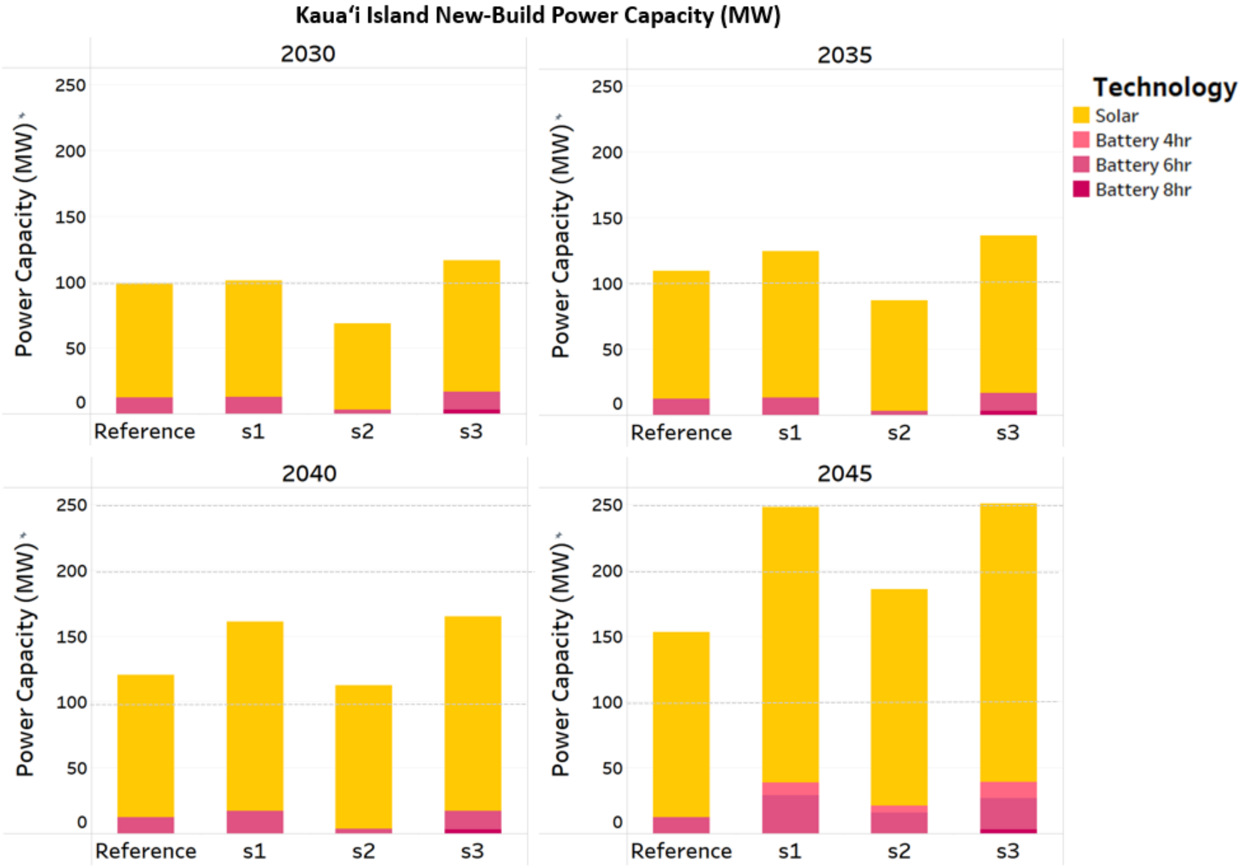

Figure C-23. Kauaʻi cumulative new capacity procured across all scenarios and simulation years.

Figure C-24 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and procured generation and storage on the system. Generation retired prior to the snapshot year do not appear in these capacities. The 2030 capacities represent a midterm system including the planned West Kauaʻi Energy Project, also known as WKEP.[25] The WEKP project plan includes a mix of solar, storage, hydropower, and a pumped storage hydropower facility. The 2045 system capacities represent the technology mix that achieves a 100% RPS for each scenario. In 2045, all fossil fuel generation that is not scheduled to retire transitions to running on biodiesel.

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[25] KIUC (2023) West Kauai Energy Project

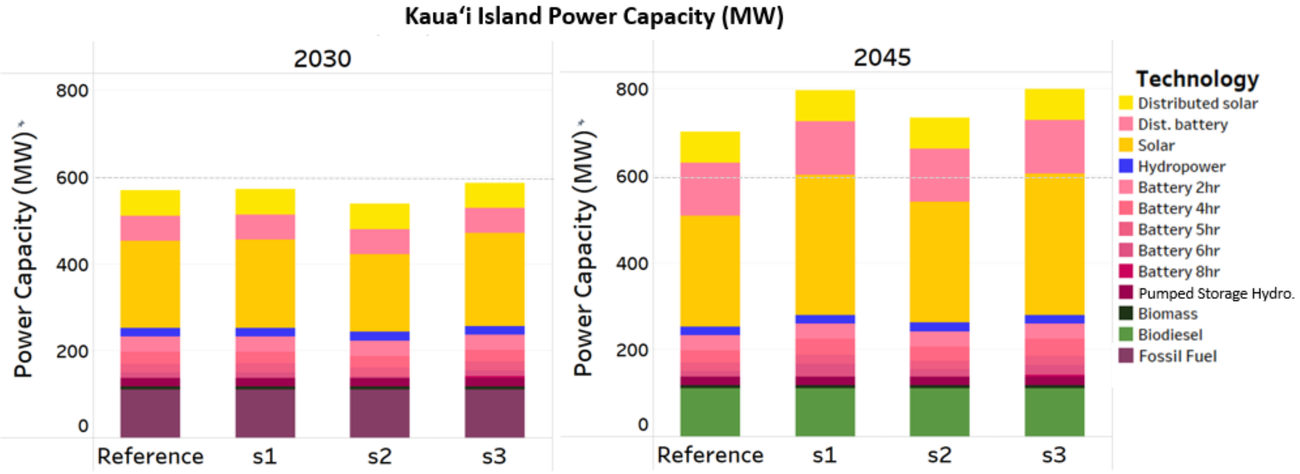

Figure C-24. Kauaʻi total system power capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Land Use Impacts

Kauaʻi has a total land area of 353,000 acres. As no study has been performed to calculate the technically feasible land area available for solar development, the land area impacts in Kauaʻi are calculated in reference to the total island land area. Table C-8 presents the estimated percent of total Kauaʻi land area required for planned and model-selected capacities of solar and land-based wind in each scenario by 2045. The land use availability and results were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report.[26] All scenarios estimate less than or equal to 0.45% of total island area is used for solar development. Further analysis should be performed to understand proportions of technically feasible land that would be impacted by development in accord with these results.

Table C-8. Kauaʻi estimated percent of total Kauaʻi land area used by selected capacities of solar in each scenario by 2045.

Scenario	Total Land Impact (%)	Kauaʻi Annual Demand in 2045 (GWh)
Reference Land Use	0.32	583
S1 Total Land Use	0.45	683
S2 Total Land Use	0.37	617
S3 Total Land Use	0.45	686

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[26] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Kauaʻi model finds that the most cost-effective resource portfolios lead to greater proportions of renewable energy generation than outlined in the RPS requirements. Kauaʻi already achieved relatively high renewable generation achievements relative to the RPS requirements, with 60% of total generation coming from renewables in 2022. Figure C-25 shows all scenarios achieve more than 95% renewable generation between 2030 and 2040. This result indicates that building and operating renewable resources and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045. All scenarios see a slight decrease in the proportions of renewable energy generation between 2035 and 2040. This decrease occurs because the model finds that running a slightly larger proportion of fossil fuels is more cost-effective than procuring additional storage to meet demand during a few periods of low variable renewable generation.

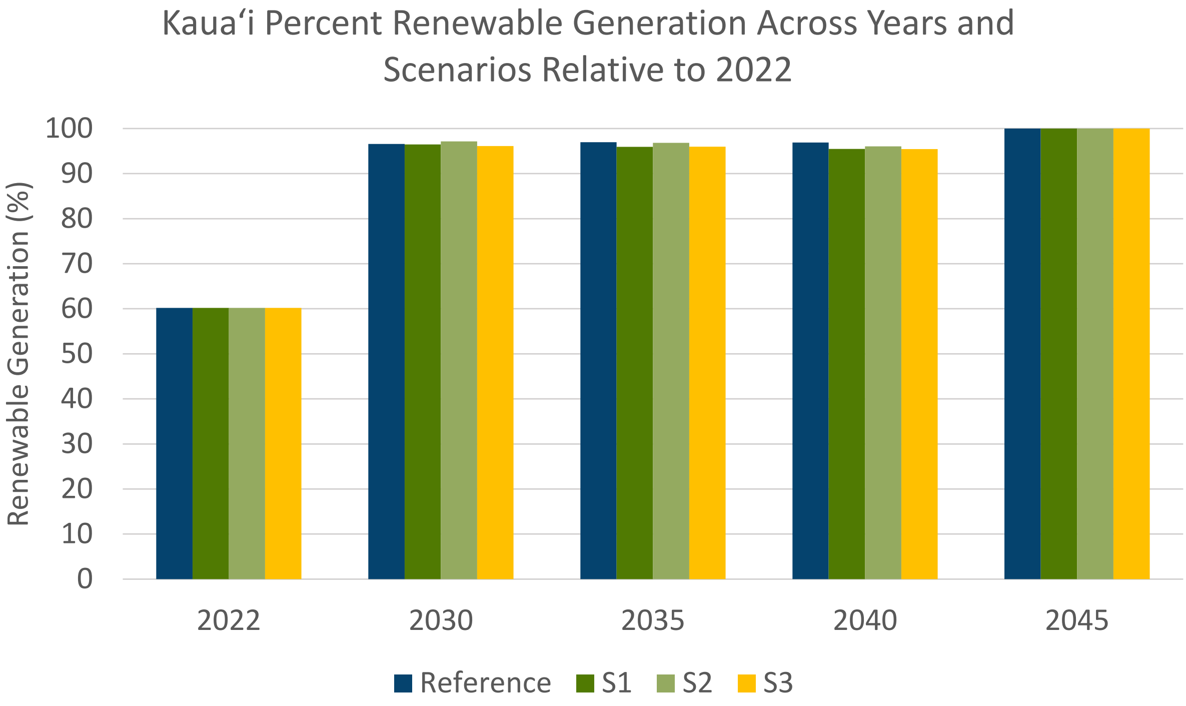

Figure C-25. Kauaʻi percent renewable generation across yeas and scenarios relative to reported 2022 renewable generation percentage.[27]

Figure C-26, Figure C-27, and Figure C-28 show the electric sector electricity supply costs, total demands, and unit cost of electricity supply per megawatt-hour across all simulation years and scenarios. The total costs presented in Figure C-26 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the State-Wide Electric Sector Results section, these costs only

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[27] KIUC (2023). 2022 Annual Renewable Portfolio Standards ("RPS") Status Report

represent the costs associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit cost of electricity supply provides a basis for comparison of the relative cost of energy, not a utility rate.

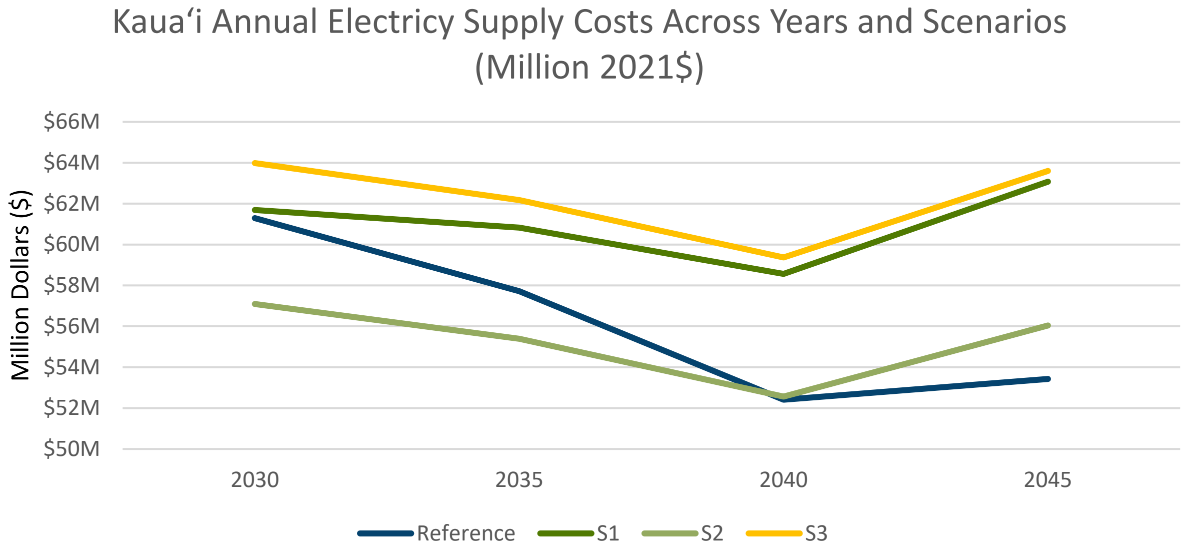

Figure C-26. Kauaʻi annual electricity supply costs across model simulation years and scenarios (in million 2021$).

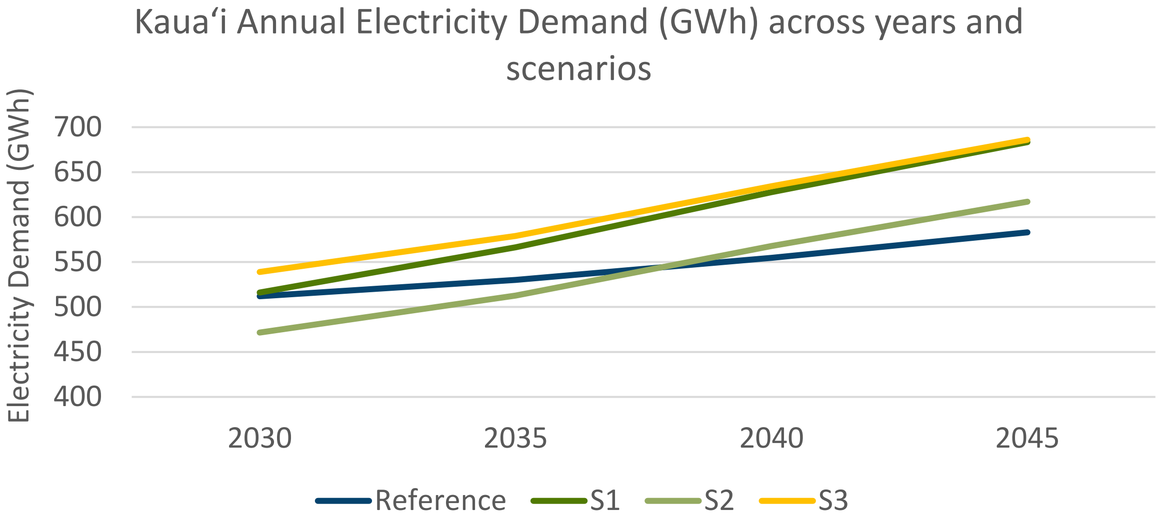

Figure C-27. Kauaʻi annual electricity demands (GWh) across scenarios and years.

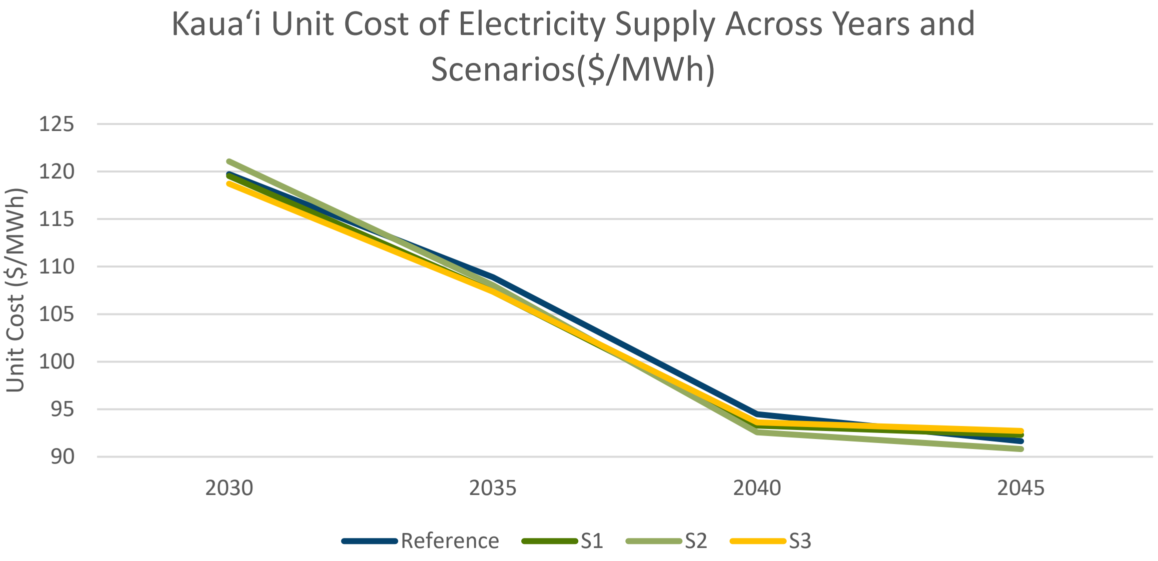

Figure C-28. Kauaʻi unit cost of electricity supply ($/MWh) across years and scenarios.

Figure C-26 shows the system costs for scenarios S1, S2, and S3 decline steadly over time until 2045. The system costs for scenarios decline as PPA prices for existing generation decline over time and the new solar procurement costs do not outweigh the other model cost reductions. All total system costs grow from 2040 to 2045 due to increased renewable generation procurement and the increase in biofuel generation relative to 2040 fossil fuel generation (leading to greater fuel and variable operating costs).

The unit cost of electricty supply per megawatt-hour decreases across all years. The biomass and hydropower plants play a notable role in the Kauaʻi model's ability to operate a flexible system with low biofuel generation (less than 0.05% of 2045 generation comes from biofuel generators). Figure C-29 illustrates the quantity of generation from each technology type that achieves a system with 96–97% renewable generation in 2030 versus a system with 100% reneweable generation in 2045.

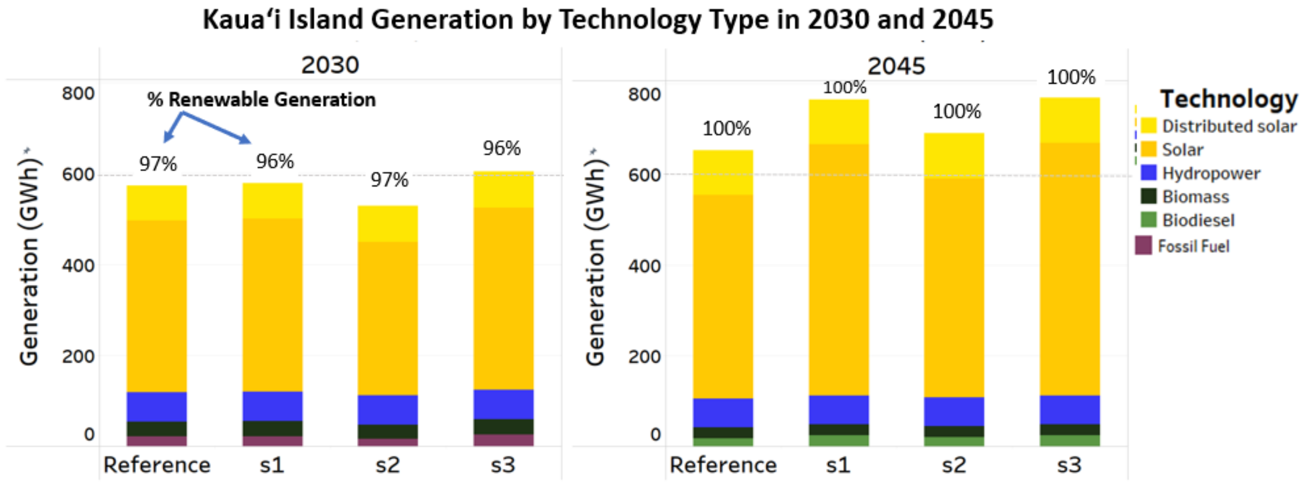

Figure C-29. Kauaʻi generation (GWh) by technology type across scenarios to achieve 96-97% renewable generation in 2030 and 100% in 2045.

Island-Specific Results – Molokaʻi

This section discusses the Molokaʻi-specific electric sector modeling results.

New-Build Capacity Results

Figure C-30 presents the cumulative technologies and capacities procured by the model from 2030 to 2045. As shown in Figure C-30, the Molokaʻi model procures solar and storage across all years as well as biodiesel generation in 2045. See the Large-Scale Versus Distributed Solar section below for a discussion about the scale of solar technologies procured in the model. The model procures the largest quantity of new renewable generation in 2030 and 2045. Across scenarios, 8–11 MW of solar and 28–39 MWh of storage are procured in 2030. By 2045, scenarios procure 15–25 MW of solar and 51–65 MWh of storage. Capacity expansion options included the costs for battery energy storage technologies, as these are currently the most cost-effective storage technology options. Emerging technologies such as hydrogen, pumped storage hydropower or other long-duration storage technologies could become more cost-competitive with the storage and dispatchable technologies represented in this study by 2045.

Due to feedback from HSEO that the generators were likely too old to operate in 2045, all existing fossil fuel generators (15.8 MW) were retired by 2045 instead of being converted to run on biofuel. As a result, the model cost optimally built 1.7 - 2 MW of new biodiesel generation, and subsequent feedback from the resource adequacy analysis required an additional 4 MW of capacity be procured in order to meet the 2.4 event-hr/8760 target during unplanned outage events and low solar resource weather years. Ultimately, all scenarios required 5.7-6 MW of new biodiesel generation to meet the 2045 decarbonization and 100% renewable penetration goal. The technology types that will be available and the technology cost reductions that will be achieved by 2045 are highly uncertain, and the technology types and costs used in this study should be reevaluated over time.

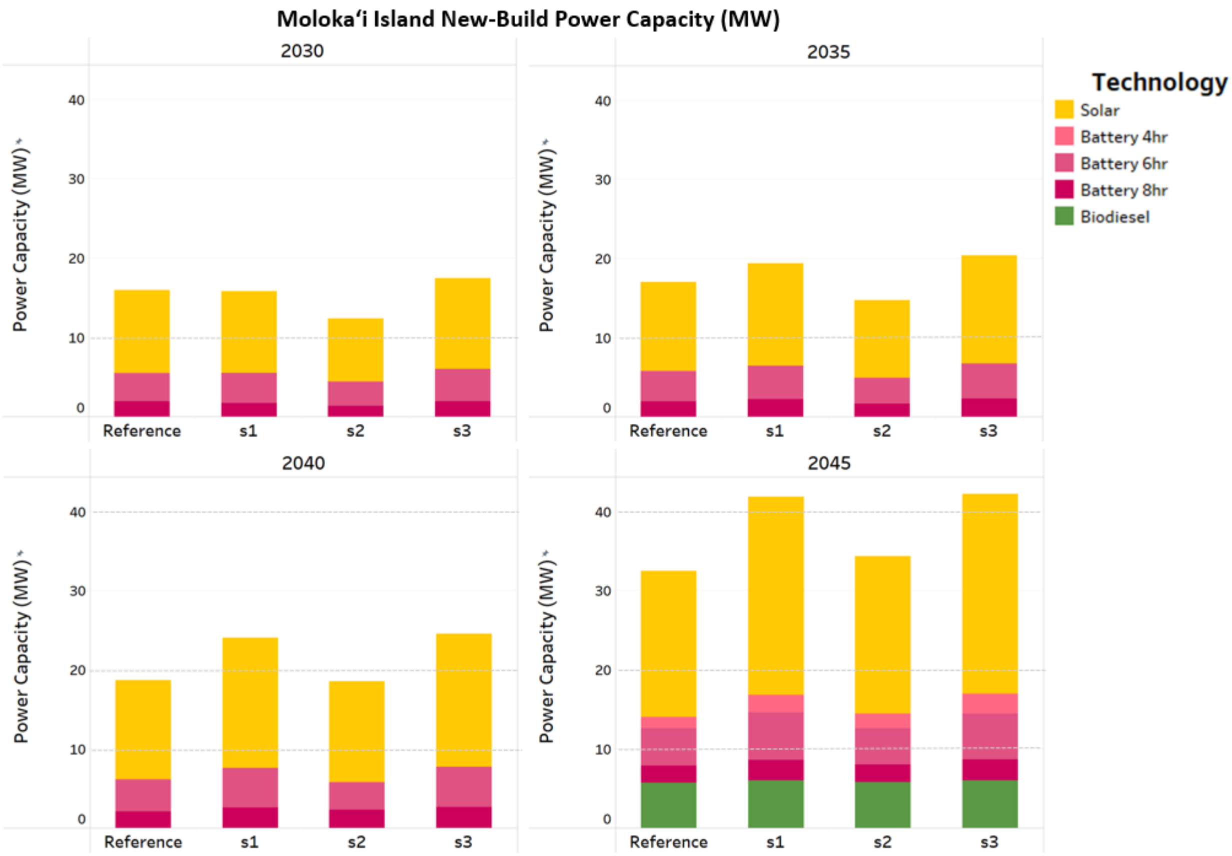

Figure C-30. Molokaʻi cumulative new capacity procured across all scenarios and simulation years.

Figure C-31 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and procured generation and storage on the system. Generation retired prior to the snapshot year do not appear in these capacities. The 2030 capacities represent the midterm system with the Community Energy Resilience Action Plan (CERAP) energy roadmap items two and three, as described in CERAP.[28] The 2045 system capacities represent the technology mix that achieves a 100% RPS for each scenario.[29]

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[28] Sustainable Molokai (2023) Molokai Community Energy Resilience Action Plan (CERAP)

[29] The Molokaʻi CERAP contains a total of 10 energy roadmap objectives. Not all energy roadmap objectives are represented in the Molokaʻi model due to model configuration challenges and time constraints. This Molokaʻi energy system analysis should be a reference to how Molokaʻi emissions will contribute to statewide decarbonization goals but should not be seen as a proposed procurement plan.

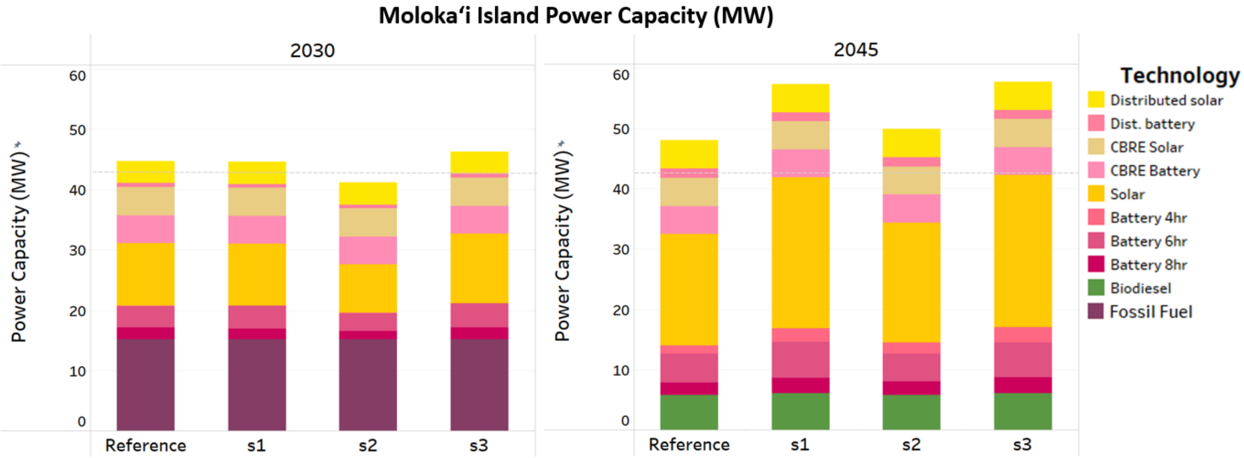

Figure C-31. Moloka‘i total system capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Unlike islands with a greater variety of economical technology options, Moloka‘i relies primarily on solar and storage to meet demand. The Moloka‘i model finds that relying heavily on solar and storage is the most cost-effective option for the island. To meet the island's demand under varying weather conditions, and while minimizing the use of more expensive fossil fuel or biofuel generators, Moloka‘i procures a greater proportion of additional solar generation. The procurement of this additional solar generation leads to the proportionally large solar curtailment seen on Molokaʻi (Figure C-32).[30]

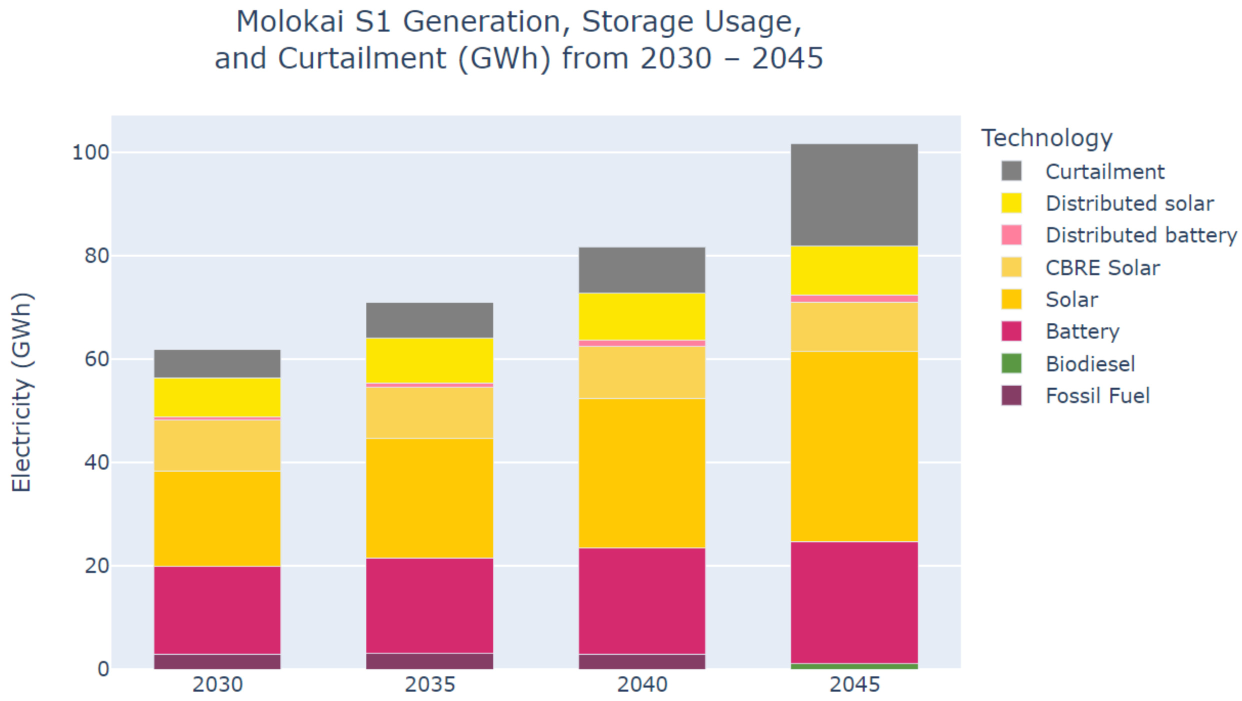

Figure C-32. Molokaʻi S1 generation, storage usage, and curtailment (GWh) from 2030 to 2045. The battery bar represents the gigawatt-hours of electricity that battery energy storage technologies output to the grid each year. Renewable curtailment represents the gigawatt-hours of all available solar generation that was not sent to the grid or stored in a battery. The Molokaʻi model realizes a relatively larger proportion of curtailment than Hawaiian Islands with greater resource diversity to meet system needs in the most cost-effective way.

Large-Scale Versus Distributed Solar Capacity Expansion Results

Distributed solar was represented in two ways in the model, both as a capacity expansion option and as a planned resource based on the customer adoption projections sourced from the Hawaiian Electric IGP Base scenario (Appendix C-1). The distributed solar referenced in Figure C-30 and Figure C-31 represents the projected customer adopted distributed solar. The technology in the new-build capacity charts (Figure C-30) labeled “Solar” represents a mix of capacity-expanded large-scale and distributed solar.

The capacity expansion solar technologies are not broken out by their respective large-scale and distributed solar breakdowns, as the model is likely underestimating the cost of the capacity expansion distributed solar option. The cost of capacity expansion distributed solar in the model represented a cost to procure the solar component of a paired solar rooftop and storage system, while the cost of distributed storage represented the cost to procure the storage component of a paired rooftop solar and storage system. Paired solar and storage systems can be less expensive than the sum of the costs of standalone solar and storage systems of equivalent capacities. However, while the model did procure the rooftop solar

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[30] NREL (2022) Reframing Curtailment: Why Too Much of a Good Thing Is Still a Good Thing

technology component, the model did not procure any capacity of the more expensive distributed storage component. The model did not procure the more expensive distributed storage because the distributed solar in the model could send electricity to the grid to charge the less-expensive, large-scale storage. Without representing the combined cost of procuring distributed storage with the distributed solar, the model likely underrepresents the cost to build distributed solar.

A deeper analysis of distributed solar costs is needed to assess the cost-competitiveness of large-scale solar versus distributed solar and present a projection of procurement capacity breakdown between the two technology types. Whether through utility procurement or customer-side adoption, distributed solar and storage will play an important role in meeting Hawaiʻi's decarbonization goals and associated electricity demands and warrants further future study.

Land Use Impacts

Table C-9 outlines the total land available for solar and wind development on Molokaʻi as defined in the Alt-1 scenarios of the 2021 NREL solar and wind technical potential report.[31] The land use availability and results were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report.[32]

Table C-9. Total technically feasible land on Molokaʻi for land-based wind and solar generation facilities.

Molokaʻi Total Land Area (acres)	**Total Technically Feasible Land (acres)**	
	Solar	Wind
2,580,000	495,000	415,000

Table C-10 presents the percent of technically feasible land required for planned and model selected capacities of solar in each scenario by 2045. The percent of technically feasible land use results in Table C-10 include the CERAP energy roadmap items two and three, as described in CERAP.[33] All scenarios estimate solar development to require less than or equal to 0.33% of technically feasible land. Scenarios S3 and S1 see the highest electricity demands, and thus require the largest build-out of solar and associated land impacts. This study did not include a site-specific capacity expansion analysis of solar build-out.

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[31] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[32] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[33] Molokai Clean Energy Hui (2023). Molokai Community Energy Resilience Action Plan.

Table C-10. Molokaʻi estimated percent of technically feasible land needed for planned and selected capacities of solar in each scenario by 2045.

Scenario	Technically Feasible Land Used (%)[34]	Molokaʻi Annual Demand in 2045 (GWh)
Reference Land Use	0.27	38.7
S1 Total Land Use	0.33	44.7
S2 Total Land Use	0.28	37.6
S3 Total Land Use	0.33	45.0

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Molokaʻi model finds that the most cost-effective resource portfolios lead to greater proportions of renewable energy generation than outlined in the RPS requirements. Figure C-33 shows all scenarios achieve 92%, 93%, and 94% renewable generation in 2030, 2035, and 2040 respectively. This result indicates that building and operating renewable resources and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045.

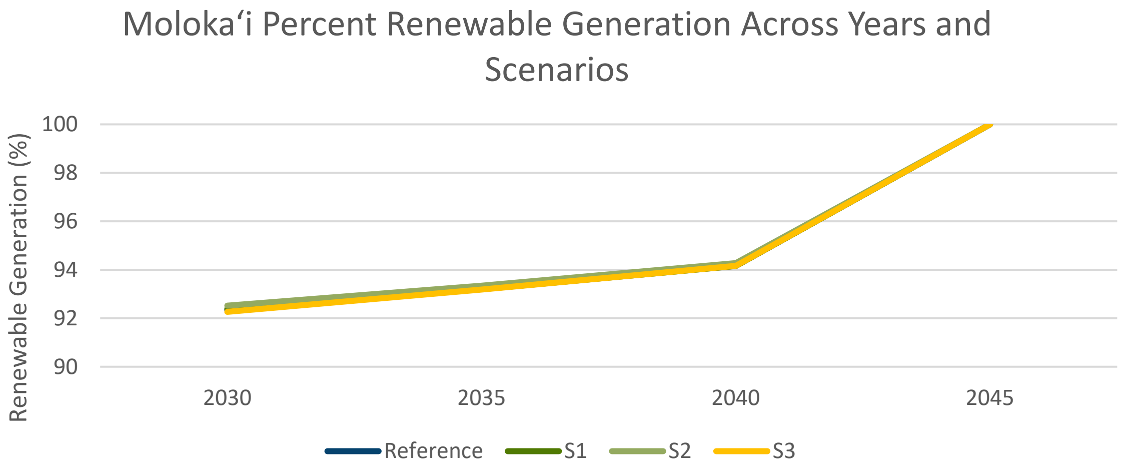

Figure C-33. Molokaʻi percent renewable generation across years and scenarios.

Figure C-34, Figure C-35, and Figure C-36 show the relative electric sector total costs, total demands, and unit cost of electricity supply across all simulation years and scenarios. The total costs presented in Figure C-34 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the Statewide Electric Sector Results section, these costs only represent the costs

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[34] To represent the upper end of potential solar land use impacts, the percent of available land used for solar values assumes all new-build solar capacity selected by the model is large-scale solar.

associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit costunit cost of electricity in Figure C-36 demonstrates the relative cost of energy, not a utility rate.

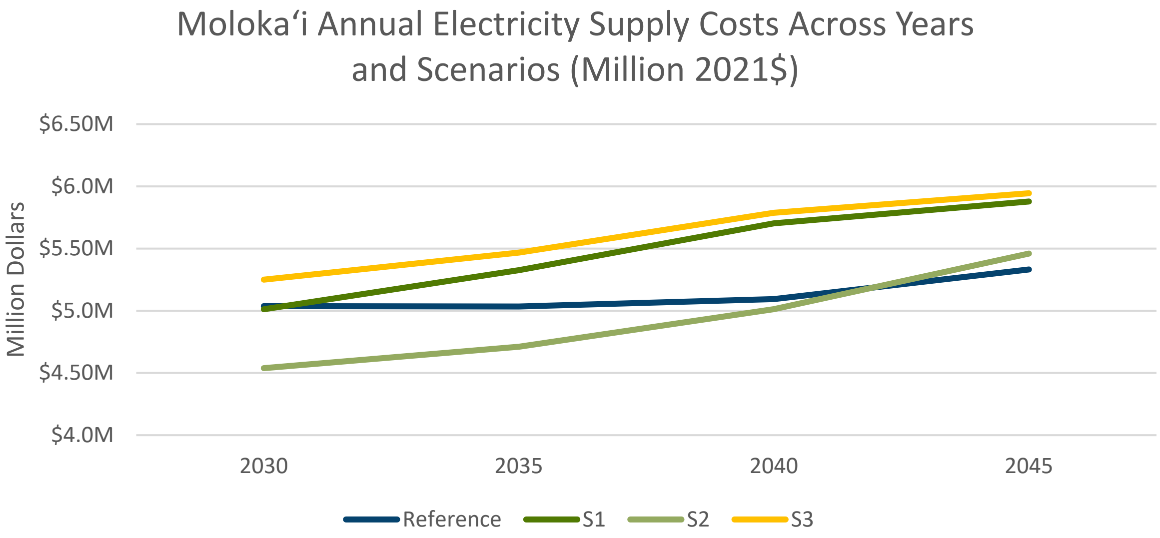

Figure C-34. Moloka‘i annual electricity supply costs across model simulation years and scenarios (in million 2021$).

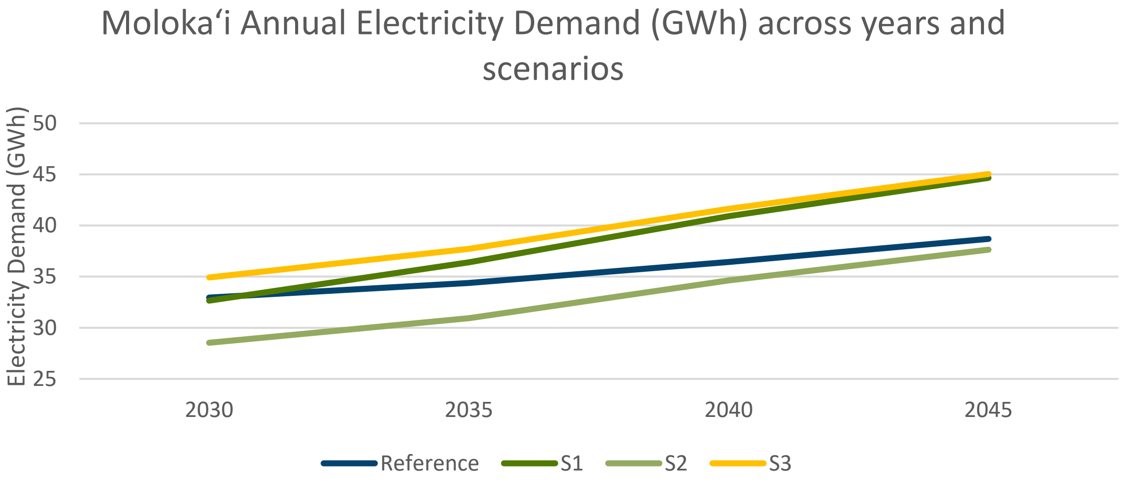

Figure C-35. Moloka‘i annual electricity demands (GWh) across scenarios and years.

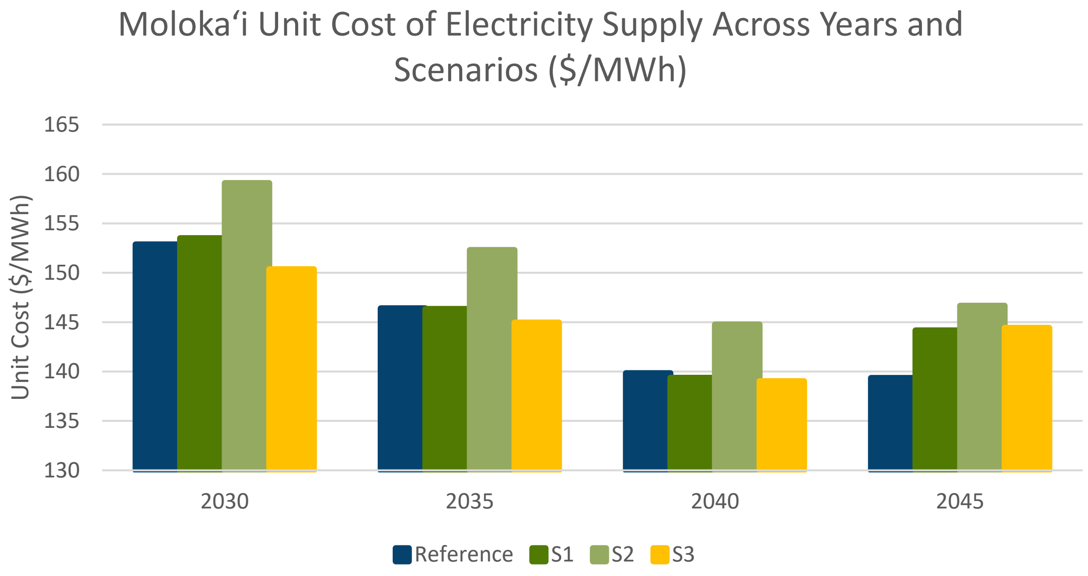

Figure C-36. Moloka'i unit cost of electricity supply ($/MWh) across years and scenarios.

Figure C-34, Figure C-35, and Figure C-36 show the system costs for scenarios gradually growing from 2030 to 2045 while the average electricity supply costs per unit (MWh) of generation generally declines through 2045. Scenarios S1, S2, and S3 experience an uptick in the unit cost of electricity supply in 2045 due to the models procuring larger capacities of solar and storage as well as additional biodiesel to meet the resource adequacy needs. The Reference scenario procures relatively less solar and storage than the other senarios, allowing the unit system costs to decrease slightly in 2045.

Figure C-37 demonstrates the transition from a system with a 92% renewable penetration to a system with 100% renewable penetration across all scenarios. The fossil fuel generation seen in 2030 is largely replaced with new solar and biodiesel generation by 2045.

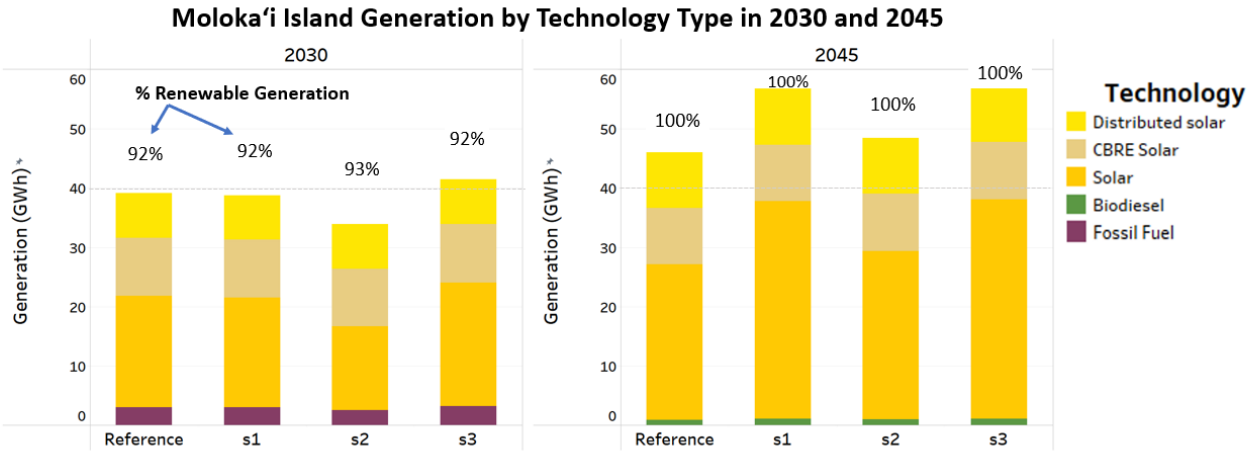

Figure C-37. Generation (GWh) by technology type across scenarios to achieve 100% RPS in 2045 from 92-94% RPS in 2040.

Island-Specific Results – Lāna‘i

This section discusses the Lāna‘i-specific electric sector modeling results.

New-Build Capacity Results

Figure C-38 presents the cumulative new solar capacities procured by the model. The Lāna‘i model only adds new solar capacity across years and scenarios, procuring 0-2 MW of solar capacity in 2030, and 3–7 MW of solar capacity by 2045. The system does not need to procure storage, as the model views the planned procurements prior to 2030 to be sufficient to meet the demand. Lāna‘i capacity expansion results meet resource adequacy industry standards (2.4 event-hr/8760) across all scenarios and weather years.

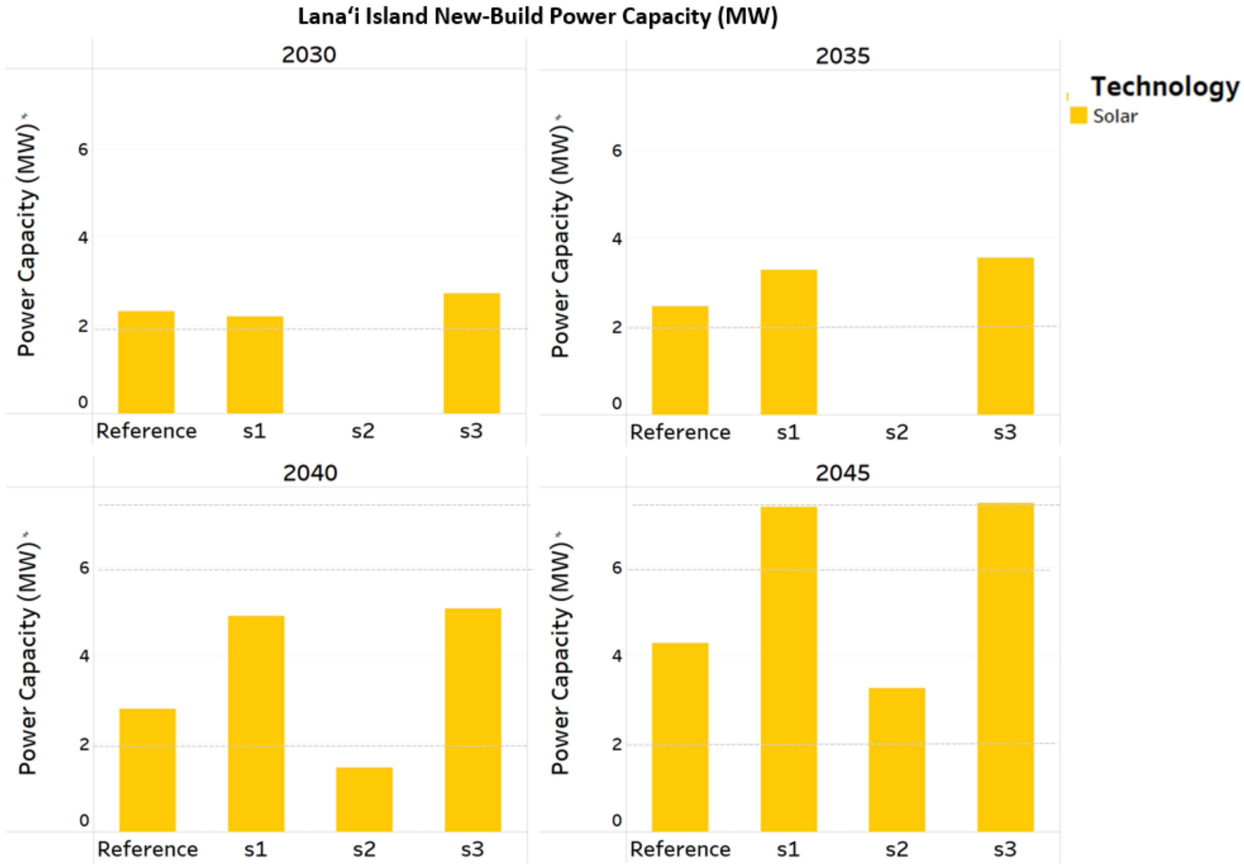

Figure C-38. Lāna'i cumulative new capacity procured across all scenarios and simulation years.

Figure C-39 presents the total system capacities in 2030 and 2045. The total system capacities represent all existing, planned, and procured generation and storage on the system. Generation retired prior to the snapshot year does not appear in these capacities. The 2030 capacities represent a midterm system with the installed and planned CBRE generation capacities. The 2045 system capacities represent the technology mix that achieves a 100% RPS for each scenario. In 2045, all fossil fuel generation that is not scheduled to retire transitions to running on biodiesel.

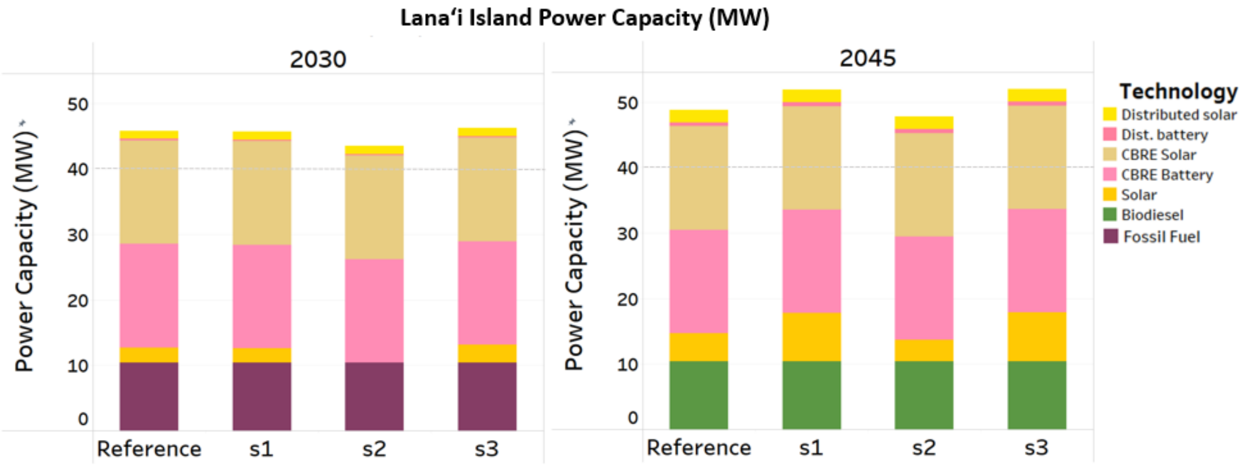

Figure C-39. Lānaʻi total system capacity in 2030 and 2045 across all scenarios. Distributed battery resources have an average 2.7-hour storage duration.

Unlike islands with a greater variety of economical technology options, Lānaʻi relies primarily on solar and storage to meet demand. The Lānaʻi model finds that relying heavily on solar and storage is the most cost-effective option for the island. In order to meet the island's demand under varying weather conditions, and while minimizing the use of more expensive fossil fuel or biofuel generators, Lānaʻi procures a greater proportion of additional solar generation. The procurement of this additional solar generation leads to the proportionally large solar curtailment on Lānaʻi (Figure C-40).[35]

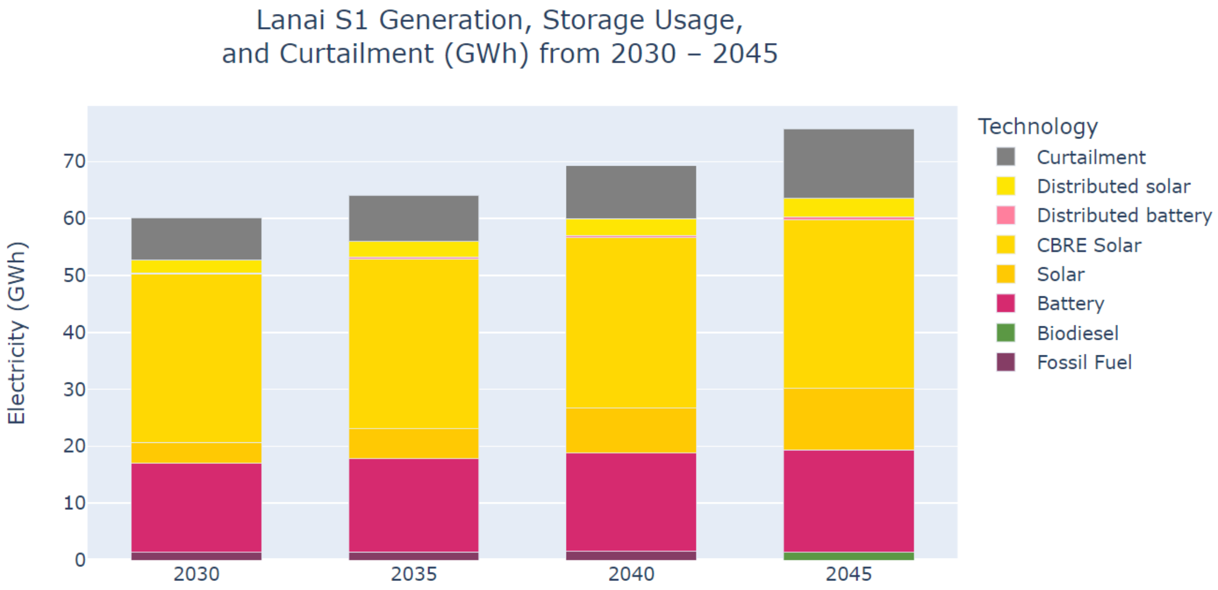

Figure C-402. Lānaʻi S1 generation, storage usage, and curtailment (GWh) from 2030 to 2045. The battery bar represents the gigawatt-hours of electricity that battery energy storage technologies output to the grid each year. Renewable curtailment represents the gigawatt-hours of all available solar generation that was not sent to the grid or stored in a battery. The Lānaʻi model realizes a relatively larger proportion of curtailment than Hawaiian Islands with greater resource diversity to meet system needs in the most cost-effective way.

Land Use Impacts

Table C-11 outlines the total land available for solar and wind development on Lānaʻi as defined in the Alt-1 scenarios of the 2021 NREL solar and wind technical potential report.[36] The land use availability and results were calculated using a 0.154 MW/acre solar system capacity density value and a 0.012 MW/acre land-based wind capacity density value, sourced from the same Alt-1 scenarios defined in the 2021 NREL report.[37]

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[35] NREL (2022) Reframing Curtailment: Why Too Much of a Good Thing Is Still a Good Thing, Video explains curtailment and why curtailment is an important piece of an energy system with high penetrations of renewable generation

[36] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

[37] Grue, N., Waechter, K., Williams, T., & Lockshin, J. (2021). *Assessment of Wind and Photovoltaic Technical Potential for the Hawaiian Electric Company.* National Renewable Energy Laboratory.

Table C-11. Total technically feasible land on Lānaʻi for land-based wind and solar generation facilities.

Total Lānaʻi Land Area (acres)	Total Technically Feasible Land (acres)	
	Solar	Wind
89,900	63,000	42,000

Table C-12 presents the percent of technically feasible land required for planned and model selected capacities of solar in each scenario by 2045. The percent of technically feasible land use results in Table C-12 include 16 MW of planned and targeted solar generation. All scenarios estimate less than 0.25% of technically feasible land would be used for solar development. Scenarios S3 and S1 see the highest electricity demands, and thus require the largest build-out of solar and associated land impacts. This study did not include a site-specific capacity expansion analysis of solar build-out.

Table C-12. Lānaʻi estimated percent of technically feasible land needed for planned and selected capacities of solar in each scenario by 2045.

Scenario	Technically feasible land used (%)	Lānaʻi Annual Demand in 2045 (GWh)
Reference Land-use	0.21	35.0
S1 Total Land-use	0.24	38.6
S2 Total Land-use	0.20	32.0
S3 Total Land-use	0.24	38.8

Renewable Generation, Demands, and Costs

In the years leading up to 2045, the Lānaʻi model finds the most cost-effective resource portfolios lead to greater proportions of renewable energy generation than outlined in the RPS requirements. Figure C-41 shows all scenarios achieve more than 96% renewable generation between 2030 and 2040. This result indicates that building and operating solar and storage is less costly than running much of the existing fossil fleet or building and running new fossil generation prior to 2045.

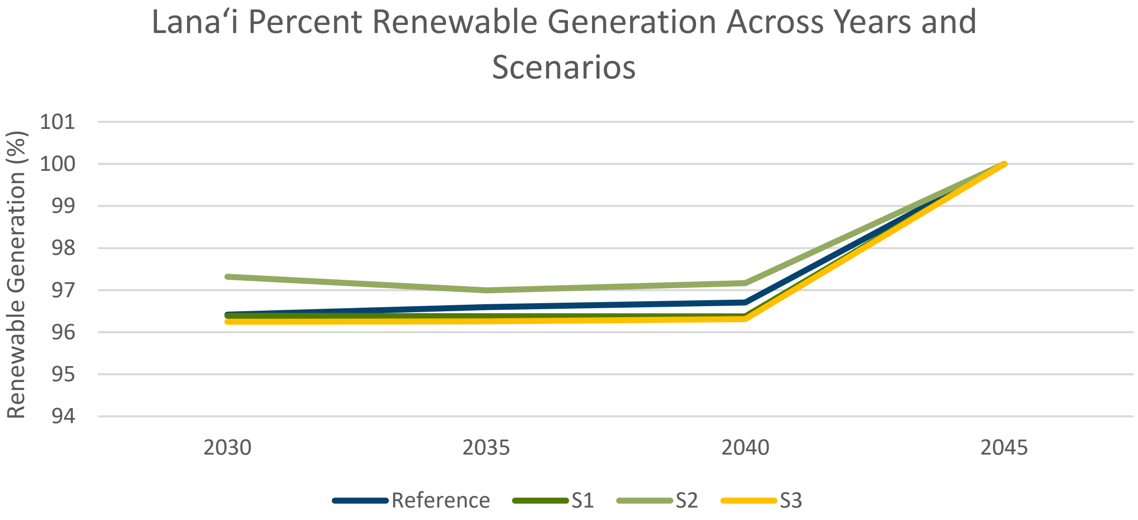

Figure C-41. Lānaʻi percent renewable generation across yeas and scenarios.

Figure C-42, Figure C-43, and Figure C-44 show the electric sector electricity supply costs, total demands, and average cost of electricity supply per unit (MWh) across all simulation years and scenarios. The total costs presented in Figure C-42 include the costs associated with procuring new renewable capacity through PPA contracts and operating the preexisting system in each year and scenario. As noted in the Statewide Electric Sector Results(4.6), these costs only represent the costs associated with generation, storage, and transmission and do not represent all costs incurred by the energy system operator. The unit cost of electricity supply in Figure C-44 provides a basis for comparison of the relative cost of energy, not a utility rate.

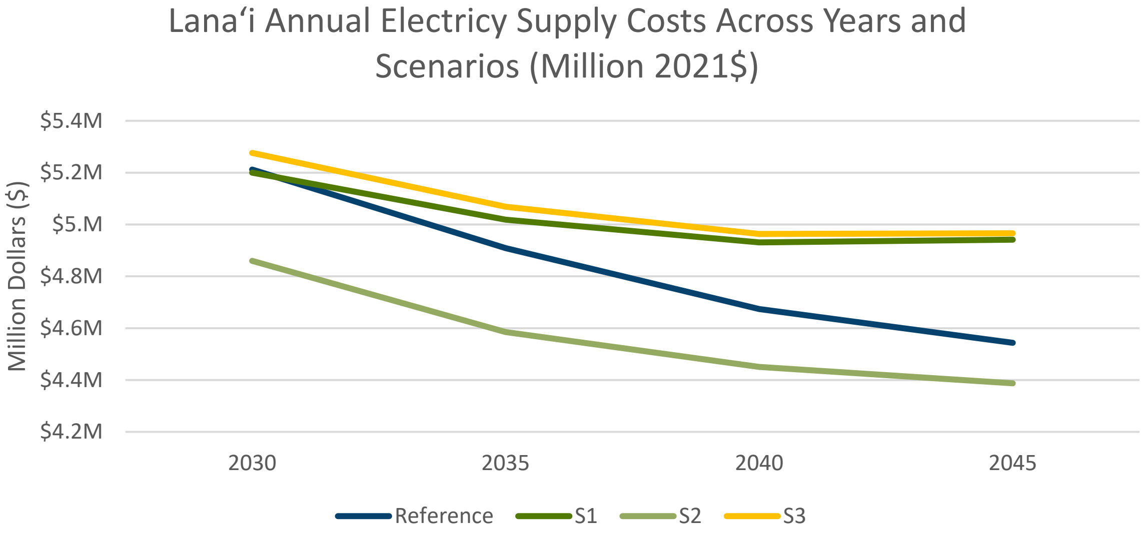

Figure C-42. Lānaʻi annual electricity supply costs across model simulation years and scenarios (in million 2021$).

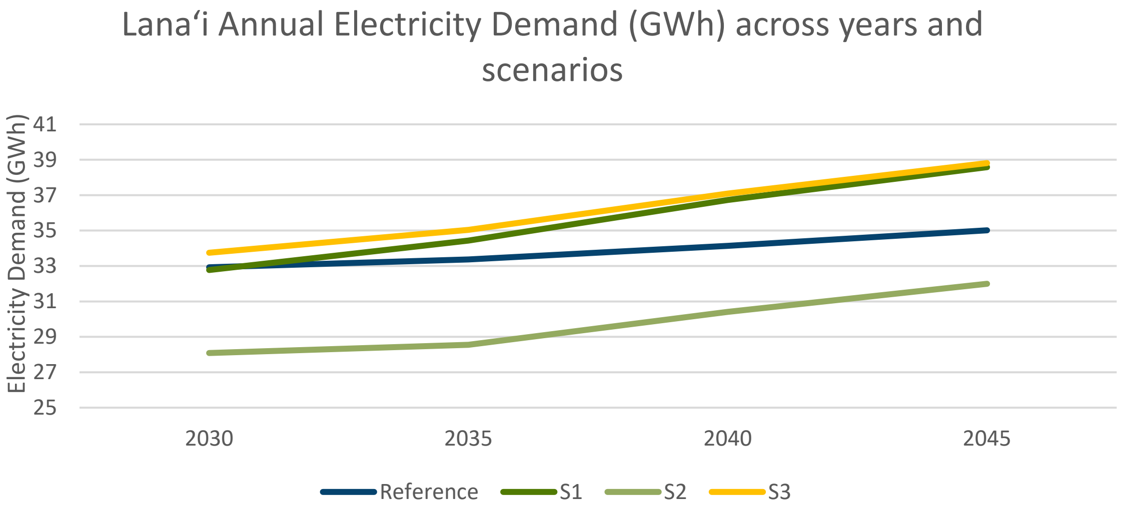

Figure C-43. Lānaʻi annual electricity demands (GWh) across scenarios and years.

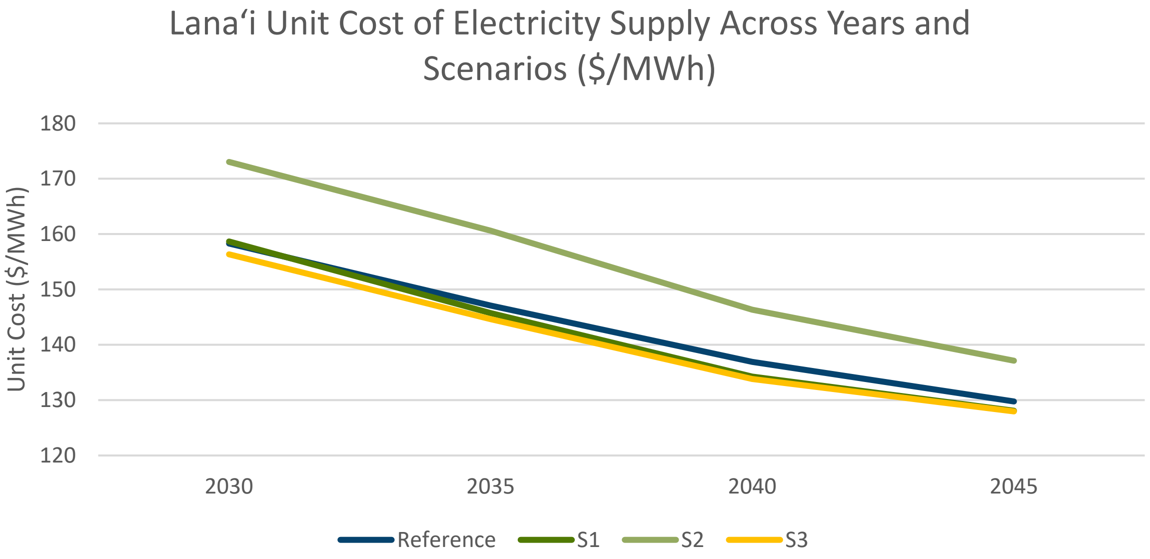

Figure C-44. Lānaʻi unit cost of electricity supply ($/MWh) across years and scenarios.

Figrues C-42, C-43, and C-44 present the annual electricity suply costs, annual demands, and unit cost of electricity supply across years and scenarios. Figure C-42 shows the system costs for scenarios decline across all scenarios from 2030 to 2040 as PPA prices for planned CBRE projects decline over time and the new solar procurement costs do not outweigh the other model cost reductions. The S2 unit cost is consistenly greater than the other scenarios due to the significanly lower loads seen in the S2 scenario on Lānaʻi, which still maintains the same annual contractual (PPA) and utility-owned operation and maintinance costs from the existing and planned system. The technology types that will be available and the technology cost reductions that will be achieved by 2045 are highly uncertain, so costs used in this study should be reevaluated over time.

APPENDIX D

ATMOSPHERIC CARBON REMOVAL PATHWAYS IN HAWAIʻI

A PRIMER ON PATHWAYS FOR ATMOSPHERIC CARBON REMOVAL AND STORAGE AND NEGATIVE EMISSION TECHNOLOGIES

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Contents

Forward

The State of Hawaiʻi and its citizens are uniquely positioned to set a global example on how to address climate change while fostering positive economic transformation and revitalization through carbon dioxide capture, utilization, and storage. As Hawaiʻi works to transform the energy sector through renewable energy deployment, transformation of the transportation sector, and energy efficiency; the role of carbon dioxide storage, utilization, and sequestration will play a critical role in increasing the capacity of local carbon dioxide sinks to achieve the state's ambitious climate targets—namely, to sequester more carbon dioxide than emitted by 2045. There is an uncharted opportunity to capture carbon and revitalize our agriculture, transportation, and other industrial sectors while safely and permanently sequestering the remainder of the carbon deep underground.

We sincerely appreciate you taking the time to read this first primer on the potential for direct air carbon dioxide capture, utilization, and storage in Hawaiʻi. We believe this will be the starting point for many future discussions about our state's future, including achieving its ambitious and nation-leading climate goals.

Key Definitions

Carbon Capture and Storage (CCS) – The process by which carbon dioxide is captured from a smokestack or flue from a power plant or factory and then sequestered underground. This is an industrial process. CCS captures emissions from a point source GHG emitter and not the atmosphere (see Direct Air Capture). It is not considered a net-negative action, rather CCS is a mitigative action aimed to reduce emissions from point source facilities such as factories, refineries, or energy production facilities.

Carbon Capture and Utilization (CCU) – The process by which carbon dioxide is captured and converted into useful products including sustainable aviation fuel, carbon-negative concrete, or carbon dioxide for industrial and commercial use, such as use in beverages.

Carbon Dioxide Equivalent (CO_2e) – The metric used to standardize/compare emissions from various greenhouse gases based on their global warming potential. It is the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

Carbon Dioxide Removal (CDR) – The process by which CO_2 gas is removed from the atmosphere and sequestered.

Sequestration (carbon sequestration) – The process of capturing and removing CO_2 from the atmosphere for long-term storage. There are three types: 1) Biological - storage of CO_2 in vegetation, soils, and oceans; 2) Geological - storage in geological formations (underground rocks); and 3) Technological - storage in engineered molecules.

Direct Air Capture (DAC) – the process by which carbon dioxide is removed from the ambient air into a form in which it can be stored or utilized.

Direct Air Capture with Carbon Storage (DACCS) – A carbon dioxide removal method in which carbon dioxide is captured from the ambient air via a contractor and is compressed into a pure stream to be injected into a geological reservoir for long-term storage or used to make products, such as cement.

Geological Sequestration – A technology in which captured carbon is mixed with water and injected into an appropriate substrate, such as basalt, where it creates a carbonate rock and is stored for millennia.

Negative Emissions Technology (NET) – A technology that removes more carbon out of the air than it emits during its full life cycle, also known as greenhouse gas removal technology. NETs include DACCS and CCS.

Introduction and Purpose

Hawaiʻi seeks to lead by example in adapting to the impacts and mitigating the extent of climate change. Mitigating the extent of global warming and its impacts requires an expeditious reduction in greenhouse gas emissions; secondary to reducing emissions, it will likely require the active removal of greenhouse gases from the ambient air. In 2015, Hawaiʻi became the first state to legally mandate that one hundred percent of the electricity sold by Hawaiʻi's utilities must come from renewable sources by 2045.[1] Hawaiʻi is currently ahead of its interim renewable energy[2] benchmarks and this white paper assumes the state will continue to meet its energy goals and that any negative emission technology (NET), if developed would be complementary to emission reduction, and will not undermine or compete with efforts and resources needed to reduce greenhouse gas emissions.

In 2018, Hawaiʻi further recognized bringing greenhouse emissions down to zero was not enough and mitigating the effects of climate change would also require the active removal of greenhouse gases, namely carbon dioxide from the atmosphere. Hawaiʻi became the first state to establish a statewide net-negative target in law; specifically, HRS §225P-5 establishes a zero-emissions clean energy economy target to "sequester more atmospheric carbon and greenhouse gases than emitted within the State as quickly as practicable, but no later than 2045."[3]

Most recently, in 2022, the Hawaiʻi State Legislature passed HB 1800, Act 238 which expands on Act 15 and provides an interim target of reduction, considering both emissions as well as offsets, "of at least 50 percent below the level of statewide greenhouse gas emissions in 2005"[4] by 2030. Act 238 further tasks the Hawaiʻi State Energy Office to "analyze pathways and develop recommendations for achieving the State's economy-wide decarbonization goals."

Hawaiʻi's current nature-based methods of removing carbon from the atmosphere including agricultural, aquacultural, and agroforestry[5], while critically important for reasons beyond the carbon reduction benefits, may not be enough; the state must begin to explore new sequestration technologies that contribute to the net carbon-negative goal.[6] Direct Air Capture with Carbon Storage (DACCS) with geological carbon storage is an emerging technology in which carbon dioxide (CO_2) is captured from the surrounding air, transported, mixed with water, and injected into the ground where the liquid CO_2 reacts with basalt to form a solid carbonate rock—ultimately sequestering the greenhouse gas geologically for millennia. The process has been commercialized successfully in Iceland; Hawaiʻi is a promising location where the technology could be successfully utilized.[7]

Hawaiʻi's volcanic origins make the island chain an ideal location for long-term geological sequestration due to the basaltic composition of the rock and subsurface throughout the entire island chain. Studies and pilot facilities have shown when carbon dioxide is mixed with water and injected in liquid form, the carbon dioxide can be permanently stored and removed from the atmosphere—providing a promising tool to

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[1] H.B. 623, Act 97 (Haw. 2015).

[2] Haw. Rev. Stat. §269-91 (2015)

[3] H.B. 2182, Act 15 (Haw. 2018), codified as HRS § 225P-5.

[4] H.B. 1800, Act 238 (Haw. 2022).

[5] *Greenhouse Gas Sequestration Explained*. (n.d.). State of Hawaii Office of Planning and Sustainable Development. Retrieved January 13, 2023, from https://planning.hawaii.gov/ghgstf/carbon-farming-explained/

[6] "Forests are a crucial line of defense against climate change. But trees can't absorb enough CO_2 to stop climate change on their own, no matter how many we plant." "Why Don't We Just Plant a Lot of Trees?" Ask MIT Climate. MIT Climate Portal, September 22, 2020. https://climate.mit.edu/ask-mit/why-dont-we-just-plant-lot-trees.

[7] "Carbfix Atlas." Where does it work? Carbfix. Accessed July 18, 2022. https://www.carbfix.com/atlas.

mitigate increasing carbon emissions and climate change.[8] In addition to long-term geological carbon storage, Hawaiʻi also has a demand for carbon dioxide direct use, in other words, captured CO_2 can be utilized to create products that may lower the net costs of emission reductions and DAC. Various pathways for utilization exist and could be scaled to reduce net GHG emissions in the state. Utilization pathways for captured CO_2 include incorporation in concrete building materials, synthetic fuel production, and direct use. These pathways vary in their ability to store carbon for the long term but could provide a more immediate mechanism with commercial value to capture and utilize carbon dioxide.

This paper provides a reconnaissance of Hawaiʻi's options for carbon removal, long-term storage, and utilization. The paper is intended to identify and explain these options and provide an initial discussion on the benefits, feasibility, potential risks and tradeoffs, and barriers to implementation. The whitepaper shall not be construed as a prescriptive study and is not recommending or discouraging the development of NET facilities.

It is critical, any individual project that is sought go through a comprehensive environmental review, life cycle greenhouse gas assessment, community outreach, and consultation with Native Hawaiian Organizations and communities.

Any projects considered should complete a holistic review of impacts on Native Hawaiian culture and indigenous rights and evaluation of potentially significant impacts to culturally and spiritually significant places and resources beyond what is required by law. This paper does not recommend a single project or pathway, and therefore these necessary comprehensive reviews are not included in this paper.

The Carbon Cycle

Understanding the carbon cycle—where carbon is and how it moves through the earth's ecosystems—is crucial for understanding carbon sequestration and the time scales in which it occurs both in nature and if technologically driven through negative emissions technologies. A high-level understanding of the carbon cycle is critical for determining how to best store/sequester carbon dioxide from the atmosphere.

Carbon is a chemical element that is vital for the existence and formation of life on Earth. Carbon naturally moves through living organisms, the atmosphere, soil, the ocean, and lithosphere (rocks). Plants and algae absorb carbon in the form of CO_2 from the atmosphere and use the energy from the sun to photosynthesize CO_2 and water into organic compounds (proteins, carbohydrates, etc.). Animals rely on plants or other animals for their carbon and energy intake. When terrestrial organisms die and decay, carbon from their bodies is transferred into the soil. When organic matter in soil is eventually decomposed by bacteria and fungi, part of the carbon is released back into the atmosphere as CO_2 and a portion stays in the soil as humus. Soil holds approximately three times more carbon than the atmosphere[9] although the exact amount is dependent on temperature, soil water content, and other environmental factors which affect decomposition rates. Soil preservation is another critical carbon reduction pathway; however, it is not evaluated in depth in this whitepaper.

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[8] Beuttler, Christoph, Louise Charles, and Jan Wurzbacher. "The role of direct air capture in mitigation of anthropogenic greenhouse gas emissions." *Frontiers in Climate* 1 (2019): 10. doi: 10.3389/fclim.2019.00010

[9] Oelkers, E. H. & Cole, D. R. (2008) Carbon dioxide sequestration: a solution to the global problem. *Elements* **4**, 305-310.

The ocean holds larger amounts of CO_2 than terrestrial systems; currently, the ocean absorbs the large majority of emitted CO_2. It is estimated the ocean carbon pool can hold about ten times more carbon than terrestrial organisms, soils, and the atmosphere combined.[10] Where the atmosphere and the ocean meet, CO_2 is absorbed by the water from the atmosphere via molecular diffusion, or air-sea gas exchange. A small amount of the dissolved CO_2 is absorbed by phytoplankton and algae which, like terrestrial plants, use to photosynthesize organic compounds. The carbon then travels up the food chain into zooplankton, fish, and other marine animals. During the process, some of the carbon is released back into the atmosphere or is dissolved in water via respiration, and some is released as excrement back into the water. Excrements, as well as dead organisms, sink toward the sea floor taking the carbon from the surface waters into the deep ocean, where it is stored for longer periods. Although marine organisms significantly contribute to the movement of carbon from shallow waters to deeper water, the amount of carbon stored in living organisms and dead biomass is small. Most of the carbon in the oceans is in the form of dissolved inorganic carbon.[11] As CO_2, dissolves in the water, most of it reacts with the water and forms carbonic acid (H_2CO_3), a weak acid that then breaks down (dissociates) into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) which constitutes the most common form of carbon in the oceans. While carbon in the form of CO_2 molecules can move relatively easily between the atmosphere and the water (via diffusion), carbon that is in the form of HCO_3^- ions tend to stay in the water. It is this quality that allows substantial amounts of carbon to be stored in the ocean. Without the ocean absorbing enormous quantities of CO_2 from the atmosphere, the concentration of CO_2 in the atmosphere would be much higher than it is today; the ocean is responsible for absorbing about 30% of the atmospheric CO_2. The absorption of inorganic carbon by the ocean has resulted in a chemical imbalance as the pH of ocean water has measurably decreased resulting in ocean acidification.[12] Ocean acidification is threatening the fundamental chemical balance of the oceans. It is especially threatening to organisms that need carbonic ions for the construction of their shells, skeletons, and other calcium carbonate structures. The extra hydrogen ions (H^+) coming from the carbonic acid react with carbon ions leaving little left for living organisms to use for their skeletons and shells. If the pH falls too low their shell may even start to dissolve.

Fossil Fuels and the Carbon Cycle

Coal is compressed dead plant matter that has not decayed, but instead accumulated over millions of years.

Petroleum (crude oil) and natural gas are made of plankton that has not decayed and has accumulated on ancient sea floors eventually getting buried deeper by sediment and mud. The increased pressure as well as heat gradually turned the sediment into a rock and the dead plankton into **oil and gas**.

When fossil fuels such as coal and oil are burned all the carbon these organisms have captured and accumulated over **millions of years is released**. Thus, millions of years' worth of sequestered/stored carbon have been released over a period of several decades since the industrial revolution. Burning fossil fuels results in the release of carbon, which had taken a millennium to sequester, in a matter of seconds, letting out millennia worth of stored carbon into the atmosphere.

Understanding the global carbon cycle and carbon budget is fundamental to understanding possible carbon removal pathways and technological limitations.

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[10] Houghton, R. A. (2007) Balancing the global carbon budget. *Annual Review of Earth and Planetary Sciences* **35**, 313-347.

[11] Inorganic carbon is found in the forms of *carbon dioxide (CO_2), carbonic acid, bicarbonate,* and *carbonate.*

[12] The ocean is not acidic, it is basic/alkaline. However, the ocean's pH has decreased, from 8.2 to 8.1 since the Industrial Revolution. Although a change of 0.1 pH units may seem small, a decrease in one pH unit is a ten-fold increase in acidity, the 0.1 change thus translates to a 25% increase in acidity.

Climatic impacts of CO_2 are not only a function of the quantity or concentration of CO_2 in the atmosphere—but also the time it resides in the atmosphere. The longer it resides in the atmosphere, the more global warming potential it has. Carbon dioxide, however, is not destroyed over time like other GHGs, instead, CO_2 molecules move between distinct sinks including the atmosphere, ocean, biosphere, pedosphere (soil), and geosphere (rock) – as described above.

A key part of the carbon cycle is cycling which occurs between the lithosphere (Earth's crust and mantle) as well as in rocks and minerals. On a longer timescale, CO_2 can also be naturally locked away into the lithosphere through chemical weathering. The process occurs when CO_2 and H_2O react with reactive rocks, such as basalt. As explained above, CO_2 reacts with water to form carbonic acid. This acid is weak; however, over long timescales, it can dissolve certain rocks, a process called weathering, and leach calcium, magnesium, potassium, or sodium ions. The carbonate ions, from the dissociated carbonic acid, then eventually react with the leached ions to form solid carbonates. In nature, this process happens over long geological time scales. The rate of drawdown naturally occurring from this process cannot keep up with the rate at which humans emit carbon dioxide into the atmosphere. However, technological advancements have found a way to mimic this natural process and speed up the rate at which CO_2 is stored geologically, so it can be stored/sequestered in more permanent long-term sinks.

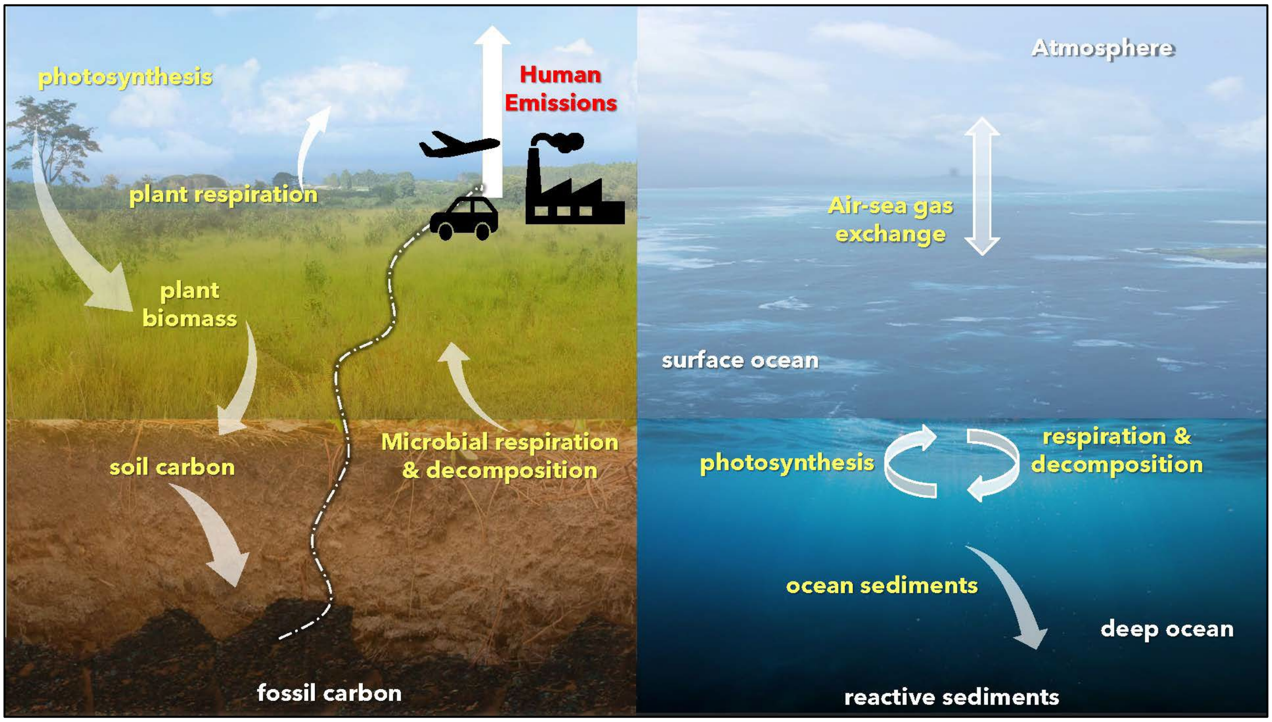

FIGURE 1 THE CARBON CYCLE - ARROWS SHOW THE MOVEMENT OF CARBON BETWEEN THE LAND, ATMOSPHERE, AND OCEANS. THE YELLOW TEXT INDICATES NATURAL FLUXES (ACTIVE CARBON CYCLE), THE WHITE TEXT INDICATES STORED CARBON (OR SINKS) , AND THE RED TEXT INDICATES HUMAN EMISSIONS. THE GRAPHIC IS SIMPLIFIED. ADAPTED FROM NASA EARTH OBSERVATORY[13]

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[13] *The Carbon Cycle* (June 16, 2011) NASA Earth Observatory. Retrieved December 2022, from https://earthobservatory.nasa.gov/features/CarbonCycle

Carbon Sequestration

Carbon sequestration is the process of capturing and removing CO_2 from the atmosphere for long-term storage. There are different types of sequestration. Biological sequestration stores CO_2 in the biosphere - in vegetation, soils, and oceans, which as mentioned above has limited capacity. Geological sequestration is the storage of carbon from CO_2 in geological formations (underground rocks); however, is an extremely slow process that happens over geological timescales (i.e. millions to tens of millions of years). Scientists have worked to mimic long-term geological storage in shorter time frames by injecting CO_2 dissolved in water into the bedrock where it mineralizes within two to three years. Technological sequestration which refers to the storage of carbon from atmospheric CO_2 in engineered molecules is also a mechanism to store carbon on longer timescales, taking the CO_2 out of the "active carbon cycle" and placing the carbon in a "sink" (Figure 1).

Carbon sequestration has been explored within Hawaiʻi; however, current, and past studies and policies have focused on storage in soil and terrestrial land-use sinks such as those provided by agriculture, forestry, and other land-use (AFOLU) reservoirs, all of which play a key role in Hawaiʻi's carbon balance.[14]

While important, these biological sequestration methods do not exhibit the same level of assurance as geological sequestration, as they are dependent on naturally entropic system states vulnerable to land use change, including the proliferation of invasive species, the unpredictable threats of wildfire, and decreases in net primary production (NPP) in plants, which can occur for a variety of reasons such as prolonged drought, pathogens or pests (such as rapid ʻōhiʻa death), or soil nutrient depletion. Ultimately, land- and ocean-based removal methods can be vulnerable to reversal, though this does not negate the importance of maintaining and promoting these mechanisms as critical sinks. Losing these natural sinks would only further exacerbate the problem.

The options of carbon capture previously investigated in Hawaiʻi largely store carbon in the short term rather than the long term. However, both methods of storage will be necessary to meet our net negative carbon emission goals by 2045. Table 1 shows various carbon removal technologies.

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[14] Jacobi, James D., Jonathan P. Price, Lucas B. Fortini, Samuel M. Gon, and Paul Berkowitz. "Baseline land cover." *Baseline and projected future carbon storage and carbon fluxes in ecosystems of Hawai'i. US Geological Survey Professional Paper 1834. Reston, VA: US Department of the Interior, US Geological Survey: 9-20. Chapter 2* 1834 (2017): 9-20.

TABLE 1: CARBON SEQUESTRATION AND REMOVAL PATHWAYS

LAND- AND OCEAN-BASED REMOVAL		TECHNOLOGICAL / INDUSTRIAL REMOVAL (ENERGY INTENSIVE)	
Land	**Ocean***	**Land**	**Ocean**
• Biochar application • Engineered Wood • Soil Carbon Sequestration • Land Use • Afforestation and Reforestation	• Alkalinity enhancement • Macroalgae/seaweed cultivation • Nutrient fertilization • Ecosystem restoration	• DACCS: Direct Air Capture with Carbon Storage and Geological Sequestration • Concrete and Building Materials - Incorporation in building material integrating vegetation and mineralized carbon in concrete mixtures.	• Electrochemical carbon scrubbing and alkalinity enhancement

**Ocean methods are not evaluated substantially in this document as they are in the earlier stages of development and can have severe unintentional ecological consequences if not appropriately and adequately studied.*

The Hawai‘i Greenhouse Gas Emissions Report for 2019 published by the Hawai‘i Department of Health (DOH) Clean Air Branch estimated the total agricultural, forestry, and other land use (AFOLU) sinks (2.59 MMT CO_2e in 2019.) in Hawai‘i exceeded statewide AFOLU sources.

A 2017 comprehensive study conducted by the U.S. Geological Survey found the main Hawaiian islands (excluding Ni‘ihau) were projected to remain a net carbon sink, however, projected land-use changes on O‘ahu and Kaua‘i could convert the islands to net carbon sources by 2061,[15] if actions are not taken to both maintain the integrity and increase the capacity of natural AFOLU sinks in the future. Ultimately, AFOLU sinks have not been enough to outweigh anthropogenic emissions sources from predominately the transportation and energy sectors. Table 2 shows emissions from statewide sources and sinks, in 2019 net emissions statewide were estimated at 19.42 million metric tons (MMT) of CO_2e.[16]

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[15] Jacobi, et al. (2017).

[16] ICF and University of Hawaii Economic Research Organization (UHERO). “Hawaii Greenhouse Gas Report for 2005, 2018, and 2019 Report.” Hawaii State Department of Health, April 2023. https://health.hawaii.gov/cab/hawaii-greenhouse-gas-program/.

Table 2: Emissions Summary by Sector for 2019 (UHERO and DOH GHG Inventory)

Carbon Sink or Source	**Quantity Emitted or Absorbed Annually (MMT CO_2E)**	**Source**
Energy Sector Emissions*	19.44	2019 GHG Emissions Report[17]
IPPU	0.84	
Waste	0.41	
AFOLU (Sources)	1.31	
Total Emissions	**22.01**	
AFOLU (Sinks)	(2.59)	
Net AFOLU	**(1.28)**	
Net Emissions	**19.42**	
Orca Facility, DACCS Facility Iceland	*(0.004)*	CarbFix
Mammoth Facility, DACCS Facility Iceland	*(0.036)*	CarbFix
Project Bison, DACCS Facility Wyoming	*(5.00)*	CarbonCapture Inc.[18]

Quantification and summation of energy sector emissions do not include international bunker fuels. Totals may not sum due to independent rounding. Parentheses indicate negative values or sinks. *Energy sector emissions are inclusive of the electricity sector (stationary combustion) and transportation emissions.

Geological Carbon Storage

Climate researchers have recognized highly reactive basalt rocks can be a solution to the carbon storage problem because of their physical and chemical makeup.[19] When a volcano erupts, lava flows in a series of repeated events. In areas where lava exhibits low silica content, such as Hawaiʻi or Iceland, this basaltic lava accumulates, thickens, and solidifies becoming a basalt formation. Basalt rock has relatively low silica mineral content and has high proportions of magnesium, iron, and calcium, which are highly reactive minerals within basalt. Their ions (Mg^{2+}, Ca^{2+}, and Fe^{2+}), which are released during dissolution become key components of the mineralization reaction. When the dissolved ions within the basalt react with the bicarbonate ions, originating from the dissolution of CO_2 in water, the reaction forms stable carbonate minerals providing long-term CO_2 storage.[20] Geological sequestration takes advantage of this process, by capturing the CO_2 (either through CCS or CDR technology such as DACCS), mixing the CO_2 with water or placing

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[17] Id

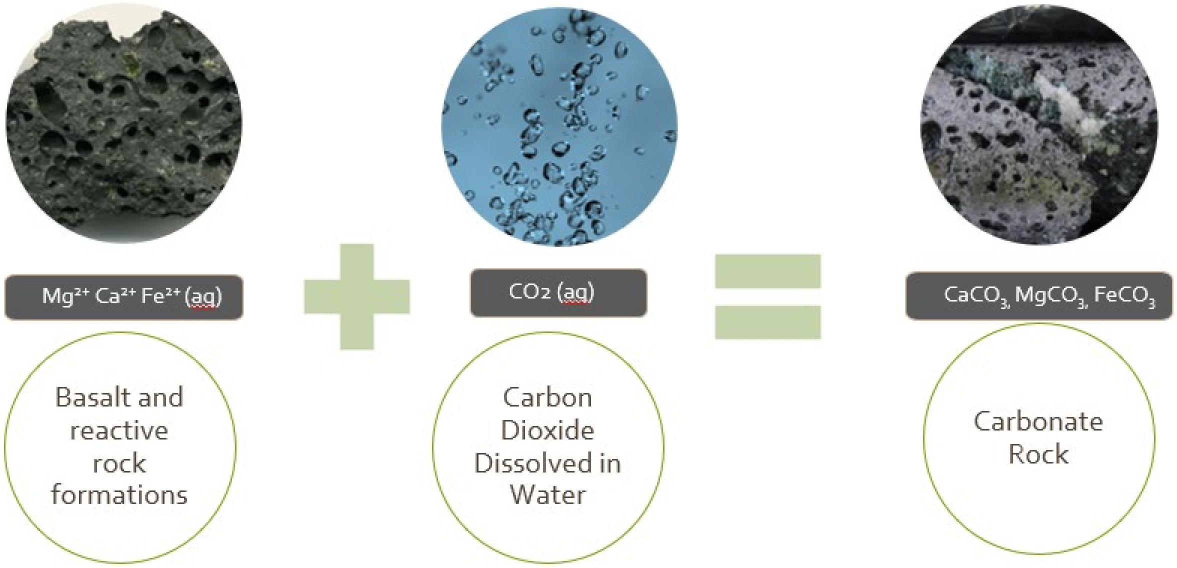
[18] CarbonCapture Inc. Announces Five Megaton Direct Air Capture and Storage Project in Wyoming. Press Release, 2022 https://www.businesswire.com/news/home/20220908005446/en/CarbonCapture-Inc.-Announces-Five-Megaton-Direct-Air-Capture-and-Storage-Project-in-Wyoming

[19] Cartier, K. "Basalts turn carbon into stone for permanent storage." *Eos* 101, no. 6 (2020).

[20] International Energy Agency (IEAGHG). "Geological Storage of CO2 in Basalts," September 2011. https://ieaghg.org/docs/General_Docs/Reports/2011-TR2.pdf.

the CO_2 in supercritical form, then transporting the aqueous or supercritical[21] CO_2 through injection wells to deep geological basalt formations, where it reacts with the substrate to form carbonate rock.[22]

Alkalinity also plays a key role in the chemical reaction, because groundwater in basaltic formations is typically brackish with a pH between 8.5 and 9.2.[23] When CO_2 is injected into the basalt it reduces the pH to approximately 3.5 or lower, releasing hydrogen ions and driving the reaction forward.[24] Pyroxene, olivine, and spinel, which are iron-rich minerals in basalt formations, are unstable at low pH; therefore, dissolution readily occurs.[25] The dissolved iron reacts with CO_2 to form solid ferrous carbonate minerals such as siderite.[26] In carbon storage experiments tied to geothermal power plants in Iceland, 90% of injected carbon dioxide (CO_2) transformed into minerals in just two years.



The process mimics the natural carbonate-silicate weathering process, a key component of the carbon cycle, but accelerates it to a scale that could more closely match the rate at which carbon dioxide has been emitted into the atmosphere, and eventually, if emissions are low enough, drawdown or reduce carbon dioxide concentration in the atmosphere.[27]

FIGURE 2: MINERALIZATION PROCESS, *ADAPTED FROM CARBFIX*

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[21] DePaolo, D. J., Thomas, D. M., Christensen, J. N., Zhang, S., Orr, F. M., Maher, K., ... & Mito, S. (2021). Opportunities for large-scale CO2 disposal in coastal marine volcanic basins based on the geology of northeast Hawaii. International Journal of Greenhouse Gas Control, 110, 103396.

[22] Vilarrasa, Victor, and Jonny Rutqvist. "Thermal effects on geologic carbon storage." *Earth-science reviews* 165 (2017): 245-256.. https://doi.org/10.1016/j.earscirev.2016.12.011.

[23] McGrail, B. Peter, Anita M. Ho, Steve P. Reidel, and Herbert T. Schaef. "Use and features of basalt formations for geologic sequestration." In *Greenhouse Gas Control Technologies-6th International Conference*, pp. 1637-1640. Pergamon, 2003.

[24] McGrail, et al. (2003).

[25] IEAGHG (2011)

[26] IEAGHG (2011)

[27] Snæbjörnsdóttir, Sandra Ó., Bergur Sigfússon, Chiara Marieni, David Goldberg, Sigurður R. Gislason, and Eric H. Oelkers. "Carbon dioxide storage through mineral carbonation." Nature Reviews Earth & Environment 1, no. 2 (2020): 90-102. https://doi.org/10.1038/s43017-019-0011-8

Environmental and Geologic Considerations

In Hawaiʻi, selecting a site for a geological sequestration facility would be determined by both physical factors—impacted by the geological substrate, technical feasibility, environmental and safety considerations, and social factors driven by community acceptance.

Technical Feasibility

The site selection of the sequestration facility, or injection site, is determined by the underlying geology. The injection site substrate needs to be both porous and permeable to ensure the injected CO_2-water mixture can be held within the substrate but can also move through the substrate. To ensure there is no leakage back into the atmosphere during mineralization, the selected site ideally has impermeable caprock, however with liquid injection, this need becomes less pertinent.[28,29] An example of this is limestone caprock overlying a basalt rock formation. Additionally, future studies would have to examine what type of rift zone and lava flow would be best suitable for an injection site in the Hawaiian Islands. A rift zone is a geologic setting where surface bedrock is experiencing tension. That is, bedrock is being pulled open, leading to a zone of faults and increased porosity and permeability where carbon dioxide injection will have an abundance of rock surfaces for mineralization. All Hawaiian shield volcanoes have rift zones associated with them.

Once this is known, a cost-benefit analysis would be required to examine cap rock availability and the location of the most ideal basalt/rift zones. The depth of the injection site is generally location dependent and corresponds to a variety of factors, including the depth to reach basalt rock. The number of wells required is dependent on the amount of CO_2 stored as well as the horizontal permeability and porosity within the substrate. Past studies in Iceland have shown that the mineralization process takes approximately two years,[30] but it is also a function of rock porosity.

Understanding the pore space and underlying geological substrate at depth is the first part of moving forward with carbon sequestration options. To understand the geological substrate, slim hole wells are needed. While Hawaiʻi has the chemical composition needed to sequester carbon – knowledge of pore space is the critical next step.

Groundwater Resource Considerations

A significant environmental consideration is the impact of a sequestration facility on potential groundwater resources. To minimize the impact on groundwater resources the injection site would ideally be situated seaward or makai of underground drinking water sources. This boundary is commonly denoted as the "UIC Line." Another potential impact to consider is the effect of mineralization on the porosity of the

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[28] Hannon Jr, Michael J., and Richard A. Esposito. "Screening considerations for caprock properties in regards to commercial-scale carbon-sequestration operations." International Journal of Greenhouse Gas Control 32 (2015): 213-223.

[29] Bond, Clare E., Yannick Kremer, Gareth Johnson, Nigel Hicks, Robert Lister, Dave G. Jones, R. Stuart Haszeldine et al. "The physical characteristics of a CO_2 seeping fault: The implications of fracture permeability for carbon capture and storage integrity." *International Journal of Greenhouse Gas Control* 61 (2017): 49-60. https://doi.org/10.1016/j.ijggc.2017.01.015

[30] Carbfix. "How It Works." Accessed July 20, 2022. https://www.carbfix.com/how-it-works/.

rock; as mineralization occurs the porosity is effectively decreased.[31] This must be considered in detail for any site selected to ensure that the impact on subsurface geology characteristics does not impact the future use of groundwater resources. Further, as the rock porosity at the injection site decreases there is a reduction in the efficiency of the carbon mineralization reaction, underscoring the need for the substrate to have adequate porosity to ensure ongoing efficiency of carbonation reactions. The impact on groundwater resources would be mitigated by drilling and injecting below the groundwater reservoir as depicted in Figure 3.[32]

In addition to changing the physical characteristics of subsurface hydrogeology, CO_2 injection also has the potential to impact groundwater chemistry. When CO_2 is injected into groundwater it acts as an effective solvent for organic compounds such as benzene, phenols, and aromatic hydrocarbons; CO_2 injection could result in their mobilization and transport.[33] This underscores the need to ensure there is no CO_2 leakage into any drinking water aquifer and that the mineralization occurs at a depth adequate to ensure the CO_2 solution does not come into contact with historic contaminants to prevent mobilization into groundwater.

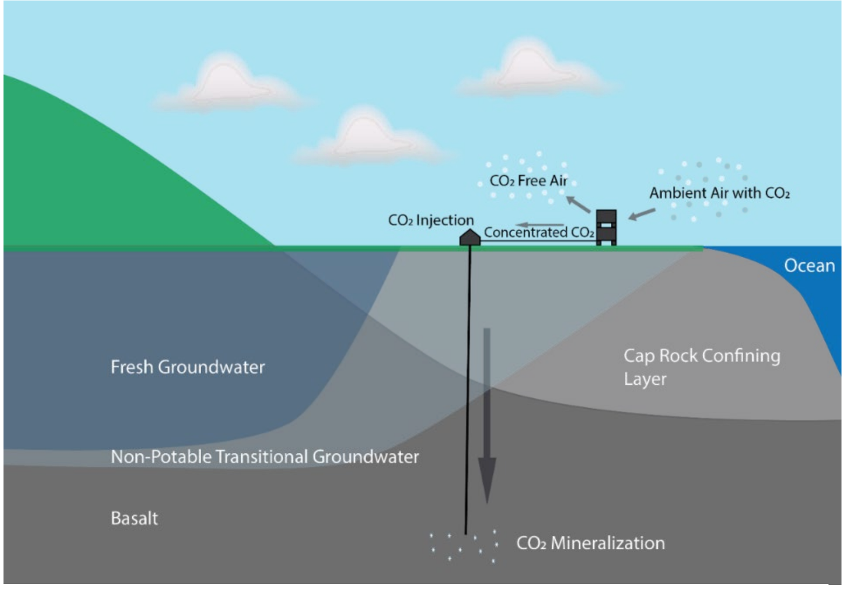

FIGURE 3 CARBON CAPTURE AND SEQUESTRATION PROCESS THROUGH DIRECT AIR CAPTURE AND MINERALIZATION

Carbon Dioxide Leakage

Carbon dioxide leakage refers to the re-release of sequestered carbon dioxide back into the atmosphere before mineralization takes place. Leakage is a significant concern when considering the environmental benefits of a sequestration project. The carbon dioxide injected into the subsurface must remain within the subsurface while mineralization occurs, to ensure permanent carbon sequestration and net negative emissions.[34] Despite this concern, geologic sequestration has demonstrated adequate security and carbon retention so long as relatively impermeable caprock can prevent rapid migration of carbon dioxide from the subsurface back to the atmosphere, potentially implicating the storage site selection.[35] Leakage is also

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[31] Kharaka, Y., David R. Cole, James J. Thordsen, Kathleen D. Gans, and R. Burt Thomas. "Geochemical monitoring for potential environmental impacts of geologic sequestration of CO2." *Geochemistry of Geologic CO2 Sequestration* 77 (2013): 399-430.

32 Newmark, R. L., Friedmann, S. J., & Carroll, S. A. (2009). Water Challenges for Geologic Carbon Capture and Sequestration. Environmental Management, 45(4), 651-661. https://doi.org/10.1007/s00267-010-9434-1

33 Kharaka, et al. (2013).

[34] Miocic, Johannes M., Stuart Gilfillan, Norbert Frank, Andrea Schroeder-Ritzrau, Neil M. Burnside, and R. Stuart Haszeldine. "420,000 year assessment of fault leakage rates shows geological carbon storage is secure." *Scientific reports* 9, no. 1 (2019): 1-9. https://doi.org/10.1038/s41598-018-36974-0

[35] Bond, et al. (2017).

prevented through the dissolution of the CO_2 into liquid form, as the dissolved gas is no longer buoyant reducing potential leakage at the surface.[36] Further, CO_2 injection occurs far below the fresh

Seismic Considerations

Seismic concerns must be adequately addressed during both site selection and operations. There are pilot projects and studies that evaluate these risks and provide valuable insight as to how to both evaluate risk and actively manage injection activities to ensure risk is minimized.[37]

During a site assessment, it is important to include a study for seismic activity because information on the potential for earthquakes to be induced by formation pressure derived from CO_2 injection should be understood before any injection occurs.[38] If geologic sequestration is to be implemented or studied in Hawaiʻi, it is imperative that a site assessment and funding for research studies are done for Hawaiʻi to examine the geological conditions that would be best suitable for the injection of aqueous CO_2 to prevent seismic risk associated with CO_2 injection.

During operations, injection of CO_2 mixture into the substrate results in increased risk for seismic activity, but if it is closely monitored significant seismic activity can be regulated and prevented. The CO_2 Storage Research Group at the Research Institute of Innovative Technology for the Earth in Japan has developed a system called the Advanced Traffic Light System (ATLS), an example of a robust seismic monitoring and management system.[39] This system communicates the level of safety related to injection rate with traffic light colors. The color that is shown is based on observed real-time data of micro-seismicity.[40] This system is designed to identify any irregularity as early as possible and would enable injection operators to control the CO_2 injection rates in accordance with the information.[41] CO_2 Storage Research Group has also investigated identifying micro-seismicity in observation data without errors. Carbfix has implemented a seismic traffic light system as a successful method to minimize the risk of induced seismicity. It operates by controlling and adjusting flow rates as needed during injection. This method has been in operation for the Hellisheiði injection system since 2012.[42]

Environmental Needs and Inputs

The carbon dioxide sequestration or underground storage and mineralization process can take place anywhere with porous basalt that can be accessed without impacting groundwater resources. The depth of the porous basalt may be a limiting factor (e.g. if there is significant caprock that must be drilled through to reach basalt). Other needs include the use of these highly valued and limited resources: 1) Water, 2) Land, 3) Energy.

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[36] Ratouis, Thomas MP, Sandra O. Snæbjörnsdóttir, Gunnar Gunnarsson, Ingvi Gunnarsson, Bjarni R. Kristjánsson, and Edda SP Aradóttir. "Modelling the Complex Structural Features Controlling Fluid Flow at the CarbFix2 Reinjection Site, Hellisheiði Geothermal Power Plant, SW-Iceland." In Proceeding: 44th Workshop on Geothermal Reservoir Engineering, Stanford University, CA, USA. (2019).

[37] Lee, Kang-Kun, William L. Ellsworth, Domenico Giardini, John Townend, Shemin Ge, Toshihiko Shimamoto, In-Wook Yeo, et al. "Managing Injection-Induced Seismic Risks." *Science* 364, no. 6442 (2019): 730–32. https://doi.org/10.1126/science.aax1878.

[38] Research Institute of Innovative Technology for the Earth (RITE) "Research Content" CO2 Storage Research Group. Accessed July 13, 2022. https://www.rite.or.jp/co2storage/en/detail/#anch03.

[39] Id

[40] Id

[41] Id

[42] *Proven*. Carbfix. Retrieved November 29, 2022, from https://www.carbfix.com/proven

Energy Needs for DAC

As discussed above, Hawaiʻi is presently on track to reach its goal of producing 100 percent of its energy from renewable sources before its legal deadline of 2045. The energy source used to power any direct air capture (DAC) facility will contribute to the overall net negativity of the system. Studies have indicated that the climatic benefits of DAC are highly dependent on the energy source used to power the associated capture facility.[43] The energy requirements for a DAC facility can generally be divided into two components:

1) Energy for mechanical components such as the fans to collect the CO_2 from the air, and
2) Energy to adequately heat the CO_2 collected and desorb it from the surface of the collection adsorbents (carbon filters).

Estimated energy requirements for CO_2 capture using Climeworks DAC technology, as demonstrated by the first net-negative facility Orca in Hellisheiði, are about 500 kilowatt-hours (kWh) per ton CO_2 for electricity, not including the electricity consumption for CO_2 compression, and 1,500 kWh per ton CO_2 for heat (for temperatures around 100°C).[44, 45]

As an example, the Climeworks Orca DAC facility in Iceland, which captures approximately 4,000 tons per year, requires approximately 2,000 megawatt-hours (MWh) per year of mechanical energy, excluding the energy used for compression, and approximately 6,000 MWh of energy for heating requirements per year. In total, operations require about 8,000 MWh per year for a facility of Orca's size. The facility in Iceland is powered by excess geothermal energy from the Hellisheiði Power Plant.

Carbon dioxide concentration in the ambient air has reached about 420 parts per million, as measured on Mauna Loa on Hawaiʻi Island this year.[46,47] Such an elevated level of carbon dioxide available in the ambient air means that direct air carbon capture methods can effectively pull carbon dioxide from the atmosphere almost anywhere on Earth. However, energy requirements decrease when the concentration of CO_2 is higher. For example, capturing carbon dioxide from a more concentrated source, such as from flue gas of an emissions source can reduce the energy requirements of direct air capture. Further, if emissions are captured from a non-renewable energy source, it also raises the question of whether capturing these emissions perpetuates the use of fossil fuels.

Energy requirements also vary based on the configuration and energy sources for the DAC system. For an autonomous system (not attached to the utility grid), that is entirely powered by photovoltaic electricity (including a high-temperature heat pump (HTHP) operated with electricity from the grid), energy requirements increase, as there is no direct heat source.

For perspective, solar energy facilities throughout Hawaiʻi generate a comparable amount of electricity annually. In 2020, Kalaeloa Renewable Energy Park (5 MW, ~20 acres) generated 7,812 MWh of electricity,

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[43] Terlouw, T., Treyer, K., Bauer, C., & Mazzotti, M. (2021). Life cycle assessment of direct air carbon capture and storage with low-carbon energy sources. *Environmental Science & Technology*, *55*(16), 11397-11411

[44] Terlouw, et al. (2021).

[45] Deutz, S., & Bardow, A. (2021). Life-cycle assessment of an industrial direct air capture process based on temperature–vacuum swing adsorption. *Nature Energy*, *6*(2), 203-213.

[46] Fletcher, Chip. "CO2 Level Just Passed an Important Benchmark – a Measure of Humanity's War on Nature." The Hill, June 6, 2022. https://thehill.com/opinion/energy-environment/3513460-co2-level-just-passed-an-important-benchmark-a-measure-of-humanitys-war-on-nature/

[47] Stein, Theo. "Carbon Dioxide Peaks near 420 Parts per Million at Mauna Loa Observatory." Welcome to NOAA Research, June 7, 2021. https://research.noaa.gov/article/ArtMID/587/ArticleID/2764/Coronavirus-response-barely-slows-rising-carbon-dioxide.

South Maui Renewable Resources Project (2.87 MW, ~11 acres) generated 6,480 MWh of electricity, and Aloha Solar Energy Fund (5 MW) in Kapolei generated 8,605 MWh.[48] These solar facilities are not accompanied by battery storage. However, if paired with batteries their energy output could be significantly higher. The recently completed approximately 150-acre Mililani I solar project with the nameplate capacity of 39 MW paired with 156 MWh battery storage is estimated to generate 93,121 MWh of electricity per year,[49] exceeding the energy requirements of a carbon capture system like Orca.

Water Needs

Approximately 32 tons of fresh water are needed to dissolve each metric ton of CO_2 at 25°C and 25 bar pCO_2, which is a substantial volume of water.[50] In the future, the injection of seawater with dissolved CO_2 into basalts could be a successful approach for long-term safe CO_2 mineral storage which is shown using the technology at Carbfix.[51]

An estimated 32 tons of fresh water are needed to dissolve 1 ton of CO_2

A study that focused on freshwater versus seawater for CO_2 injection suggests that the carbonation of gas-charged seawater may be in many cases as efficient as the carbonation of gas-charged freshwater.[52] More research needs to be accomplished to improve the efficiency of the technology so that salt water can be used. There is an ongoing field pilot injection using seawater for the Carbfix technology in Iceland on the Reykjanes peninsula that started in 2022.[53] Results from this study will be very important for the implementation of a facility in Hawai‘i. Given the current water crisis, particularly prevalent on the islands of O‘ahu and Maui, and drought conditions in other parts of the state, a facility requiring freshwater would be impracticable given the water intensity and requirements for this type of sequestration.

Land Requirements

Direct air carbon capture methods vary, but some engineered solutions require relatively little land area when compared to land-based carbon capture alternatives such as tree planting. For reference, the Climeworks’ Orca facility in Reykjavik, Iceland, sits on a plot of land that is roughly 2,000 square meters

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[48] Hawaii State Energy Office. “Hawaii Statewide Energy Project Directory.” July 2022. https://histategis.maps.arcgis.com/apps/webappviewer/index.html?id=416f769becc94bee89fbc93a463bc95b.

[49] Application of Hawaiian Electric Company for Approval of Power Purchase Agreement for Renewable Dispatchable Generation with Mililani I Solar, LLC. (2018, December 31) Docket 2018-0434.

[50] Deutz et al. (2013)

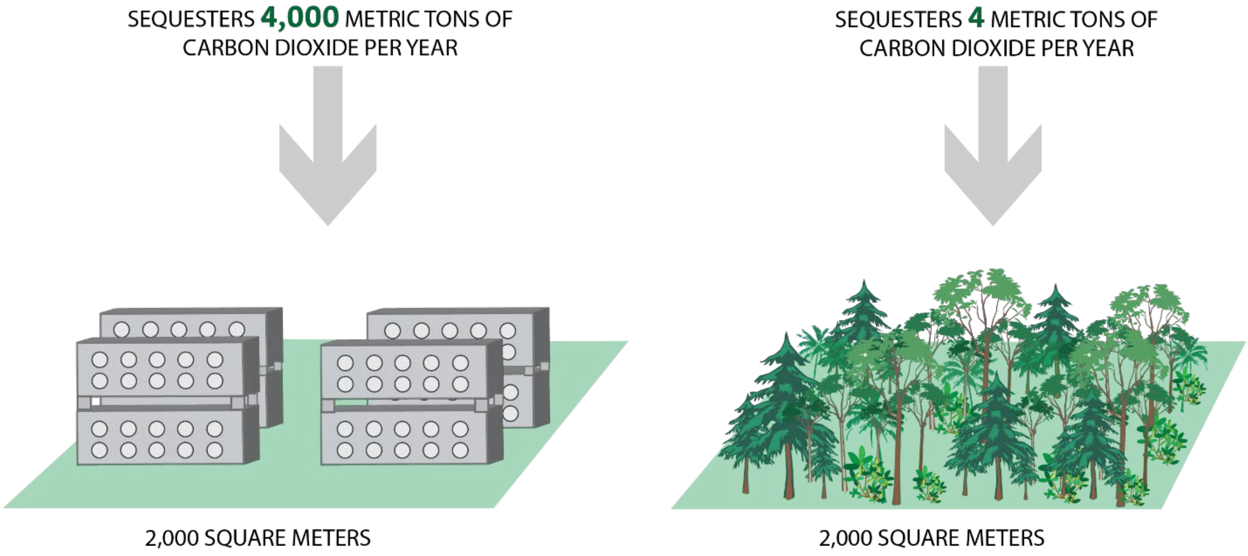
[51] “Carbfix Technology Validated Using Seawater.” We turn CO2 into stone. Carbfix. Accessed July 13, 2022. https://www.carbfix.com/carbfix-technology-and-seawater/.

[51] Deutz, Sarah, and André Bardow. “Life-Cycle Assessment of an Industrial Direct Air Capture Process Based on Temperature–Vacuum Swing Adsorption.” *Nature Energy* 6, no. 2 (2021): 203–13. https://doi.org/10.1038/s41560-020-00771-9.

[52] Marieni, Chiara, Martin Voigt, Deirdre E. Clark, Sigurður R. Gíslason, and Eric H. Oelkers. “Mineralization Potential of Water-Dissolved CO2 and H2S Injected into Basalts as Function of Temperature: Freshwater versus Seawater.” *International Journal of Greenhouse Gas Control* 109 (2021): 103357. https://doi.org/10.1016/j.ijggc.2021.103357.

[53] Voigt, Martin, Chiara Marieni, Andre Baldermann, Iwona M. Galeczka, Domenik Wolff-Boenisch, Eric H. Oelkers, and Sigurdur R. Gislason. "An experimental study of basalt–seawater–CO2 interaction at 130° C." Geochimica et Cosmochimica Acta 308 (2021): 21-41. https://doi.org/10.1016/j.gca.2021.05.056

(6,562 square feet, ~0.5 acres).[54] At approximately 0.15 acres it is smaller than the size of a high school gymnasium. The Orca facility sequesters roughly two metric tons of carbon dioxide per square meter and permanently sequesters 4,000 metric tons of carbon dioxide per year. If those same 2,000 square meters were planted with trees, it would sequester just four tons of carbon dioxide.[55]



Climeworks' technology used for the Orca facility is modular. Each module contains multiple fans which are each the size of a shipping container (40 feet x 8 feet x 9.5 feet). At the Orca facility in Iceland, there are eight modules. The modules can be stacked to save space and further increase the metric ton per square meter calculation, however, it is important that adequate spacing between modular units is available to ensure concentrations of CO_2 in the adjacent air is high enough to efficiently pull the CO_2 out of the air.[56]

It is estimated that the land required to space out air contactors for a million-ton CO_2/year DAC facility is in the range of 1–7 square kilometers.[57]

Policy Process

Compliance with Hawaiʻi State Law

Hawaiʻi Revised Statutes section 225P-5 sets a target to "sequester more atmospheric carbon and greenhouse gases than emitted within the State as quickly as practicable, but no later than 2045."[58] This

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[54] Ono, David. "The Time Machine: This Technology Filters Carbon out of Earth's Atmosphere." ABC7 Los Angeles. KABC-TV, November 24, 2021. https://abc7.com/edge-on-the-earth-climate-change-carbon-capture-technology-orca/11265880/.

[55] Ono, David. (2021)

[56] Climeworks. "Climeworks Begins Operations of Orca, the World's Largest Direct Air Capture and Co_2 Storage Plant." Achieve net zero targets with Climeworks direct air capture. Climeworks, September 8, 2021. https://climeworks.com/news/climeworks-launches-orca.

[57] Negative Emissions Technologies and Reliable Sequestration: A Research 722 Agenda, The National Academies Press, Washington, DC, 2019.

[58] Haw. Rev. Stat. § 225P-5.

statutory target provides the rationale for the following speculation on the regulatory process that could be required.

Given the complexity and potential impacts on the surrounding environment and communities, the state would need to implement a comprehensive regulatory structure to adequately manage the capture and geologic sequestration of carbon dioxide in Hawaiʻi. Currently, there is no Hawaiʻi-specific regulatory regime that regulates such use, however, there are several state and local environmental and land use laws that could come into play. Some, but not all of them, are identified herein.

State resources are protected by Article XI of the Hawaiʻi Constitution, Conservation, Control, and Development of Resources also known as the Hawaiʻi Public Trust Doctrine, which extends protections to “land, water, air, minerals, and energy sources”, and requires state agencies and all political subdivisions to “promote the development and utilization of these resources in a manner consistent with their conservation and furtherance of the self-sufficiency of the State.” [57]

Under Hawaiʻi Revised Statutes, Chapter 343, the Hawaiʻi Environmental Policy Act (HEPA), an applicant is required to do at least an Environmental Assessment if the applicant proposes specific uses or uses on specified types of land.[58] For instance, the applicant must comply with the HEPA if it proposes:

1) The use of state or county lands or the use of state or county funds”,
2) Any use within any land classified as a conservation district by the state land use commission; or,
3) Any use within a shoreline area.”[59]

The question remains open as to whether the state government inherently owns the geologic formations underground that would be ideal for a CCS project. Under Article XI, section 1 of the Hawaiʻi Constitution:

For the benefit of present and future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals, and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and furtherance of the self-sufficiency of the State.

All public natural resources are held in trust by the State for the benefit of the people.[59]

Geologic sequestration of carbon dioxide would likely trigger HEPA review as a use of state resources and the potential impacts of geologic sequestration would also likely require a constitutional public trust analysis due to the potential impacts on mineral resources underground.

Under Hawaiʻi Revised Statutes Chapter 182, Hawaiʻi’s State Reservation and Disposition of Government Mineral Rights, the state reserves to itself “All minerals in, on, or under state lands or reserved lands are reserved to the State; provided that the board may release, cancel, or waive the reservation whenever it deems the land use, other than mining, is of greater benefit to the State.”[60] However, the statute defines the term minerals as “any or all of the oil, gas, coal, phosphate, sodium, sulfur, iron, titanium, gold, silver, bauxite, bauxitic clay, diaspore, boehmite, laterite, gibbsite, alumina, all ores of aluminum and, without limitation thereon, all other mineral substances and ore deposits whether solid, gaseous, or liquid, including all geothermal resources, in, on, or under any land, fast or submerged; but does not include sand, rock, gravel, and other materials suitable for use and used in general construction.”[61] For context, the statute also defines geothermal resources as “the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines,

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[59] Haw. Const. Art. XI, sec. 1.

[60] Haw. Rev. Stat. § 182-2 (2022).

[61] Haw. Rev. Stat. § 182-1 (2022).

associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, other hydrocarbon substances, and any water, mineral in solution, or other product obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, and not used for electrical power generation."[62]

Geologic sequestration of carbon dioxide is a use that Hawaiʻi's government, including the courts, has not yet considered. The only comparable land use case with judicial precedence implemented in the state at this time is the Puna Geothermal Powerplant on Hawaiʻi Island. In addition, there are statutes and regulations for leasing and drilling of wells for other purposes, such as leasing of lands for geothermal energy, which may serve as a good framework regarding what could be required for a similar regime to regulate carbon storage wells.[63]

The Hawaiʻi Public Utilities Commission's March 16, 2022 Decision and Order 38276, Docket Number 2019-0333 regarding the then-proposed powerplant, discussed important constitutional public trust doctrine concepts. First, the Commission noted that under Hawaiʻi Supreme Court precedent when "a proposed project poses a reasonable threat to a trusted resource, the Commission 'as a trustee must further assess that threat; and to approve the project's Power Purchase Agreement, it must affirmatively find that there is no harm to the trusted resource or that potential harm is justified.'"[64] Further, the Commission noted that under the Hawaiʻi Supreme Court precedent, for there to be "a reasonable threat to a public trust resource, there must be something more than vague and tenuous concerns about a project's surrounding environment; there must be tangible evidence that reasonably connects the threatened harm to the proposed project."[65]

The geologic impacts and constitutional public trust doctrine considerations in the case of Puna Geothermal are distinguishable from the geologic sequestration of carbon dioxide. First, geologic sequestration of carbon dioxide is not extractive in nature in that sequestration does not diminish the amount of the resource; however, the action does change the physical and chemical composition. In the case of geothermal energy, heat is extracted from underground to produce energy for consumption, whereas, in geologic sequestration, carbon dioxide mixed with water is added to the underground resource.

In the case of geologic sequestration, it is not clear whether the act of sequestration would affect geologic resources including minerals and state land, but Hawaiʻi's governmental agencies would be required to "assess that threat" and "affirmatively find that there is no harm to the trusted resource or that the potential harm is justified." Experts in geologic sequestration have found that the process can cause increased seismic activity, as discussed above, but at this stage, it is unclear whether and to what extent this impact will have on underground natural resources. Due to the impacts of global climate change because of excess carbon dioxide in the atmosphere and the state's net negative goal it could be determined that other public interests outweigh possible negative effects.

Facilities located or with infrastructure along the coastline would likely be regulated by Hawaiʻi Revised Statutes, Chapter 183C - Conservation Districts and the Hawaiʻi Coastal Zone Management Act, Chapter 205A. Facilities with the potential to impact protected species or their habitats must comply with Hawaiʻi

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[62] Haw. Rev. Stat. § 182-1 (2022).

[63] HRS *§§ 183-18 ("The permittee shall be required to comply with the requirements of all federal, state, and applicable county laws, rules, and regulations."), -55(c) ("subject to the requirements of chapter 343 Hawaii Revised Statutes.").*

[64] Hawaiʻi Public Utilities Commission Decision & Order No. 38276, Docket No. 2019-0333 (Mar. 16, 2022) at 44 (quoting Paeahu at *7).

[65] Hawaiʻi Public Utilities Commission Decision & Order No. 38276, Docket No. 2019-0333 (Mar. 16, 2022) at 46 (quoting Paeahu at *8).

Revised Statutes, Chapter 195D (Conservation of Aquatic Life, Wildlife, and Land Plants). As stated previously herein, this is not a complete list of potential state regulations and does not include other potentially applicable federal or local regulations.

EPA Class VI Wells

The injection of carbon dioxide for geologic sequestration would require the drilling and associated permitting of an underground injection control (UIC) well. Wells used for geologic sequestration of carbon dioxide are deemed "Class VI" wells. The EPA defines the Class VI injection practice as the "process of injecting carbon dioxide, captured from an industrial (e.g., steel and cement production) or energy-related source (e.g., a power plant or natural gas processing facility), into deep subsurface rock formations for long-term storage."[66] wells. For all UIC wells. the state and federal government share regulatory oversight under the national system of "marble cake federalism".[67] The U.S. Environmental Protection Agency (EPA) is granted primary enforcement authority under the Safe Drinking Water Act and currently has federal primacy to regulate Class IV wells.

Hawai'i has not attained primacy of jurisdiction over the regulation of any class of wells. Per EPA regulation, "If a state, territory, or tribe does not obtain primacy for all or some UIC well classes, EPA implements the program directly through one of its regional offices."[68] Although Hawai'i has not formally applied for and been granted primacy jurisdiction over any class of injection wells, the state does regulate Class I-V UIC wells which are used for injection of non-hazardous fluids into or above underground sources of drinking water. The Hawai'i DOH Safe Drinking Branch regulates UIC wells under Hawai'i Revised Statutes Chapter 340E (Safe Drinking Water) and Hawai'i Administrative Rules Chapters 11-23 and –23a (Underground Injection Control). The state currently regulates the wells and issues individual permits and applicants must comply with dual regulatory oversight. At the federal level, the EPA regulates the wells using "authorization by rule" which refers to "the operation of a category of injection wells operated in compliance with these Regulations, without the need for a permit or Rule Authorization letter."[69] To date, only one facility, Puna Geothermal Powerplant on Hawai'i Island discussed above, has been issued an Underground Injection Control Permit from the EPA. DOH has not begun to research the geologic requirements of Class VI injection wells, however dual regulatory oversight by the federal and state governments may be inefficient.

Applying for Primacy Jurisdiction to Regulate Class VI Wells

Application and approval of state primacy is a phased process. In Phase I, an interested state engages with the federal agency in "identifying available resources and the critical elements... of a primacy application..."[70] In Phase II, the federal agency "receives and reviews complete drafts of applicable critical elements of a state submission including the governor's letter, attorney general's letter, program description,

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[66] "Class VI - Wells Used for Geologic Sequestration of Carbon Dioxide." Environmental Protection Agency, July 6, 2022. https://www.epa.gov/uic/class-vi-wells-used-geologic-sequestration-carbon-dioxide.

[67] "Marble cake federalism" is a bakery metaphor often used to describe the model of cooperative federalism. This model of federalism holds that the local, state, and national governments do not act in separate spheres, but instead have interrelated policy goals and administrative duties." http://encyclopedia.federalism.org/index.php/Marble_Cake_Federalism.

[68] US EPA, OW. "Primary Enforcement Authority for the Underground Injection Control Program." Overviews and Factsheets, June 28, 2022. https://www.epa.gov/uic/primary-enforcement-authority-underground-injection-control-program-0.

[69] https://www.lawinsider.com/dictionary/authorization-by-rule.

[70] US EPA, "Primary Enforcement Authority for the Underground Injection Control Program."

memorandum of agreement, and public participation documentation. The EPA and a state may engage in a continued dialogue to ensure that questions are clarified before the end of this phase."[71] In Phase III, the federal agency conducts "a comprehensive evaluation of the regulations and other elements of the primacy application" and "will evaluate, in detail, every aspect of each element and coordinate with an applicant to gain clarity and confirm stringency or effectiveness."[72] In Phase IV, the final phase, the EPA will draft its own rule approving (or disapproving) the state's request for primacy, which includes a summary of the public comments and will be published in the Federal Register.[73] A complete guide published by the EPA is available online for the review and approval of primacy applications.[74]

Ocean-Based Carbon Capture and Removal

Another carbon capture mechanism explored in Hawaiʻi includes the removal of carbon dioxide from ocean water, also known as ocean-based CDR (carbon dioxide removal). Ocean-based CDR technologies are premised on the fact that the ocean acts as a critical carbon dioxide sink and has absorbed an estimated 25 to 30 percent of the atmospheric CO_2 emitted by humans to date.[75] Unfortunately, the ocean's ability to act as a sponge has uncertain limits—how much more carbon the ocean can absorb is unknown. Acidification also comes with detrimental consequences to sea life, notably due to associated acidification—a direct consequence of ocean CO_2 absorption.

Most ocean-based technologies are in the early research or pilot stages; ocean-based technologies utilize different mechanisms to remove CO_2 from ocean water. Researched mechanisms include electrochemical CO_2 scrubbing, alkalinity enhancement, seaweed and macroalgae cultivation, nutrient fertilization, and ecosystem restoration.[76] Ocean-based CDR, particularly non-biological technology has not yet been implemented on a large scale. Of the listed mechanisms, electrochemical scrubbing requires electricity/energy inputs. Electrochemistry considers chemical reactions that result in the production or consumption of electricity. There are multiple distinct methods using electrochemical pathways for ocean-based CDR, but as a summary, electrochemical approaches pass electric currents through seawater to rearrange water and salt molecules into a basic and acidic solution, the acidic stream can be utilized to degas the CO_2 from the seawater for storage or use, the basic stream can be used to enhance ocean alkalinity.[77] These induced chemical reactions effectively use electricity to drive chemical reactions that ultimately result in the removal of carbon dioxide from the atmosphere.[78] For all ocean-based, specifically, electrochemical CDR approaches, there are intended and unintended consequences with potentially substantial impacts on the environment, ecological systems, and coastal communities. The global scientific knowledge base

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[71] id

[72] id

[73] US EPA, "Primary Enforcement Authority for the Underground Injection Control Program."

[74] "Guidance Documents for Review of UIC Primacy Applications and Program Revisions." Underground Injection Control. Environmental Protection Agency. Accessed July 18, 2022. https://www.epa.gov/uic/guidance-documents-review-uic-primacy-applications-and-program-revisions.

[75] Watson, A. J., Schuster, U., Shutler, J. D., Holding, T., Ashton, I. G., Landschützer, P., ... & Goddijn-Murphy, L. (2020). Revised estimates of ocean-atmosphere CO2 flux are consistent with ocean carbon inventory. *Nature communications*, *11*(1), 1-6.

[76] National Academies of Sciences, Engineering, and Medicine. (2021). A research strategy for ocean-based carbon dioxide removal and sequestration. https://doi.org/10.17226/26278.

[77] Jayarathna, C., Maelum, M., Karunarathne, S., Andrenacci, S., & Haugen, H. A. (2022). Review on direct ocean capture (DOC) technologies. Available at SSRN 4282969.

[78] National Academies of Sciences, Engineering, and Medicine. (2021). A research strategy for ocean-based carbon dioxide removal and sequestration. https://doi.org/10.17226/26278.

on the unintended consequences is limited, therefore, scaling these systems will require substantial research and pilot monitoring before full implementation.

Nutrient fertilization methods for ocean-based CDR are also possible pathways. Put simply, marine phytoplankton depend on nutrients such as iron, phosphorus, and nitrogen.[79] Marine phytoplankton uptake carbon dioxide through photosynthesis and thus the artificial addition of these nutrients on the surface can mimic this natural process and stimulate carbon dioxide removal from the ocean. The phytoplankton become part of the larger marine ecosystem which eventually sinks to the bottom of the ocean where it can stay for a century or longer. Iron fertilization studies have had some documented success but have also faced resistance.[80]

Carbon Capture and Utilization

While there is a clear need to capture and store carbon dioxide permanently, carbon, namely carbon dioxide, also has economically valuable commerce applications that make carbon capture and use (CCU) technology an appealing industry to expand in Hawaiʻi. Currently, Hawaiʻi imports carbon dioxide for a variety of uses. The onset of the COVID-19 pandemic in 2020 highlighted this vulnerability when the supply chain tightened and CO_2 for commercial use became severely limited. The CO_2 used for various industrial processes throughout Hawaiʻi is sourced from the contiguous U.S. or sourced from the local refinery, underscoring the need for local production decoupled from fossil fuel production.[81]

Uses for Carbon After Direct Air Capture	Benefits of Direct Air Capture for Utilization
• Concrete additive • Industrial materials • Sustainable Aviation Fuel and other synthetic fuels • Dry ice industry • Refrigerants • Agriculture Fertilizer and Pesticides • Food processing • Beverage carbonation • pH control in swimming pools	• Local sources less vulnerable to supply chain disruptions • Limited land and water footprint • Viability of locating plants on non-arable land • Capture facilities can be on a small or large scale

Direct Air Capture and Sustainable Aviation Fuel

The aviation sector accounts for a substantial portion of Hawaiʻi's GHG emissions. In 2017, aviation emissions from domestic and military flights totaled 4.1 MMT accounting for 17% of total statewide

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[79] Doney, et al. (2021). A Research Strategy for Ocean-Based Carbon Dioxide Removal and Sequestration. Consensus Study Report Highlights. Accessed on November 20, 2023. https://nap.nationalacademies.org/resource/26278/Ocean_CDR_2021.pdf

[80] "Iron Fertilization." Woods Hole Oceanographic Institution. Accessed November 20, 2023. https://www.whoi.edu/know-your-ocean/ocean-topics/climate-weather/ocean-based-climate-solutions/iron-fertilization/#:~:text=from%20the%20atmosphere.-,Iron%20fertilization%20is%20a%20Carbon%20Dioxide%20Removal%20(CDR)%20technique%20that,to%20stimulate%20growth%20of%20phytoplankton.

[81] Teruya, L. (2021, October 27). Chemical Shortages Are Hitting Hawaii From Pools To Breweries. Honolulu Civil Beat. https://www.civilbeat.org/2021/10/chemical-shortages-are-hitting-hawaii-from-pools-to-breweries/

emissions (excluding sinks).[82] Unfortunately, the aviation sector remains difficult to decarbonize; it is widely considered “hard to abate”. Electrification of flights will be limited to short-distance flights with fewer passengers, due to the “pack-level” specific energy and energy density limitations of batteries (i.e. batteries remain too big and heavy). The aviation industry is thus looking towards other sustainable aviation fuels (SAF). Currently, the American Society of Testing and Materials (ASTM), which sets industry standards for commercial jet fuel has approved the blending of certain SAF with conventional jet fuel, with most SAF pathways limited to 50% volume blends.[83] However, the development of SAFs is still in its infancy with varying technological pathways under development.

One way of producing SAFs is through power-to-fuel technologies. Up until recently, humans burned fuels (wood, coal, gas) to create electricity. With renewable electricity generation on the rise and the need to end the use of GHG-emitting fuels, the direction is likely to be reversed. Instead of using fuels to generate electricity, electricity will be used to generate fuels or other carriers of energy. At the frontier of power-to-fuel technologies are renewable synthetic fuels (“e-fuels”) which are synthesized in several ways from various sources of CO_2 and water. Some of these e-fuel pathways are looking to use CO_2 captured from a point source (e.g., factory emissions) and some are also looking into using DAC as a source of CO_2. This captured CO_2 is mixed with water and converted via an electrolysis unit into synthetic gas (“syngas”). The syngas is then transformed into liquid hydrocarbons by a modular Fischer-Tropsch (FT) reactor and then it is further refined into aviation fuel. Once the jet fuel is burnt all the captured CO_2 is returned to the atmosphere.

As with most CO_2 utilization, the CO_2 is not sequestered/stored long-term. The overall carbon benefit is ultimately determined by the life-cycle carbon intensity of the renewable energy used to capture CO_2. What is appealing about e-fuels is that they can relatively easily replace conventional jet fuel without the need for new infrastructure or redesigning of aircraft. This pathway is worth further exploration and consideration as the next step for the decarbonization of Hawaiʻi’s aviation sector; however, the aviation sector is also highly regulated with safety being the number one priority. Any fuel will need to meet the rigorous national ASTM standards; the state’s largest role is ultimately to support the infrastructure required to meet the need.

Current Incentives and Legislation for Carbon Utilization

In October 2022, the White House announced actions under the Federal Buy Clean Initiative to prioritize the purchase of lower-carbon steel, concrete, asphalt, and flat glass—materials that account for nearly half of all U.S. manufacturing greenhouse gas emissions.

In 2018, the Honolulu City Council passed Resolution 18-283, which requests the City Administration to consider using carbon dioxide mineralization concrete for all future City infrastructure projects utilizing concrete. In 2019, The Hawaiʻi Department of Transportation started testing a concrete mix injected with waste carbon dioxide as an initiative to reduce carbon emissions in transportation infrastructure 2019. Today, the “carbon-injected” concrete is produced using waste carbon dioxide from Hawaiʻi Gas. The mineralized concrete product acts as a permanent storage mechanism for the carbon dioxide that would otherwise be released into the air. Bills have been introduced into State legislation requiring the use of “carbon-injected” concrete throughout the State; however, the bills did not move forward in both the 2021 and 2022 legislative sessions.

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[82] “Hawaii Greenhouse Gas Report for 2017 Report.” Hawaii State Department of Health, April 2021.

[83] O’Rear E., Herndon W., Hiltbrand G., Wimberger E., and Larson J. (2022) Sustainable aviation fuels: The key to decarbonizing aviation. *Rhodium Group*. Retrieved from https://rhg.com/research/sustainable-aviation-fuels/

Economic Implications and Carbon Offset Credits

The carbon offset market provides a potential financial mechanism for future and ongoing funding of a SAF production or carbon capture facility and could serve to diversify Hawaiʻi's economy. While project research, piloting, initiation, and startup costs likely need some form of upfront government subsidization, in the long term, selling carbon offset credits could provide funds for ongoing operations. Further, it could also help to provide another self-sustaining industry in Hawaiʻi resulting in the potential to further diversify the local economy. The sale of carbon offsets to fund project operations is promising as the demand for offset credits is growing and is expected to increase as companies and countries make net-zero commitments.

However, if a carbon capture facility were to sell offsets and enter itself into the carbon market as the primary source of funding, it is important that the facility carefully consider concerns surrounding today's carbon market. These concerns include:

1) Marginal costs and market longevity;
2) Double counting emission reductions;
3) Potential incentive for offset buyers to continue pollutive practices and ethical concerns relating to cross-sector transactions (i.e. tickets to pollute),
4) Current lack of regulation in the market and the impact of potential future regulation on the market carbon price; and,
5) Importance of temporal component of storage mechanisms.

Cost Margins and Market Longevity

Costs will determine whether a project can succeed without substantial government subsidy. The average cost of a carbon credit in the offset market as of January 2022, is around $7.53 per metric ton.[84] Conversely, at the low end of the cost spectrum DACCS systems have estimated costs of $134-342 per metric ton.[85] However, the Inflation Reduction Act (IRA) 45Q tax credits for carbon sequestration, have changed the characteristics of the carbon market. Before the IRA, the 45Q tax credit allocated $50 per metric ton of CO2 captured and stored, however, a new potential market has opened, as 45Q modifications raise the credit to $85 per metric ton for point source capture, and $180 for DAC facilities. However, some research suggests that reasonable expectations place costs substantially higher in the range of $600-1,000 per net metric ton removed.[86] In the current market, DACCS technology would require substantial subsidies to support its viability initially. Further cost analysis would be necessary to determine viability and costs would largely be dependent on the cost of the energy source.

Double Counting

Double counting occurs when an emission reduction unit is traded in the carbon market between two states or jurisdictions that implement separate carbon inventories. An emission credit is double counted when the reduction is counted both within the jurisdiction of origin (the place offsetting the carbon), as

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[84] Bloomberg Professional Services (2022, March 2) *Carbon offsets price may rise 3,000% by 2029 under tighter rules.* https://www.bloomberg.com/professional/blog/carbon-offsets-price-may-rise-3000-by-2029-under-tighter-rules/

[85] IEA, *Levelised cost of CO2 capture by sector and initial CO2 concentration, 2019*, IEA, Paris https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019

[86] Herzog, H. (2022). Direct Air Capture. Greenhouse Gas Removal Technologies, 31, 115. https://doi.org/10.1039/9781839165245-00115

well as within the inventory of the receiving jurisdiction, or the place/jurisdiction buying the offset. When double counting occurs the climate benefit from carbon offsets can be negated. One mechanism to help alleviate this concern is by prioritizing a local carbon market. Additionally, using recognized offset standards with robust registries tracking emission reductions and purchases can ensure that emission reductions and associated credits are only counted once. The State of Hawaiʻi Office of Planning and Sustainable Development evaluated carbon offsets in the 2019 Feasibility and Implications of Establishing a Carbon Offset Program for the State of Hawai'i study. However, the feasibility analysis provided in this report, found that it was unlikely the State of Hawaiʻi would generate significant revenue through the production of offsets, and any trading of offset credits produced within Hawaiʻi would be limited by the state's Zero Emissions Clean Economy target. The report instead suggested consideration of alternative mechanisms such as non-offset program carbon pricing, such as a carbon tax or cap-and-trade, greenhouse gas reduction funds, building codes and standards, and integrated greenhouse gas reduction plans. The study was not specific to negative emissions technologies.[87]

Next Steps and Remaining Questions

The pathways to store and utilize carbon dioxide will likely not be successful with a "one size fits all" approach. Undoubtedly, many of the industrial pathways set forth herein require a substantial need for the advancement and growth of clean renewable energy. This need coincides with the need to develop renewable energy to provide a power supply for existing uses. If geological sequestration is a chosen pathway, focused geological and hydrogeological studies would need to commence. Understanding the underlying geology is the critical next step.

Similarly, if ocean-based CDR is a chosen pathway, substantial research on potentially adverse impacts on ocean ecology and chemistry is fundamental as well as a validation of the specific methodologies. Scalability should also be carefully considered for both technology pathways. A key to implementing any preliminary studies will be adequate funding.

Conclusion

In the United States, CCS technologies have been dominantly explored by oil and gas companies to mitigate emissions. To lower atmospheric carbon concentration, mitigation alone is not adequate. CDR technologies which incorporate long-term and permanent storage powered by renewable energy sources are necessary to achieve net negative carbon goals. The technologies discussed above involve substantial energy inputs. CDR technologies, while critical to achieving net-negative goals, should not be construed as the fix-all solution. Before the implementation of any costly pathway for decarbonization, a thorough life cycle analysis of all greenhouse gas emissions should be conducted and carefully considered.

Geological sequestration provides the promise of long-term storage; however, some critical challenges and concerns must be addressed before its safe implementation in Hawaiʻi. As with any industrial facility before the adoption of the technology adequate community engagement and environmental analysis must occur. While carbon reduction is a key component of achieving state climate goals, it is important to stress that GHG emission reduction in all emitting sectors should be prioritized. CDR and NETs are a part of the solution to decarbonizing and stabilizing carbon dioxide levels in the earth's atmosphere, but it is not an alternative to drastically reducing emissions.

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[87] *Feasibility and Implications of Establishing a Carbon Offset Program for the State of Hawai'i*