

Yale University

EliScholar – A Digital Platform for Scholarly Publishing at Yale

Forestry & Environmental Studies Publications
Series

School of Forestry and Environmental Studies

Fall 2009

Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions

Matthew Eckelman

Yale Center for Industrial Ecology

Marian Chertow

Yale Center for Industrial Ecology

Follow this and additional works at: <https://elischolar.library.yale.edu/fes-pubs>

Part of the [Environmental Sciences Commons](#)

Recommended Citation

Eckelman, Matthew and Chertow, Marian, "Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions" (2009). *Forestry & Environmental Studies Publications Series*. 40.

<https://elischolar.library.yale.edu/fes-pubs/40>

This Article is brought to you for free and open access by the School of Forestry and Environmental Studies at EliScholar – A Digital Platform for Scholarly Publishing at Yale. It has been accepted for inclusion in Forestry & Environmental Studies Publications Series by an authorized administrator of EliScholar – A Digital Platform for Scholarly Publishing at Yale. For more information, please contact elischolar@yale.edu.

Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions

Matthew Eckelman and Marian Chertow
Yale Center for Industrial Ecology



Yale F&ES Publication Series
Report Number 21

PUBLICATION SERIES EDITOR	Jane Coppock
REPORT TITLE	Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions
REPORT AUTHORS	Matthew Eckelman and Marian Chertow
DATE OF REPORT	Fall 2009
ACKNOWLEDGEMENTS	The authors gratefully acknowledge the support of the Pierre and Pamela Omidyar Fund at the Hawai'i Community Foundation for the original grant that supported this work.
COVER IMAGE	Photo taken from Makapuu Point, the eastern tip of Oahu.
COVER DESIGN	Bryan Gillespie, Yale Printing & Publishing Services
PAGE LAYOUT	Dorothy Scott, North Branford, CT
PRINT ON DEMAND	Yale Printing & Publishing, 100% recycled paper
DISCLAIMER	The opinions, findings, and interpretations of research contained in this volume are those of the individual authors and do not necessarily reflect views of institutions with which they are affiliated.
TO OBTAIN COPIES	Downloadable PDFs of individual chapters are available at no charge at www.environment.yale.edu/publications . Printed copies can be ordered at the same site.

Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions

Matthew Eckelman and Marian Chertow
Yale Center for Industrial Ecology

Yale School of Forestry & Environmental Studies 2009

Table of Contents

ACKNOWLEDGEMENTS	1
EXECUTIVE SUMMARY	3
CHAPTER 1: INTRODUCTION	12
1.1 Purpose and Overview of the Report	12
1.2 Underlying Concepts: Material Flow Assessment and Industrial Ecology	13
1.3 Oahu Material Flow Summary	14
CHAPTER 2: OAHU OVERVIEW	18
2.1 Oahu Characteristics and Location	18
2.2 Oahu's Economy	19
CHAPTER 3: IMPORTS	21
3.1 Overview	21
3.2 Re-Export and Inter-Island Transport	23
3.3 Total Results	24
CHAPTER 4: ON-ISLAND EXTRACTION AND PRODUCTION	25
4.1 Mining and Minerals	25
4.2 Agriculture, Animal Husbandry, Fisheries, and Forestry	27
4.3 Water	28
CHAPTER 5: MATERIAL USE AND CONVERSION	31
5.1 Construction	31
5.1.1 Private Construction	31
5.1.2 Military Construction	32
5.1.3 Road Construction	33
5.2 Power Generation	34
5.2.1 AES Coal Plant	35
5.2.2 H-POWER Waste to Energy Plant	36
5.2.3 Oil-Fired Power Generation	38
5.3 Transportation	39
5.4 Tourism	40
5.5 Residential and Commercial Consumption	41
5.6 Military	42
5.6.1 Military Food	43
5.6.2 Military Ammunition Use	43
5.6.3 Military Fuel Use	44
5.6.4 Military Water Use	44
CHAPTER 6: EXPORTS	46
CHAPTER 7: WASTE	48

7.1	Waste Generation and Collection	49
7.2	Transfer Stations	51
7.3	Reuse and Recycling Activities	53
	7.3.1 Municipal Recycling	53
	7.3.2 Commercial Recycling	54
	7.3.3 Industrial Reuse and Recycling	56
	7.3.4 Composting and Green Waste	57
7.4	Military Waste Generation and Recycling	58
7.5	Waste Treatment and Disposal	60
	7.5.1 H-POWER	60
	7.5.2 Waimanalo Gulch Landfill	62
	7.5.3 PVT Landfill	62
	7.5.4 Wastewater Treatment	63
CHAPTER 8: ISSUES AND OPPORTUNITIES		65
8.1	Material Dependence and Import Substitution	65
	8.1.1 Construction Minerals	65
	8.1.2 Energy	66
	8.1.3 Food	67
8.2	Waste Utilization	68
	8.2.1 Residential Recycling	68
	8.2.2 Processing and Sorting at Treatment and Disposal Sites	69
	8.2.3 Materials Recycling versus Energy Recovery	69
	8.2.4 Reuse Opportunities	69
	8.2.5 Organic Materials	70
	8.2.6 Military Reuse and Recycling	70
	8.2.7 Backhauling Opportunities	70
8.3	Legislative Drivers	71
8.4	Summary	71
CHAPTER 9: CONCLUSIONS		73
REFERENCES		74
BIOSKETCHES OF AUTHORS		78

Acknowledgements

The authors would like to extend our sincere gratitude to the many people who have helped us in the creation of this report.

First, to the graduate students who did the initial data collection and reports as part of the spring 2008 Industrial Ecology course: Joe Famely, Haley Gilbert, Eva Gladek, Amy Heinemann, Matt Oden, Jooyoung Park, Tara Parthasarathy, Laura Sima, Katie Zaidel, and Christopher Ziemba. Francisco Espinoza and Neda Arabshahi were also in the class and have earned extra thanks for their additional work to complete the report. Weslynn Ashton and Jason Rauch were the first to survey how the study could be done during an initial trip to Oahu in January 2008.

Second, to those we encountered who spent time with us above and beyond the call of duty: Maurice Kaya, formerly of DBEDT and Suzanne Jones of the Honolulu Dept of Environmental Services for providing material flow data and reviewing our work; David Turner and Kirsten Baumgart Turner of Sustainability Partners for their hospitality, input, interest, and assistance in organizing events and networking; Mike Mohr and Jeff Alvord of the Omidyar Family Enterprises, who understood that a new way to look at an old problem might prove rewarding; Betsy Cole of the Kohala Center for providing much needed logistical support; and Prof. Makena Coffman of University of Hawai'i Manoa for organizing educational exchange and offering thoughtful advice.

Finally, to President and CEO Kelvin Taketa and Josh Stanbro of the Hawai'i Community Foundation (HCF) for many fruitful introductions in Honolulu and for administering the original grant that supported this work called "Waste and Material Flows in Oahu: An Industrial Ecology Approach." The grant came from the Pierre & Pamela Omidyar Fund, a donor-advised fund of the HCF, and we are grateful for the research opportunity this provided.

The report is in final form and reflects consultation and feedback from Oahu and State of Hawai'i government officials, as well as representatives of non-governmental organizations, companies, and citizens in response to the draft report of April 2009 and a series of presentations and discussions in May 2009. Comments received until July 1, 2009 are reflected in this final report.

The research team would also like to thank the many people who offered their time and insight through interviews, tours, and emails. Their inclusion in the Acknowledgements is not meant to imply endorsement of this report or the recommendations contained therein, but rather to express our appreciation for the time they took with us.

AES Hawai'i: Robert McCann, Damon Tohill

Actus Lend Lease: Brad Nichols

Ala Moana Hotel: Francis Cofran, Dennis Miho

American President Lines: Joshua Sykes

Ameron Hawai'i: Linda Goldstein

Board of Water Supply: Barry Usagawa
Cates International: Randy Cates
Concurrent Technologies Corporation: Bill Boone, Neil Huber, Donna Provance
Diamond Head Seafood: Garret Kitazaki
Enterprise Honolulu: Mark Ritchie, Mike Fitzgerald, Mark McGuffie, Pono Shim, John Strom
Forest City Construction: Charito Alcantra
Grace Pacific Corporation: Robert Creps, Henry Kitaoka, Chris Steele, Ricky Tsue
H-POWER/ Covanta Energy: Rodney Smith
HI Commission on Water Resource Management: Faith Ching
HI Dept. of Business, Economic Development & Tourism: Mary Blewitt, Maurice Kaya, Milton Kwock, Dean Masai, Michelle Palmer, Estrella Seese, Gail Suzuki-Jones, Eugene Tian
HI Dept. of Health, Environmental Management Division: Rogiette Bernardino, Steven Chang, Lane Otsu
HI Dept. of Transportation: Fred Pascua
HI Dept. of Planning and Permitting: Bob Stanfield
Hawai'i Hotel & Lodging Association: Murray Towill
Hawaiian Cement: Dane Wurlitzer
Hawaiian Dredging Corporation: Jim Prentice
Hawaiian Earth Products: Michell De Jesus, Mahina Silva
Hawaiian Electric Company: Robert Alm, Lynne Unemori
Honolulu Dept. of Environmental Services, Solid Waste Management: Suzanne Jones, Markus Owens
Honolulu Dept. of Information Technology: Keith Rollman
Island Demo: Mike Leary
Island Movers: Joey Viernes
James Campbell Company: Mary Emerson
Matson Shipping: Lek Friel
Maui Divers Jewelry: Jerry Tanaka
Norton Lilly Shipping: Jen Borja
Oceanic Institute: Charles Laidley
PVT Land Company: Stephen Joseph
Pacific Business News: Mimi Beams
Re-use Hawai'i: Selina Tarantino, Quinn Vittum
ResortQuest Hawai'i: Shari Chang
Schnitzer Steel: James Banigan, Rene Mansho
Sheraton Waikiki: Nanlyn Sue
Sustain Hawai'i: Kevin Vaccarello
University of Hawai'i at Manoa: Makena Coffman, Olwen Huxley, Ken Kaneshiro, Ev Wingert
US Air Force, Hickam Air Force Base: Ron Lanier, Mark Petersen, Lt. Kyle Slick
US Army, Hawai'i Operations: Col. Howard Killian, Alvin Char, Alan Goo
US Coast Guard: Jay Silberman
US Defense Logistics Agency: Robert Crawford
US Marine Corps, Kaneohe Bay Marine Base: Robert Lotti
US Navy, Pearl Harbor: Commander Robert Main, Michael Twilligear, Michael Zuccherro
US Dept. of Agriculture: Mark Hudson
Young Brothers Shipping: Jeffrey Low

Executive Summary

OAHU, WASTE, AND THE PREDICAMENT OF ISLANDS

More than any other geographic setting on the planet, islands face serious constraints to environmental sustainability in the modern era. Islands usually have limited natural and human resources on which to rely for economic development, making them highly import-dependent and therefore particularly vulnerable to changes in global markets. Oahu, Hawai'i, with nearly a million people, has all of these characteristics, making sustainability challenges real and immediate for business, government, and the citizenry.

In addition to these issues, Oahu has an acute waste problem. A strong tourism sector and high levels of affluence contribute to per capita municipal waste generation rates among the highest in the U.S. One of the resources in short supply is disposal capacity – H-POWER, the only waste-to-energy plant, is overflowing and is having to send unprocessed waste to the landfill, yet the only municipal landfill, at Waimanalo Gulch, requires immediate expansion if it is to remain in operation. Local regulation, combined with residents' concerns about odors, traffic, and other quality of life issues, makes it extremely difficult to find new disposal sites. While the recycling program is effective, a complicating constraint is that Oahu's economy is of an intermediate size: large enough to demand a diverse stream of products and materials but occasionally too small to provide a broad enough variety of end uses or sufficient economies of scale for recovering these resources.

AN INDUSTRIAL ECOLOGY VIEW

There are many ways to look at the problem of waste and materials. A regulatory approach requires that we examine certain defined categories: one national law, for example, covers hazardous waste as well as municipal solid waste (from homes and commercial activities) but has little guidance about non-hazardous industrial waste, which is the largest part of the waste stream, or about other materials that can contribute back to the productive economy such as leaves or wood pallets. In contrast, *industrial ecology* demands that we look at all materials and energy through a lifecycle approach, even if the materials are not targeted in law. While the law might focus on waste – the downstream end of the cycle – this pulls attention away from the materials entering the economy – the upstream end. By using a systems view, industrial ecology offers a broader conceptualization of the problem, and can suggest higher-impact solutions. In Honolulu's case, when we subtract exports from imports and add in what is produced locally, there are 13.7 million tons entering the economy at the upstream end each year compared with 1.8 million tons of waste and recycling materials at the downstream end (ES Figure 1). The partial view gained from the downstream end has led to many incremental actions for recycling and composting to minimize the waste stream, yet over time there will be more possibilities for long-term solutions emerging upstream within the 13.7 million tons entering use or being consumed every year.

ES Figure 1 A systems view of Oahu. The upstream part of the material flow system with 13.7 million tons is contrasted with the downstream part with 1.8 million tons for 2005. There is more room at the upstream end to make comprehensive system improvements such as import substitution.



Industrial ecology tools, then, provide a system-wide perspective that can generate insights for optimizing material flows, with the ultimate goal of moving current practices in a more sustainable direction.

HOW THE STUDY WAS CONDUCTED

Through a grant received in 2008 from the Hawai'i Community Foundation (HCF), four groups of Yale University graduate students used "material flow analysis" – the industrial ecology tool employed to map and quantify the flow of materials through a network of actors. Each group focused on a portion of overall material flows during the spring of 2008 as follows:

- 1) Imports, exports, and resource extraction (Famely et al., 2008);
- 2) Military (Espinoza et al., 2008);
- 3) Private sector (Parthasarathy et al., 2008); and
- 4) The waste management system (Oden et al., 2008)

Significant follow-up research to fill in data gaps and complete the material flow analysis (MFA) occurred throughout 2008. This report contains data from detailed state records and reports, but also benefited greatly from personal exchanges with those we interviewed who provided contextual information. Many of the data presented here have significant uncertainties associated with them, but all should be the correct order of magnitude. The four topics identified in this section are discussed below.

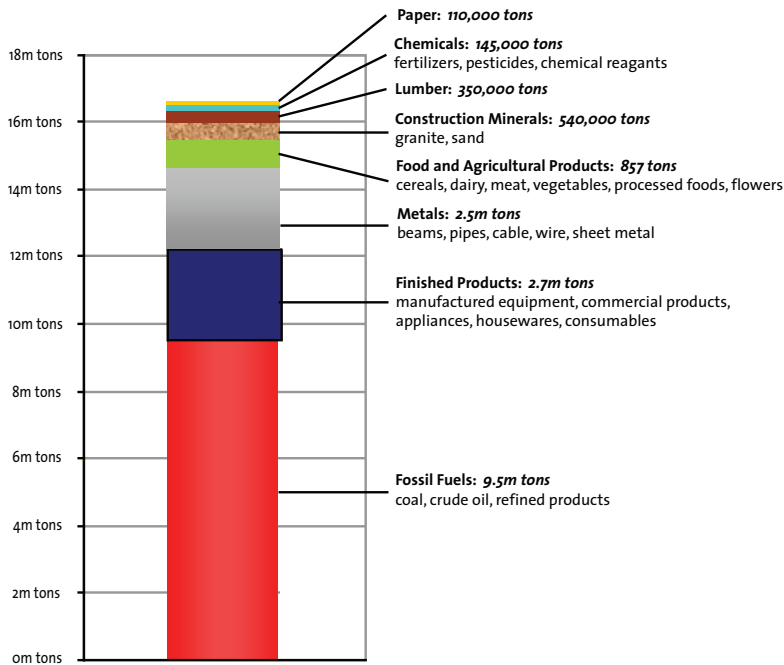
1) Imports, exports, and resource extraction

Imports and exports

The state of Hawai'i as a whole imports approximately 80% of the materials it requires to operate, including food, merchandise and construction materials. The

ports of Oahu are key to Hawaii's material flows, with 98% of imported materials arriving by ship. Oahu has limited and strictly controlled points of entry, consisting of its three commercial ports: Honolulu Harbor, Kalaeloa Barbers Point Harbor, and Kewalo Basin Harbor. Material also arrives by air via Honolulu International Airport. These places of entry are all located in relative proximity to one another along the island's southern coast. Of great importance to material flows on the island is the fact that all of the containers arriving on Oahu are full, but two-thirds of containers generally leave empty. Some of the larger retailers, such as Sears, use these empty containers to send packaging materials such as cardboard back to the mainland U.S., but these volumes are small compared to imports. In general, there are not many export products of sufficient value manufactured on the islands to merit the cost of transport to distant markets.

ES Figure 2 Imports to Oahu. Petroleum products clearly represent the largest material import to Oahu, with more than 60% of the total in 2005. This fact highlights Oahu's precarious dependence on outside fuel suppliers.



While Oahu is highly dependent on imports for many of the island's needs, there are modest amounts of exports from the island as well. The majority of exports (57%) are petroleum products shipped from the Chevron and Tesoro refineries at Barber's Point. Much of this is shipped to the outer islands for direct consumption, mostly for transportation and power generation. The remaining export shipments are largely food and farm products and waste materials. While the material throughput of Honolulu's airport is small compared to the ports, it is still an important gateway for products that are time-sensitive, such as cut flowers or mail.

Resource extraction

For most of the 20th century, Oahu was an agricultural powerhouse, producing large quantities of pineapples, sugar, and livestock. As these industries have declined, Oahu now produces very little of what it finally consumes, resulting in a large trade deficit in goods. The most significant domestic extractive industries are rock quarrying, small-scale agriculture (including flowers), fishing, and water provisioning. The island's three commercial quarries produce nearly 3.4 million tons of basalt, almost all of which goes to satisfy the island's construction industry. The island's farms and fisheries produced more than 100,000 tons of food in 2005; the most significant products were pineapples and milk. Approximately 160,000 tons of biomass (such as grass clippings and brush) end up as "green waste". Because of Oahu's peculiar volcanic history and geography, the island contains several large aquifers that support all of the island's water demand, totaling 190 million gallons of water per day. About 76% is consumed residentially, 6% by industry, and 15% is used for irrigation.

2) The military

The military plays a much larger role in the economy, in the environment, and in the material use of Oahu than it does in other parts of the country. Each branch of the military has at least one base on Oahu, and some, like the Army, have more than one. The military also owns land outside of bases, which is used for training and other purposes; military land holdings account for over 22% of Oahu's land area. The total number of armed forces personnel and military dependents on the island totals close to 100,000 people. In the 2005-2006 study period the military added 139,000 tons of material to existing building stock while reporting very high reuse of materials from home demolition. Along with construction activities, the everyday operations of military facilities on the island require a variety of material inputs: food for on-site meals in "chow halls," ammunition for training, and fuel and water for general operations as discussed in Chapter 5.

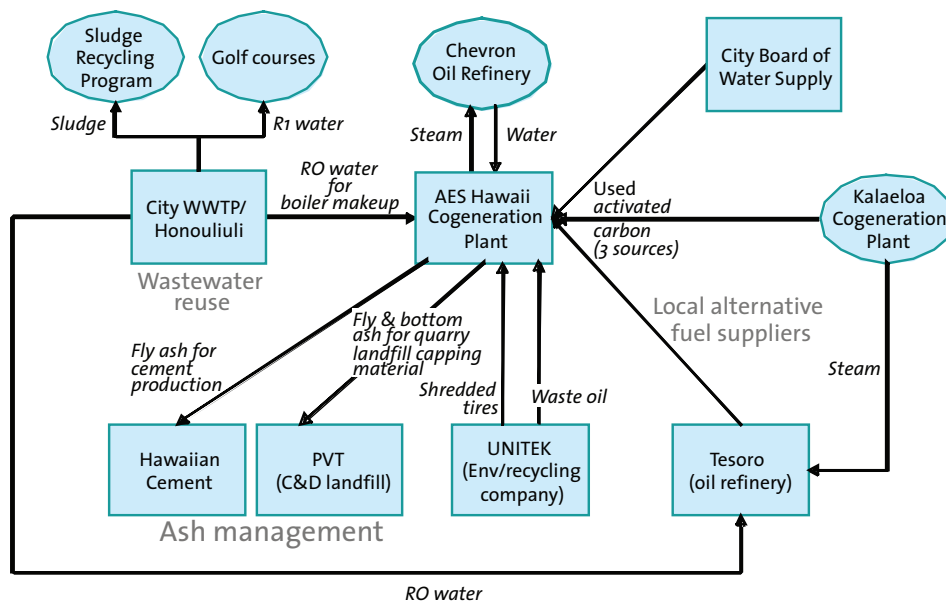
3) The private sector

Once materials enter the economy of Oahu, either through import or domestic production, they are processed and exported or used on-island by businesses and residents. The large and diverse use of material on Oahu involves many different sectors including construction, power generation, transportation, and tourism, described in Chapter 5.

In 2006, the private construction sector on Oahu was valued at more than \$1.9 billion and issued more than 16,500 building permits. Based on models calibrated with data from in-depth studies of ten projects, calculations show that Oahu's private construction sector added over 330,000 tons of material to existing building stock (excluding water and fuel). As of 2006, Oahu had 1,617 miles of paved streets and highways, not including military and private roads, which accounted for large material flows and consumption – about 39,000 tons of aggregate and 2,500 tons of asphalt per mile (Schaefers, 2008). Almost all of these roads are constructed using locally extracted aggregate, with asphalt shipped in from the mainland.

Eleven enterprises in or near the Campbell Industrial Park were found to be exchanging nine different materials across firms, including steam, reverse osmosis (RO) water as well as reclaimed (R1) water, waste oil, tires, used activated carbon, and ash. This phenomenon, known in the industrial ecology literature as “industrial symbiosis,” creates both economic and environmental benefits. The two largest environmental benefits of this collective approach were found to be conservation of primary materials and reduced landfilling. Annual landfill space savings for just one of the waste streams, 70,000 tons of ash, is equivalent to 51,400 cubic meters. This alternative business model with so many linkages emerged in Honolulu in a quiet and gradual way, and appears to have some very useful characteristics in this setting.

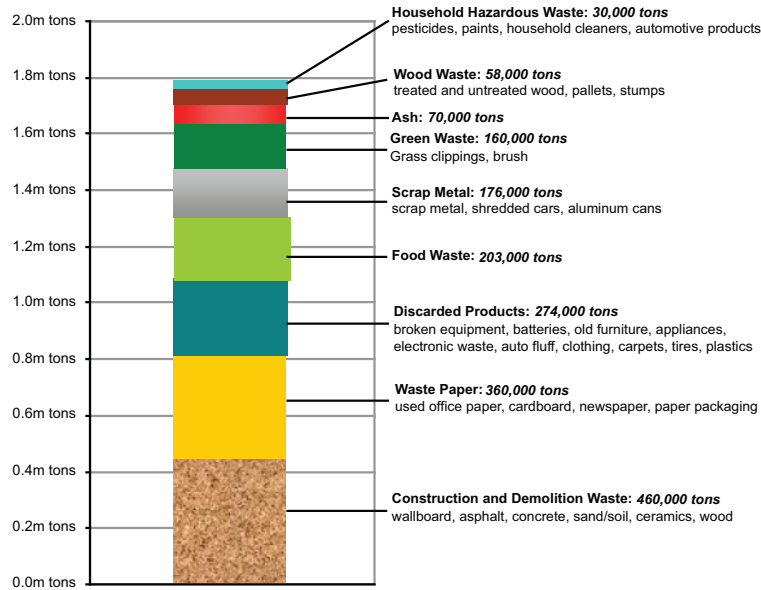
ES Figure 3 Campbell Industrial Park linkages. In a geographically limited zone where few alternative waste or material management solutions are available, several firms in the Campbell Industrial Park developed a network to exchange resources with one another. This presents an unusual example of industrial symbiosis, with substantial environmental and economic benefits from the cooperation.



4) The waste management sector

Municipal solid waste generation statistics are well-quantified and characterized, as they are tracked by both the City and County of Honolulu and the State of Hawai‘i. For other types of waste, such as construction and demolition (C&D) or recyclable materials, statistics are not as robust. Outside of the public system, approximately 200,000 tons of C&D waste and petroleum-contaminated soil is disposed annually at the private PVT landfill. This constitutes approximately 80% of all C&D waste on the island.

ES Figure 4 Waste Generation on Oahu. In 2005-2006, several major components of Oahu's waste stream were: construction and demolition waste, waste paper, and discarded products. Total waste generation was just under 1.8 million tons.



In addition to solid wastes, Oahu's institutions and industries produced roughly two million pounds of toxics in 2006. These are reported to the Toxics Release Inventory (TRI) run by the U.S. Environmental Protection Agency. The various actors on the island also released significant quantities of air pollutants into the atmosphere. In 2006, the power generation sector was the largest contributor of carbon dioxide emissions to the statewide inventory, estimated at 30 million tons of CO₂ equivalent. This also establishes that air emissions are much larger than solid waste emissions on a mass basis.

ISSUES AND OPTIONS

In many ways, Oahu's waste management system works very well. Through material recycling, nearly 34% of the total waste stream is diverted. In addition, H-POWER supplies 5-7% of the island's electricity while treating roughly two-thirds of the municipal solid waste (MSW), thus prolonging the life of the landfill. About half of the island's roughly 160,000 tons of green waste is composted. This comprehensive composting system provides a source of low-cost soil amendments for farmers and in turn results in less methane generation at the landfill and better burn rates at H-POWER. Still, this system is not sustainable given the scarcity of disposal capacity, so more diversion of waste from disposal is urgently needed. The second issue that needs to be addressed is Oahu's high dependence on imported goods, ranging from 10% for construction minerals, to over 80% for food and agriculture, to 100% for fossil fuels.

In many cases, there are underutilized resources on the island that could serve to displace some portion of these imports. Opportunities are particularly attractive in the cases of construction minerals, energy, and food as elucidated by the MFA results. Some of the options in ES Table 1 are currently being undertaken by the City, and some have yet to be considered.

One theme that could be derived from the options in ES Figure 4 below is a focus on green buildings and construction. This would include using recycled materials in roads and concrete, recycling construction and demolition waste as much as possible (which can be incentivized by banning this waste from landfills), creating a local market for recycled glass by increasing its use in public construction projects, and enabling effective reuse of furniture and other items from hotels. Some of these options overlap, but all in all, this would reduce imports by more than 100,000 tons of material per year and reduce overall wastes by approximately 10% from current levels.

Another theme is increasing self-sufficiency on the island by producing more food via agriculture and aquaculture, and beginning to produce biofuels using old plantation lands. In the catastrophic event of a cessation in shipping to the island for whatever reason, increasing self-sufficiency in food and fuel would allow for more of a buffer for residents to subsist on before normal service resumed. In addition, increasing the production of food and fuel to the maximum levels discussed in this report would reduce total imports by more than 200,000 tons per year.

A final theme is fully utilizing all waste materials, either for use on the island or for sale to international scrap markets. The primary purpose of this category of activities is to reduce the burden on waste treatment (H-POWER) as well as the public landfill. Enacting all of the waste utilization options presented here would decrease total waste generation by approximately 200,000 tons and would increase the amount of on-island reuse and recycling that takes place by almost 40%, from 440,000 tons to over 600,000 tons.

ES Table 1 Potential options for Oahu material flows. This table summarizes three sets of options that could decrease Oahu's dependence on imports, reduce waste disposal, and favor greater recycling and reuse of materials. The options are not mutually exclusive, so one cannot simply add up the column of figures to establish material targets. The list below can be regarded as a menu of options that Oahu's policy leaders and citizens could further consider in various combinations. Ranges are based on material availability and feasible recovery rates.

Reduce imports through...	Qty Displaced ('000 tons)
Increased recovery of useful construction materials by the Island Demo transfer station and the PVT landfill, which is currently restricted by operating permits	65-125
Increased recovery of glass by private and municipal recyclers and increased use of glass in public and private construction projects	20-35 ^a
On-island production of a significant quantity of ethanol or biodiesel for motor fuel to replace imported gasoline	10-20 ^b
Expansion of renewable electricity generation to 10%, from its current negligible level to replace imported crude oil, in accordance with the Hawai'i Clean Energy Initiative	140-170 ^b

Reduce imports through...	Qty Displaced ('000 tons)
Greatly expanding and diversifying the domestic supply of food on the island to replace 5-20% of imported food, using fallow but productive agricultural lands abandoned by plantations and old farms	35-140

Utilize wastes more fully by...	
Expanding the pilot curbside recycling program to cover the entire island, with regular pick-up of paper, glass, bottles and cans, and green waste	70-80
Enacting a system to screen incoming waste at the Waimanalo Gulch and PVT landfills and extract useful metals	10-20
Encouraging a system of reuse of furniture, textiles, fixtures, and usable construction pieces from hotel renovations	3-5
Expanding existing military programs for reuse and recycling, spreading best practices from each base to all of the other bases and cooperating on collection programs	3-5 ^c
Organizing large commercial entities to collect, aggregate, and backhaul corrugated cardboard and plastic film in otherwise empty containers to the mainland	30-50
Expanding on existing partnerships, increase the use of wastewater treatment sludge as a potential fertilizer	30-40
Collecting, screening, and shredding wood waste for use in the AES power plant	15-25 ^a
Enabling the expansion of capacity to process tires that are now being treated as waste into tire-derived fuel for use at the AES power plant or other applications	10-12

Consider legislation that would....	
Allow road beds to be up to 50% recycled construction materials	50-150
Allow up to 30% ash content in concrete	30-60
Ban landfilling construction and demolition waste, as has been enacted in several other states to reduce the overall strain on local landfills	85-105 ^d

^a Sum of import substitution and waste diversion

^b Assuming current levels of consumption and no additional imports are required for alternative production

^c Assuming that the military increases its recycling rate to the average of ~35%

^d Assuming that this does not result in increased illegal dumping

This report does not prioritize one option over another, but simply describes these opportunities so that citizens, government, and business leaders can make informed decisions. The many options presented here can be used in combination to provide significant savings and enhance sustainability on the island.

Overall, this analysis provides a multi-level, quantitative picture of waste and material flows on Oahu. The focus is on the mass of these material flows and does not give information about other environmental metrics, such as associated greenhouse gas emissions or impacts on human health; however, these metrics also require information about mass flows. Rather than making incremental improvements, this project seeks long-term resource use optimization and waste reduction strategies. Working in concert with Oahu's existing conservation and recycling efforts, these strategies would relieve much pressure concerning disposal capacity and would subsequently reduce the island's import-dependency.

THE REPORT

The main body of the report is structured to follow the overall path and use of materials after entering Oahu. *Chapter 1* introduces the pressing sustainability issues Oahu faces. *Chapter 2* is an overview of Oahu's economy and geography. *Chapter 3* presents data on material imports onto the island, while *Chapter 4* covers domestic production, such as agriculture and mining. Once material is on the island, it is used or consumed by various sectors of the island's economy. *Chapter 5* details the conversion and use of materials on the island. Some products are sold in the mainland or abroad – these exports are presented in *Chapter 6*. Eventually, after products reach the end of their useful lives, they are discarded. *Chapter 7* covers Oahu's waste management system and the recycling and reuse that occur on the island. Finally, many of the difficult issues and opportunities of the current system of material flows on Oahu are discussed in *Chapter 8*. This report offers options for import substitution, resource reutilization, and accompanying legislative change as a means of addressing the complementary issues of dependence and waste management. It does not directly address existing program goals or deeper consumption issues related to human social behavior.

Chapter 1: Introduction

1.1 PURPOSE AND OVERVIEW OF THE REPORT

The island of Oahu, home to the state capital, Honolulu, is the most populous and developed of the Hawaiian Islands. Like most islands it is heavily dependent on flows of imports such as food, fuel, and manufactured goods to satisfy its modern physical resource needs. The new field of industrial ecology is dedicated to the study of how these and other resources flow through human and industrial systems with an eye toward conserving energy, water, and materials. Given the acute waste disposal problem on Oahu brought about by dependence on a single municipal landfill and a waste-to-energy plant that is over capacity, a variety of near-term interventions are being explored. Therefore, it seemed prudent to investigate longer-term solutions for resource conservation and waste reduction. An island-wide material flow analysis (MFA) was performed as an innovative means of considering issues of import, export, consumption and substitution, resulting in long term strategies for diminishing waste generation that could complement current local conservation and recycling efforts.

Through a grant from the Hawai'i Community Foundation (HCF) received in 2008, four groups of Yale University graduate students traced different sectors of Oahu's economy through data gathering and interviews. These findings were integrated and amended with further research to form an island-wide material flow analysis (MFA). Each group focused on a portion of the overall material flow analysis as follows:

- 1) Imports, exports, and resource extraction (Famely et al., 2008);
- 2) Military (Espinoza et al., 2008);
- 3) Private sector (Parthasarathy et al., 2008); and
- 4) The waste management system (Oden et al., 2008).

Significant follow-up research to fill in data gaps and conduct the analysis occurred throughout 2008. During that time, interviews were conducted with individuals from a diverse range of backgrounds including among others: government officials, representatives of private companies, and members of the armed forces. The major source of statistical information about Oahu is the *Hawai'i State Data Book* (2006), published annually by the Department of Business, Economic Development, and Tourism (DBEDT), which follows the format of the *Statistical Abstract of the United States*. Material flows are summarized in each section and quantified in Table 1.1. Many of the data presented here have significant uncertainties associated with them, but all should be the correct order of magnitude.

The MFA provides a multi-level, quantitative picture of waste and material flows on Oahu. The focus is on the mass of these material flows and does not give

information about other environmental metrics, such as associated greenhouse gas emissions or impacts on human health; however, these metrics also require information about mass flows. Rather than making incremental improvements, the project seeks long-term resource use optimization and waste reduction strategies.

1.2 UNDERLYING CONCEPTS: MATERIAL FLOW ASSESSMENT AND INDUSTRIAL ECOLOGY

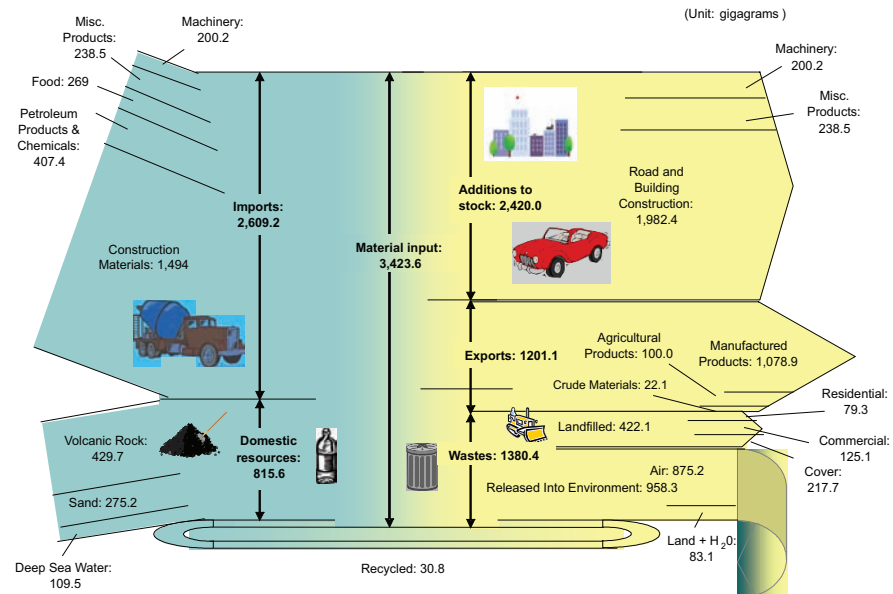
Material flow analysis or MFA is one of the most important tools used in the field of industrial ecology, which is dedicated to the system-level study of resource flows. The fundamental principle of MFA is *mass balance*, which states that the mass of inputs must be equal to the mass of outputs plus whatever inputs remain in the system over time, if any. MFA enables the tracking of material and energy flows through systems at different scales ranging from single buildings to business clusters to regions and countries. Just as islands are rich subjects of study in the biological sciences, they are emerging as a useful functional unit in industrial ecology (Deschenes and Chertow, 2004). In contrast to islands, most cities have many points of entry making it difficult to follow flows through the economy. Industrialized islands such as Oahu have far fewer points of entry, for example, Oahu has three commercial ports and one principal airport, so tracing flows becomes much more tractable.

This project is the latest in a series of in-depth island studies administered through the Yale University Center for Industrial Ecology (CIE). CIE researchers investigated material flows, industrial symbiosis and industrial clusters in Puerto Rico between 2001 and 2008 (Ashton and Chertow, 2008; Chertow, 2007). On the Island of Hawai'i, teams of Yale researchers completed a preliminary island-wide MFA (Houseknecht et al., 2007) as well as additional studies on waste (Houseknecht, 2006), water (Fugate, 2008), and energy (Johnson et al., 2006; Johnson et al., 2007). Figure 1.1 shows preliminary material flow results for the Island of Hawai'i. As on Oahu, waste disposal options on that island are few, highlighting the trade-offs between waste management practices and land use.

On the left side of Figure 1.1, imports and resources from the island itself enter the economy and mingle as material inputs into the economy. The majority of these inputs are in the form of construction minerals, such as aggregate and cement. Following the figure to the right, some of this material enters stock, as in the case of steel becoming part of a building, some material is exported, and the rest becomes waste to be released, disposed, or recycled.

There is growing curiosity and interest in “urban metabolism” – that is, an increased understanding of the amounts of materials, water, energy, and wastes that enter, leave, and are stored in human dominated systems. Studies have been done in Hong Kong, Brussels, Tokyo, Cape Town and other metropolitan areas to measure resource efficiency and the extent to which resource streams are recirculated as a way of trying to measure sustainability (Kennedy et al., 2007).

Figure 1.1 Overview of material flows on the Island of Hawai'i



Source: Houseknecht et al., 2006

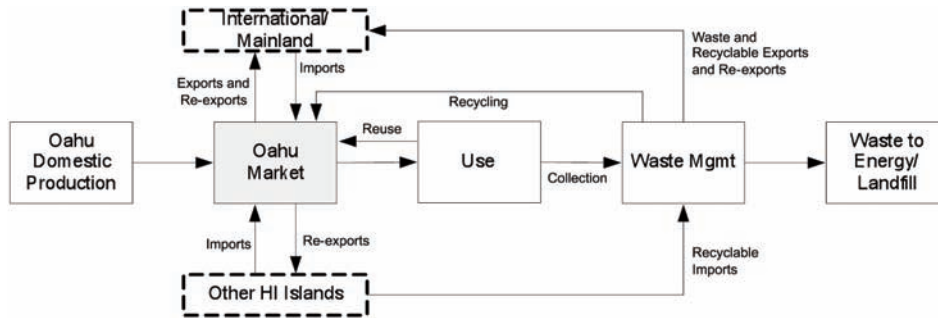
1.3 OAHU MATERIAL FLOW SUMMARY

Thinking of Oahu as a generic system, material flows on the island logically fall into the sources and stages in the boxes of Figure 1.2 (and these boxes are highlighted in bold in this text). First, both imports from **international and mainland U.S. ports** as well as products from the **other Hawaiian Islands** bring a great deal of materials to Oahu which, when combined with **domestic production**, provide the materials for the **Oahu market**. These materials then enter **use** in Oahu's economy as products. After use, remaining materials are discarded into **waste management** to be recovered or disposed. A large amount of material is reused or recycled on the island; some is also sent for export, along with commercial products from the island's industry. Oahu's exports are adjusted for re-exports to and from other islands that do not enter the system of Oahu. The balance that is not recycled is sent to **waste to energy/landfill**, at which point most of the waste is burned for electricity production, while the resulting ash and the rest of the waste are landfilled. Landfill disposal includes both the solid waste landfill (Waimanolo Gulch) as well as the landfill for construction and demolition waste (PVT) and the military landfill.

To be specific, Oahu's 906,000 residents and 22,100 businesses generate nearly 1.8 million tons of waste annually before recycling, about two-thirds of which is municipal solid waste or MSW (U.S. Census Bureau, 2007; R.W. Beck, 2007b). Though Hawaii's consumer price index is well above the national average, suggesting higher prices with consequent lower consumption, this is not the case. The large tourism sector and a relatively high level of affluence contribute to high levels of

consumption and waste generation; islanders generate 1.5 tons of MSW annually per capita, well above the national average of 0.8–1.2 tons per capita, which does not include hazardous or construction wastes (U.S. EPA, 2007; Kaufman et al., 2004).

Figure 1.2 Schematic diagram of material flows on Oahu



Rising population and waste generation rates have put waste management officials in a difficult bind: there is only one municipal landfill on the island operating under a short extension, and a lengthy re-permitting process would be required if use is to be continued (Boylan, 2009). Regulations restrict siting landfills over groundwater supplies, which exist in the interior of the island; this constraint limits possible sites to areas close to the ocean, where population densities are higher and there are many competing land uses. Combined with local concerns surrounding odors, traffic, and other quality of life issues, it is extremely difficult to find new landfill sites. A waste-to-energy plant on the island has also reached capacity, and construction of a third boiler has been approved by local officials to expand capacity. The waste disposal problems are so acute that officials are planning to ship 100,000 tons of MSW nearly 2,700 miles away to a landfill in Washington State (Yap, 2008; Boylan, 2009).

One of the primary benefits of applying MFA to what is largely a waste management problem is the ability to see the entire system of material flows on the island. By looking upstream at what is imported or produced locally, we can examine where the island is most vulnerable to external disruptions. By looking at what products are used on the island, we can anticipate what the waste stream will be like in the future when these products are ready for discard. By looking downstream at different waste management options, such as recycling, reuse, composting, export, or disposal, we can look for opportunities to reduce the waste that is generated or to use it in another way.

Table 1.1 is a summary of material flows for Oahu for 2005. Imports and Oahu's domestic production (columns 1 and 2) constitute the inputs to the system. Products that are exported from the island (column 3) constitute the non-waste outputs. The difference between inputs and non-waste outputs is known as apparent consumption (column 4), and represents the net mass of products that enters Oahu's economy. Some of these products are used and discarded within the same year and enter waste

management. To these are added products that entered the economy in the past and have reached the end of their useful lives and are thus discarded. Together, these constitute waste generation (column 5), which is balanced by the three waste management options: on-island reuse and recycling, disposal (including waste to energy and landfilling) and export of materials off-island (columns 6-8). While it is not shown in table 1, the difference between apparent consumption (column 4) and waste generation (column 5) represents material that is added to in-use stock, such as buildings and durable goods. Both apparent consumption and waste generation are calculated by mass balance, as shown in Table 1.1.

Each material category shows both the type of product input (such as fuel) and the corresponding waste material shown in italics (such as ash). While an effort has been made to separate material flows by category, there is some crossing of material categories that complicates the overall picture. This is most apparent in the case of paper. Some 70,000 tons of paper enter the economy as paper products (apparent consumption), but 360,000 tons of waste paper are generated. This large mismatch occurs because much of this waste paper existed previously as packaging on final products, or as the final products themselves (as catalogs, for example). It was not possible to ascertain what portion of the paper in waste generation entered the economy as basic unprocessed paper, highlighting the difficulties in tracking single substances through a complex economy.

Table 1.1 Island-wide material flows for Oahu, Hawai'i, 2005 (in '000 tons)

Mass Balances	1	+	2	-	3	=	4	5	=	6	+	7	+	8
Products / <i>Waste Materials</i>	Imports		Domestic Production		Exports		Apparent Consumption ^a	Waste Generation ^a		On-island Recycling		Disposal		Waste Exports
Lumber / <i>C&D, Wood</i>	350		9		270		89	58		8		50		0
Paper / <i>Paper</i>	110		0		40		70	360 ^b		0		290		70
Minerals / <i>C&D, Glass</i>	540		3,400		215		3,725	460		210		250		0
Metals / <i>Scrap</i>	2,450		0		1,600		850	176 ^b		0		21		155
Chemicals / <i>Hazardous</i>	145		0		69		76	30 ^b		15		2		13
Food and Ag. <i>Scraps, Sludge</i>	857		104		239		722	203		43		160		0
Biomass / <i>Green waste</i>	0		200		0		200	160		80		80		0
Fossil Fuels / <i>Ash</i>	9,500		0		2,700		6,800	70		70		0		0
Final products / <i>Discarded prods.</i>	2,659		5		1,534		1,130	274		15		255		4
Total	16,611		3,718		6,667		13,662	1,791		441		1,108		242

^a Calculated by mass balance

^b Incorporates waste from final products

The differences between apparent consumption and waste management clearly show that 1) fossil fuels and food and agricultural products are mostly consumed rather than entering the waste management regime, and that 2) most construction minerals, metals, and durable final products are added to stock through the process of economic growth, but will enter the waste stream at a later date. Flows of water and wastewater, which are not included in Table 1.1, are by far the largest flows by mass through the island system, orders of magnitude larger than total solid material flows.

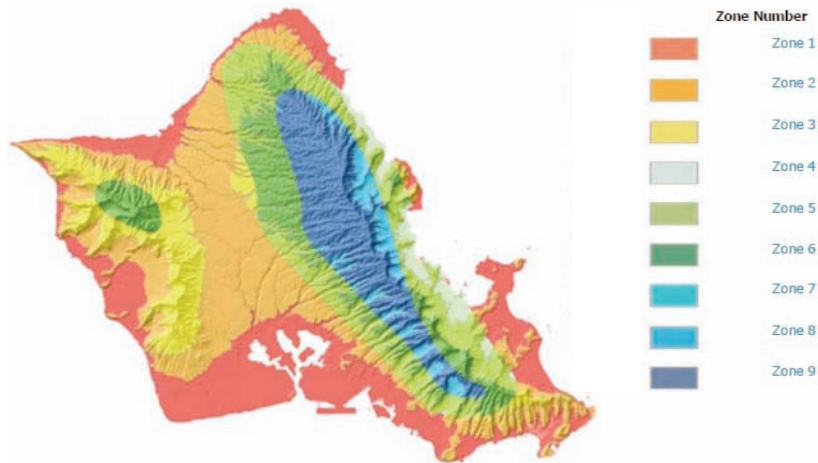
Chapter 2: Oahu Overview

2.1 OAHU CHARACTERISTICS AND LOCATION

The Hawaiian Islands were formed by the outflow of lava from a magma hotspot in the ocean seabed. Oahu is the product of two separate volcanoes: Waiʻanae and Koʻolau, which straddle the broad Oahu Plain that spans the middle of the island contributing to a total land area of 1,545 square kilometers. Because of their geologic history, the islands have few extractable natural resources and no endemic sources of fossil fuel. Oahu is a fairly uniform block of basalt covered in soil derived from the weathering of the basaltic rock and volcanic ash.

Hawaii’s climate has relatively uniform temperature and sun levels throughout the year, allowing for a 12-month growing season. The only seasonality is a slight fluctuation between a warmer, drier season from May through October and a cooler, wetter season from October through April. Persistent, northeasterly trade winds have resulted in a standard pattern of rainfall and land erosion on the islands. The windward slopes are wetter and have, over time, been carved into deep valleys with perennial streams. The leeward, southwestern slopes have drier, gentler slopes. Due to the highly permeable volcanic terrain that readily absorbs and stores water in its naturally occurring aquifers, freshwater resources are abundant. Lenses of fresh water that float on the denser salt water can also be tapped below ground (Honolulu BWS, 2008).

Figure 2.1 Climatic map of Oahu



Source: City and County of Honolulu Board of Water Supply

The jurisdictional unit of the “City & County of Honolulu” encompasses all of Oahu and divides the island into seven districts. Oahu’s land area covers 596 square

miles, making it the third largest of the Hawaiian Islands. It was historically called ‘the gathering place’, which is still fitting as Oahu is home to approximately 75% of the state’s population. The population density of 567 people per square kilometer is at least ten times greater than any of the neighboring islands (DBEDT, 2006). This value is higher than the average population density for any state in the US (U.S. Census Bureau American Fact Finder U.S. Geographic Comparison Table, 2000). For example, New Jersey, the most densely populated mainland state, has an average population density of 439 people per square kilometer (U.S. Census Bureau, 2007).

Ethnically, Hawai’i is one of the most diverse states in the nation. On Oahu, 45% of the population self-identifies as Asian, 25% as Caucasian, 9% as Native Hawaiian/other Pacific Islander, while 18% of the people on Oahu consider themselves to be of two or more races (U.S. Census Bureau, 2007).

2.2 OAHU’S ECONOMY

Many islands face physical material availability constraints, and these are exacerbated by the quantity and diversity of consumption demanded by the modern world. Oahu’s economy, like that of the entire state, has progressed through a series of social and economic phases. Prior to significant outside influence, Oahu maintained a sophisticated agricultural economy that supported several hundred thousand native inhabitants (Stannard, 1989). The islands were politically and economically divided into wedge-shaped areas called *ahupua’a*, which ran from the mountains to the sea along natural watershed boundaries. Within these boundaries, Hawaiians set up complementary farms of crops (mostly taro and banana) and aquaculture that used the slope of the land to emphasize water and nutrient cascading. These farms were extremely material efficient and enabled a sustainable domestic food supply, despite a large population.

With the advent of foreign and commercial pressures, the island transitioned to large-scale industries based on extractive harvesting, such as whaling and sandalwood. By the turn of the 20th century, plantations were established to produce large monocultures for export, such as sugarcane and pineapple. In the past several decades, the processes of globalization, especially the lowering of tariffs and trade barriers, have made these plantations unprofitable. Dole, the last remaining pineapple producer on the island, is phasing out the majority of its operations. The decline in domestic agriculture increases Oahu’s reliance on food imports.

Most recently, the tourism industry has become the dominant feature of the economic landscape. The shift to tourism began in the late 1950s, rapidly growing when Hawai’i became the 50th state in 1959. Tourism today accounts for a quarter of the Hawaiian economy and approximately a third of all jobs (Fernandes, 2002). The military presence on Oahu also remains significant; Pearl Harbor naval base alone pumps an estimated \$4 billion into Honolulu’s economy. There are currently 44,000 armed forces personnel and 53,000 military dependents on the island with military land holdings accounting for over 20% of Oahu’s land area. The large military presence has a number of material flow consequences: for example, many aspects of military waste management are run in parallel with the municipal system, and

imports of petroleum to service the military greatly increase Oahu's overall demand for this fuel.

Oahu faces significant barriers to economic diversification. The first among these is the island's remoteness and the resulting high cost of shipping. This raises prices for any sort of industrial process involving raw materials, or any agricultural business requiring fertilizer or feed, and makes exports from Oahu less competitive. In addition, Oahu's economy is of an intermediate size: large enough to demand a diverse stream of products and materials but occasionally too small to provide economies of scale or adequate market competition. From the perspective of material utilization, on the collection end, this size makes it difficult for reuse and recycling businesses to secure a consistent waste stream and, on the market end, may be insufficient to find enough uses for secondary materials.

Chapter 3: Imports

3.1 OVERVIEW

The entire state of Hawai'i imports roughly 80% of the materials it requires to operate, including food, merchandise and construction materials. The ports of Oahu are key to Hawaii's material flows, with 98% of materials arriving by ship (IWR, 2005; Pascua, 2008). Oahu has limited and strictly controlled points of entry: three commercial ports: Honolulu Harbor, Kalaeloa Barbers Point Harbor, and Kewalo Basin Harbor. Material also arrives by air via Honolulu International Airport. These places of entry are all located in relatively close proximity to one another along the island's southern coast.

The port of Honolulu, an improved natural harbor, is the largest and the only port capable of handling container traffic in the state. As a result, containers destined for other islands in the state must be off-loaded in Honolulu, reloaded onto smaller vessels, and re-exported. This greatly inflates the raw import/export data for the island, which must be adjusted. Indeed, various regulations ensure that out-of-state and inter-island traffic are handled by separate companies. Honolulu Harbor handles 13.4 million tons annually (imports and exports) or close to half of Hawaii's annual shipping (IWR, 2005). In addition to containers, Honolulu's port handles liquids (mostly petroleum), dry bulk (mostly aggregate), neo-bulk (such as lumber), and other miscellaneous shipments.

The second largest port in Hawai'i, also located on Oahu, is Kalaeloa Barbers Point. It was completed in 1990 and is situated in close proximity to the 1,400-acre James Campbell Industrial Park. The Campbell Industrial Park is a major hub of industrial activity on Oahu, comprising a network of over 200 businesses in sectors ranging from plastics manufacturing to agricultural services. Annual imports to Barber's Point amount to 3.8 million tons, most of which is petroleum. These petroleum products are handled through two offshore subsea moorings that are delivered directly to Hawaii's only two oil refineries, Chevron and Tesoro, located in the Campbell Industrial Park.

Kewalo Basin is a small, artificial port mostly used for vessel docking for fishing, charter, and research boats. It is in close proximity to the commercial fishing village, where fishermen unload and sell their wild fish catch in the commercial auction house. Around 9,000 tons of wild caught fish are offloaded and sold here annually.

Oahu is extremely dependent upon imported energy, hence tremendously vulnerable to any disruptions. Hawai'i has no fossil fuel reserves, with fuel choice driven by the specific needs of each island and the existing storage and distribution infrastructure. On Oahu, large quantities of jet fuel are needed to support both the tourism sector as well as the military. These demands, along with gasoline-powered cars, have resulted in petroleum representing nearly 90% of all energy used in Hawai'i (Energy Information Administration, 2009).

Some 75% of all imported petroleum is used on Oahu, while the rest is sent to the other Hawaiian islands. Approximately 11% of the total petroleum imported to Oahu enters as refined product (IWR, 2005). The remaining 89% is imported as crude oil and refined on Oahu by either Tesoro Hawaii Corporation or Chevron USA Incorporated. Their combined refining capacity is approximately 20,000 tons of crude oil per day.

The total petroleum consumption for Hawai'i has remained fairly steady over the past decade, largely due to improvements in the efficiencies of jet engines and conservation efforts (DBEDT, 2006). In this same decade, the percentage of crude oil imports to Hawai'i coming from the mainland U.S. has fallen dramatically from nearly 40% in 1996 to just 0.8% in 2006. Significant crude suppliers include Vietnam, with 23%, Saudi Arabia with 20%, Brunei with 11% and 10% each from China and Indonesia (Energy Information Administration, 2009).

Matson container ship in Honolulu Harbor



Source: Honolulu Advertiser

A few major players dominate Hawaii's shipping industry. Matson shipping lines handles approximately 70% of all out-of-state traffic and Horizon handles about 25%. The remaining five percent is handled by smaller companies such as Pasha, which specializes in the roll-on roll-off transport of cars. Several barging companies – primarily Young Brothers, ACT, and Sause Brothers – handle the majority of inter-island shipping (Friel, 2008).

Matson and Horizon each have regular contract accounts with retail customers and compete with one another for additional shipping engagements. Standard vessel size is around 2,600 Twenty-foot Equivalent Units (TEU), which can hold 1,300 20-foot containers. Matson, which handles the majority of the ships entering Oahu's

ports, has around five arrivals per week – two from Long Beach, CA; two from Oakland, CA; and one from Seattle, WA. Many of Matson’s clients import large volumes of material; for example:

- Safeway, a retail client of Matson’s, regularly imports 50 – 75 containers of products per month.
- Anheuser Bush ships in 50-75 containers of beer per month.
- There is a constant flow of autos on and off the island of Oahu, which occurs on an annual cycle. In 2007, Matson shipped a total of 118,000 cars, most of which were for the rental car industry, which “de-fleets” after spring break every year and imports new models beginning in the fall (Friel, 2008).

Of great importance to material flows on the island is the fact that all of the containers arriving on Oahu are full, but two-thirds of containers generally leave empty. Some of the larger retailers, such as Sears, backhaul packaging materials to the mainland U.S., but these volumes are small compared to imports. In general, there are not enough export products of sufficient value manufactured on the islands to merit the cost of transport to distant markets.

Various shipping laws and regulations have shaped the composition of the major private shipping industry in Hawai’i. First and foremost among these is the Jones Act, which mandates that any vessel transporting goods between two U.S. ports must be an American-flagged ship. Because of the strict regulations governing U.S. vessels, it is difficult for smaller firms to break into the shipping market. Hawaiian Public Utility Commission (PUC) laws govern inter-island shipping. These laws impact Jones Act carriers such as Matson and Horizon, by requiring that all their inter-island shipments must originate from out of state.

While the material throughput of Honolulu’s airport is small compared to the ports, it is still an important gateway for products that are time-sensitive, such as cut flowers or mail. Though Oahu imports significant amounts of freight and mail, on a net basis, it is actually an exporter of both. Unlike for shipping, where all traffic must pass through Honolulu, the state has several other airports that can handle international traffic.

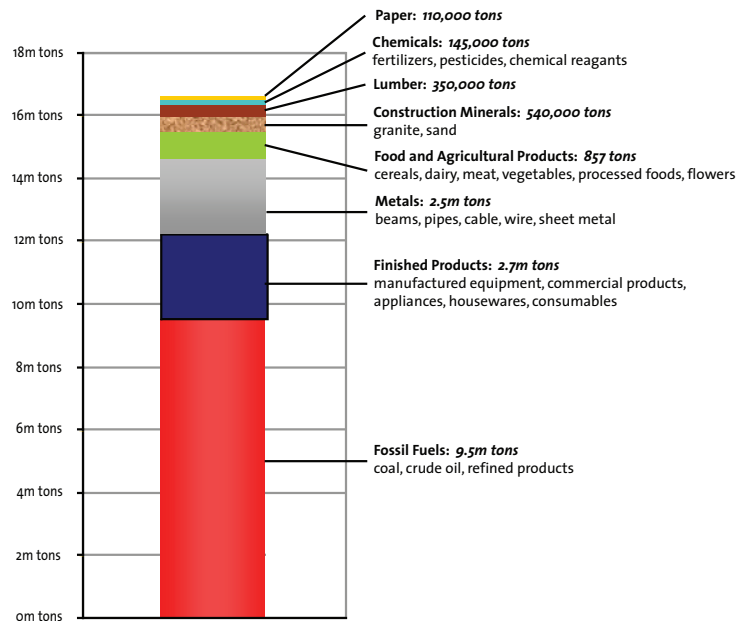
3.2 RE-EXPORT AND INTER-ISLAND TRANSPORT

As Honolulu serves as the only container port for the state, all of the cargo destined for the outer islands must pass through Honolulu, along with material being shipped from the outer islands to the mainland or other countries. This is in part because of legislation called the Jones Act, which requires that any vessel transporting goods between two U.S. ports be an American-flagged ship. This cargo is logged but does not actually leave the port, and so contributes to the overall import/export figures for Honolulu. This is called re-export and is a common issue in examining trade statistics. For example, the main export of Hawai’i Island by mass is “fabricated metal products” or machinery, which in 2005 amounted to more than 900,000 tons of material. While businesses and residents on Oahu might use some of this machinery,

the majority is re-exported to the West Coast of the U.S. So, the stated value of Oahu's import of fabricated metal products must be adjusted to account for these re-exports from Hawai'i Island (and from all other islands as well). Without this adjustment, there is the potential for some material flows to be "double counted." In the case of the airport, it was assumed that Honolulu serves as the aggregation and distribution center for all outer islands except for Hawai'i Island.

The adjustment was made by subtracting out the flows to other islands. Oahu imports minus neighboring island exports yielded "net Oahu import" values – or a measure of the materials staying on the island. Oahu exports minus neighboring island imports yielded "net Oahu export" values – or a measure of the materials permanently leaving Hawai'i. The import to export ratios in these two scenarios varied considerably. When looking at the "Oahu only" values, imports were 5.6 times the volume of exports, whereas in the combined scenario they were only 1.8 times the volume of exports. This adjustment to the data was more consistent with statistics that show that 80% of all materials in Hawai'i are imported, and would in fact suggest that an even larger percentage of Oahu's materials are imported in comparison to neighboring islands.

Figure 3.1 Imports to Oahu



3.3 TOTAL RESULTS

Imports into Oahu are shown in Figure 3.1.

Petroleum products clearly represent the largest material import of Oahu, with more than 60% of the total. This fact belies Oahu's precarious dependence on outside fuel suppliers.

Chapter 4: On-Island Extraction and Production

For most of the 20th century, Oahu was an agricultural powerhouse, producing large quantities of pineapples, sugar, and livestock. As mentioned earlier, these industries have nearly collapsed, leaving Oahu producing very little of what it finally consumes, resulting in a large trade deficit in goods. The most significant domestic extractive industries are rock quarrying, small-scale agriculture (including flowers), fishing, and water provisioning. The island's three commercial quarries produce nearly 3.4 million tons of basalt, almost all of which goes to satisfy the island's construction industry. The island's farms and fisheries produced more than 100,000 tons of food in 2005; the most significant products are pineapples and milk (DBEDT, 2006). Nearly 160,000 tons of biomass (such as grass clippings) end up as "green waste". An unknown amount of biomass is also composted at private homes. Because of Oahu's peculiar volcanic history and geography, the island contains several large aquifers that support all of the island's water demand, totaling 790 million cubic meters (or 870 million tons) of water per day. As is usually the case, material flows of water dominate the overall material flow picture by mass.

4.1 MINING AND MINERALS

The minerals sector represents a relatively minor part of the Hawaiian economy; non-fuel raw mineral production for the state in 2005 was valued at \$100 million (USGS, 2007). However, the extraction of minerals from the Hawaiian Islands supports a great deal of the construction activity in the state and represents an important flow of materials, on a mass basis. The large amount of rock mined and used on the island avoids the import of this material from foreign or mainland sources. This means that the island is largely self-sufficient for this important input into its economy.

Throughout the state of Hawai'i, volcanic basaltic traprock is quarried and crushed for various construction applications such as concrete, asphalt, road base, and fill. There are two grades of basalt: Grade A basalt is harder stone and is used primarily for concrete and asphalt; Grade B basalt is softer rock and is used as fill and base material. In some locations, gravel and sand are extracted for construction applications and dimensional limestone is quarried. There are three basalt quarries on the island of Oahu: Ameron Hawaii's Kapa'a Quarry, Grace Pacific Corporation's Makakilo Quarry, and Hawaiian Cement's Halawa Quarry.

Kapa'a, the largest quarry, belonging to Ameron Hawaii, has been operating since 1949 and covers 416 acres, approximately 4 km west of Kailua. Supplying over 50% of Oahu's concrete needs, Ameron operates ready-mix batching facilities at the Kapa'a Quarry and on Sand Island in Honolulu. Ameron Hawai'i estimates that the Phase I Quarry has a 10-year supply of basalt left; operations on the Phase II Quarry have

already commenced. The Kapa'a Quarry produces a mix of 80% Grade A rock, some of which is milled into sand, and 20% Grade B. Manufactured sand is not as suitable for concrete as real sand, therefore greater quantities are needed to obtain the right consistency of concrete. In FY2007, the Kapa'a Quarry processed a total of 1.3 million tons of basalt. When rainwater collects at the bottom of the quarry it is pumped to industrial users downstream, including a composting facility, a rock sculptor, and two construction companies. The exact quantities of water shared in this way were not available. (Goldstein Interview, 2008)

The second largest quarry, Grace Pacific Corporation's Makakilo Quarry, is located approximately 12 km southwest of Pearl City and produced a mix 40% Grade A and 60% Grade B aggregate in FY2007. The quarry's supply of Grade A basalt was exhausted at the end of FY2007, at which time the company began importing 230,000 tons of Grade A material per year from Canada to support its own hot bed paving needs, which supports about 75% of Hawaii's paving market. A new permit was granted for expansion of the Makakilo Quarry in October 2008 (Honolulu Advertiser, 2008) with another in process. The expansion would supply 25 years of rock at an average rate of 900,000 tons per year.

As FY 2008 was a transition year for Grade A material at Makakilo, the data presented here are from FY2006, which is more representative of the past decade. During FY2006, the quarry sold more than one million tons of basalt, with approximately equal proportions of Grade A and Grade B. The Makakilo Quarry also produces construction aggregate and is the only permitted concrete recycler in the state. During FY2006, Grace Pacific received 100,000 tons of asphalt and concrete for recycling. Grace Pacific also recycles approximately 150,000 gallons of water per year at their operations and sold approximately 18,000 tons of scalplings by-product (vegetation that has been removed from construction sites) as fill in 2006 (Creps, 2008; Kitaoka, 2008).

Hawaiian Cement's Halawa Quarry lies about 7 km southeast of Pearl City and supplies Hawaii with cement, aggregate, and ready-mix concrete. On Oahu, it operates the Halawa Quarry, where it produces approximately a 40% Grade A and 60% Grade B mix of basalt aggregate. As there are no dune sand deposits on Oahu, Hawaiian Cement imports approximately 70,000 tons of sand from Canada each year for concrete production. The Halawa Quarry processed approximately one million tons of basalt in FY 2007 (Wurlitzer, 2008).

Yearly basalt extraction on Oahu totals 3.4 million tons. Statewide in 2005, total crushed traprock extraction was 5.4 million tons for 18 quarries, indicating that traprock mining in the three Oahu quarries constitutes the majority of the state's aggregate mining flow (USGS, 2007). Since no crushed stone is exported off-island, aggregate production is dependent on the intensity of local construction activity and is therefore influenced by the general economic activity on the island. Also, it is important to note that all quarries keep stockpiles of crushed stone on-site and do not operate as crush-to-order businesses. Therefore, the amount of rock extracted from the island each year does not exactly represent the flow of material into use over the same time period. It is, however, a good indicator of the levels of activity and use on the island.

Independent divers harvest Black Coral, Hawaii's state gem, from the deep reef slopes surrounding Oahu. This operation, although much smaller than extraction from quarries, is very high value. Maui Divers Jewelry buys the raw coral from these independent contractors and finishes the raw material as jewelry. Though it does not directly harvest black coral, Maui Divers represents the major user of coral on Oahu. The jewelry company buys approximately 200 pounds per month from independent black coral divers. About 60-70% of this purchased weight is waste rock, so only 80 pounds of actual coral is harvested each year. The coral is polished down into a gem-like state and scrap particles and shavings are used to fill in gaps in settings, thereby assuring virtually 100% use of the extracted coral.

4.2 AGRICULTURE, ANIMAL HUSBANDRY, FISHERIES, AND FORESTRY

Agriculture has represented a constant 3% of gross state product (GSP) since 1992 (NASS, 2005). This figure is probably smaller for the island of Oahu, where agriculture has undergone a steep decline in recent decades. Agricultural products also represent a relatively minor flow from a materials perspective – in 2005 there was an estimated 100,000 tons of on-island food production, excluding fish catch. However, food resources are of disproportionate importance, because of the need to satisfy basic human nutritional requirements. Hawai'i currently imports 90% of its food, which puts it in a precarious position in terms of food security. In addition, there are material flow concerns regarding agricultural flows. While agricultural products represent a relatively small mass of material on their own, they contain many upstream or “embedded” material flows. This means that a great deal of material inputs, such as water and petroleum, are required to produce agricultural goods, even though they are not part of the final product. Agriculture is also associated with large volumes of waste (such as run-off and organic wastes). On Oahu, which only has an estimated 283 km² of land in active agricultural production (NASS, 2005) the daily water usage for irrigation (both surface and ground water) amounts to 150 million cubic meters (USGS, 2009). In addition to consuming water and farming inputs and producing food, agricultural activity can also generate a significant number of byproducts, such as manure and plant waste, which should not be neglected as these could serve as useful materials for other systems. Turn *et. al* (2002) conducted a report assessing the quantity of available biomass resources generated in Oahu concluding that the majority of these were unnecessarily wasted.

The present study considers several different sub-sections of the agriculture sector: crops and floriculture, livestock, aquaculture and fisheries, and forestry. Throughout Hawai'i, diversified agriculture, which includes all commodities except sugar and pineapple, now makes up the bulk of agricultural production. On Oahu, pineapple, one of the traditional monocrops, still accounted for the largest output in 2005 at an estimated 48,000 tons of production per year. For the time being, this eclipses the production volumes of all other crops on the island, with milk coming in at a fairly distant second with 26,000 tons of production annually. Remaining food crops, which include a variety of fruits and vegetables, are produced in much smaller quantities.

Oahu produces around a third of the state's flower and nursery products by value, with widespread floriculture operations throughout the island. A large portion of these nursery products is exported. We were unable to find a suitable estimate for calculating the mass of floriculture products specifically, as production is usually reported in non-mass units such as dozens of sprays or numbers of potted plants (HDoA, 2004).

Former pineapple fields near the Dole plantation in Wahiawa



Source: Yale University

Seafood consumption in Hawai'i amounts to over 23,000 tons annually, considerably higher per capita consumption than anywhere else in the U.S. Only 30% of this demand is satisfied through local fish catches (out of the 10,000 tons of fish caught in Oahu annually, a small portion is exported to the mainland U.S. and Asia). Supply cannot be expanded significantly, however, without exceeding sustainable fishing capacity. An alternative option for satisfying seafood demand is the expansion of aquaculture. Although aquaculture is still a nascent industry in Hawai'i, it has been growing rapidly. There are currently 46 aquaculture operations on Oahu alone, which include both commercial and research facilities. Hawai'i grows about 30 different aquaculture products, ranging from fresh to salt water, edible to ornamental. Though the primary aquaculture crop in Hawai'i is algae – particularly spirulina, which is used in health food supplements – Oahu's major operations include several disease-free shrimp stock farms and finfish operations (DBEDT, 2006; Laidley, 2008).

There is no commercial forestry on the island of Oahu, though high-value Hawaiian woods such as koa are imported from the other islands and can be found in Oahu's lumberyards. Vegetation on land that is cleared for construction (called scalping) is disposed of on-island in brush piles and compost.

4.3 WATER

Each of the Hawaiian Islands was formed from lava as it emerged from the earth's crust. Varying conditions and environmental interactions have caused this lava to evolve into different types of rock and form different structures. The majority of volcanic rock is very porous, which allows freshwater to infiltrate into groundwater reserves instead of

simply flowing into the ocean as runoff. Oahu features large sections of less-permeable rock called dikes that are formed when lava is allowed to cool more slowly. These dikes create vertical barriers to the flow of groundwater, and thus create aquifers. Dike-impounded aquifers are found in the mountainous interior regions of the island. The majority of the groundwater is held in basal (low-level) aquifers closer to the shore.

Oahu is a relatively mature island. While lava is still flowing on Hawai'i Island, lava reached the capping stage on Oahu about 1.8 million years ago. In this capping period, Oahu has developed a thick layer of caprock at the perimeter. Caprock is a dense material formed from the deposition of sediment and the erosion of coral. The caprock creates a barrier between the fresh groundwater and the saline ocean forming a basal aquifer. The aquifer's lower boundary is governed by the rate of freshwater addition and the rate of saltwater intrusion. It is therefore crucial to the maintenance of the aquifer that the groundwater not be taxed in excess of what can safely be removed, thereby allowing detrimental saltwater intrusion. This is the basis by which sustainable yield estimates can be produced for the regions of Oahu.

Oahu currently uses about 190 million gallons of groundwater per day: 76% is consumed residentially, 6% by industry and 15% is used for irrigation. Compared to the nearly 450 million gallons per day that could be sustainably extracted, 190 million gallons may seem small (Honolulu BWS, 2008; CWRM, 2005). However, the sustainable yield value represents the total amount of water that can be extracted across the entire region without overtaxing the various aquifers. As water usage approaches the sustainable yield, the water becomes more difficult and more expensive to extract. Geologic and geographic obstructions may prevent some portion from ever being utilized. Less developed regions of Oahu have more comfortable cushions between their usage and sustainable groundwater yield. As water demand increases throughout the island, the costly transportation of groundwater from one region to another will become more prevalent. Water is measured in millions of gallons per day (mgd).

Table 4.1 Water use and supply in different regions of Oahu in 2005

REGION	RESIDENTIAL WATER USE (MGD)	MAXIMUM SUSTAINABLE YIELD (MGD)
Honolulu	45	53
Pearl Harbor	103	165
Central	11	23
Wai'anae	5	15
North	5	90
Windward	24	98
TOTAL	193	444

Source: Commission on Water Resource Management

There is some cultural opposition to the diversion of freshwater resources. Diverting or overtaxing a stream or river for agricultural uses can destroy the

downstream watershed ecosystem. The traditional concept of the *ahupua'a* has been redefined in a more modern context. The watershed boundaries were historically the political boundaries between communities. In traditional Hawaiian culture, the value of water was always given tremendous respect, and human activities minimized disruption. The staple food crop, the taro plant, was cultivated in small channels that diverged and then rejoined the river system. Oahu is unlikely to return to its *ahupua'a* roots; however, the desire to preserve the freshwater ecosystem prevails.

Surface water represents only about 4% of the total freshwater usage on Oahu. The only significant demand is for irrigation, and about 80% of this demand is met with groundwater (USGS, 2009). The volume of streams and rivers varies dramatically, both spatially and temporally, across the island. The stream system is very much dependent on contributions from resurfacing groundwater to maintain base flow. The windward side of Oahu receives tremendous amounts of rainfall, while the leeward side receives very little.

Sustainability in water is a matter of both quantity and quality. Industrial activity on Oahu is limited to a few pockets, such as Campbell Industrial Park and Sand Island. Therefore, the majority of public water contamination concerns are directed at military bases. The military has indeed been responsible for toxic releases into areas such as Pearl Harbor; however, a recent USGS study suggests that the groundwater quality on Oahu failed to meet standards in only a few cases (Hunt, 2004). Various solvents have been detected in military areas. Pesticides, fertilizers and fumigants haven been detected in agricultural areas. On the other hand, groundwater contamination in urban areas is, in general, surprisingly low, with good overall water quality. The extensive geological interaction imparts elevated levels of calcium, magnesium, silica and other minerals in the groundwater (Honolulu BWS, 2008).

The Honolulu Board of Water Supply has made great progress in educating residential and commercial customers about the value of water conservation. These efforts have allowed water usage to stabilize in recent years, despite modest population growth. Still, many of the benefits of conservation campaigns yield one-time results, such as savings from switching to low-flow devices. It is projected that freshwater demand will increase as the population continues to rise.

Table 4.3 Projected change in water demand in different regions of Oahu in 2030

REGION	DE FACTO POPULATION 2000	PROJECTED POPULATION 2030	ADDITIONAL DEMAND 2030 (MGD)
Wai'anae	41,731	52,273	2.34
Ewa	66,819	199,415	27.21
East Honolulu	45,702	51,150	1.21
PUC	482,251	562,767	13.59
Central Oahu	142,667	183,699	6.42
Ko'ohau Poko	113,256	112,048	-0.22
Ko'alau Loa	15,346	20,863	0.58
North Shore	17,672	20,386	0.53
TOTAL	925,444	1,202,600	51.70

Source: Commission on Water Resource Management

Chapter 5: Material Use and Conversion

Once material enters the economy of Oahu, whether through import or domestic production, it is either processed and exported, or used on-island by businesses and residents. The large and diverse use of material on Oahu involves many different sectors. The material flow calculations presented here focused on the sub-sectors with the largest contributions to material use and economic activity: construction, power generation, tourism, transportation, residential and commercial consumption of food, and military uses. Most of these sectors are interconnected in that they send and receive water, energy, materials and waste in a complex network.

5.1 CONSTRUCTION

5.1.1 Private construction

In 2006 the private construction sector on Oahu was valued at more than \$1.9 billion (Honolulu DPP, 2006) and issued more than 16,500 building permits, of which 60% were for residential projects, the remainder for commercial and industrial projects. Based on models calibrated with data from in-depth studies of ten developments, calculations show that Oahu's private construction sector added over 330,000 tons of solid material to existing building stock. The primary feature of the models is an estimate of material-intensity per square foot, which is then multiplied by the total floor area of a project (from building permits) to arrive at material stock. Major inputs into the construction sector include concrete, steel, wood, plumbing fixtures, and other metals (copper and aluminum).

A residential home being constructed in Makiki



Source: Wiseco Development Corp.

In order to estimate the amount of material used in the construction of new homes, a case study from Michigan was used to determine the mass per square foot of different materials (Keoleian et al., 2000). The study found that 278 metric tons were used to construct a 4,125 square foot house. Therefore an estimate of 150 pounds per square foot of house is used to generate the amount of materials used per housing type.

Water and fossil fuel quantities for the construction sector were not readily available and are excluded from the above data. However, representatives of the construction industry (Prentice, 2008) describe water usage at an average commercial construction site as follows: projects valued at \$100 million or more use over 6,000 gallons of water per day for cleaning and dust removal. The water that is mixed to form concrete is not included here because it does not always occur at the construction site. Most of the mass is stored in the buildings (in-use stock) until the building undergoes renovations or is demolished. Unused parts of the materials are labeled construction and demolition waste and removed; however, these are minimal compared to the amount of material that is added to the building stock.

Skyscrapers of downtown Honolulu, requiring large amounts of steel, glass, concrete, and other materials



Source: Yale University

5.1.2 Military construction

The U.S. military also contributes a significant amount to construction, primarily in housing. In 2005-2006 the military added 139,000 tons of material to existing building stock while reporting some reuse of materials from home demolition (Espinoza *et al.*, 2008). Construction on military bases may be broken down into two areas: road/other infrastructure (see next section) and buildings. Projects in each area can then be further subdivided into new construction and maintenance.

The Department of Defense (DoD) has a federal mandate to contract out as much work as possible to private enterprise via open project bidding (OMB, 2003). As a result, there may be dozens of contracting companies completing construction projects on a base at any one time. These companies further subcontract portions of the construction project making it challenging to collect comprehensive information about material utilization. The largest portion of new military construction is 'private' off-base family housing, primarily replacing older model homes that are being demolished in significant numbers over the past several years. Two contractors, Actus Lend Lease (Army and Air Force) and Forest City (Navy and Marine Corps) build most new military housing projects. Each contractor is installing solar hot water heaters on the roofs of all homes and follows some energy efficient building practices during construction. The contractors recycle significant quantities of concrete from demolition into structural fill for new buildings, but other useful construction materials from demolition are discarded to landfill. Based on interviews with Actus and Forest City, this concrete comprises an estimated 25% of the demolition waste stream.

Actus has a 10-year contract with the Army to build 5,388 new homes and renovate 2,506 existing homes between 2005 and 2015. In 2005 there were 7,814 houses, by 2015, through a combination of demolition, new construction, and renovation, there will be 7,894 new homes. Construction will focus on three bedroom duplex homes, but there will also be four bedroom duplexes and single-family homes (Nichols, 2008). Similar to the Army, the Air Force will build 1,000 new housing units over a five-year period (DBEDT, 2006).

Large military construction projects also require significant amounts of material. While it is possible to obtain budgets for these projects, it was not possible to ascertain exactly the amounts of types of materials used for each, and so this information is not reported here (Slick, 2008; Lotti, 2008; Goo, 2008).

5.1.3 Road construction

As of 2006, Oahu had 1,617 miles of paved streets and highways, not including military and private roads (DBEDT, 2006). These roads account for large material flows and consumption, containing about 39,000 tons of aggregate and 2,500 tons of asphalt per mile (Schaefer, 2008). Almost all of these roads are constructed using locally extracted aggregate and asphalt shipped in from the mainland.

Grace Pacific Corporation (GPC) (see Section 4.1) provided the information necessary to determine the material requirements of road construction on the island, including: estimates for the total aggregate quarried at Makakilo, ratios of virgin and recycled material used on road construction jobs, proportions of aggregate and asphalt used, GPC's portion of total road construction jobs on Hawai'i, and the amount of virgin aggregate GPC had imported from the Vancouver area of Canada. These data was used to calculate total aggregate and, proportionately, total asphalt consumed for road construction in the state.

Our estimate reveals that Oahu invested more than 2 million tons of aggregate and asphalt in road construction in 2006 and has a total of nearly 75 million tons of

material locked up in its road system. Approximately 100,000 tons of recycled concrete were used by GPC for their construction projects.

In addition, military road construction requires imports of some construction materials. For example, the Air Force has rigorous quality standards for landing strips and higher than average road quality criteria, thus it spends approximately \$200,000 per year on routine road repairs. Asphalt composes 2-3% of the material used for these repairs. There is an attempt to recycle the road material, but it can only be used as filler on military projects so new asphalt is purchased for all road repair projects (Slick, 2008).

The H₃ Highway on Oahu



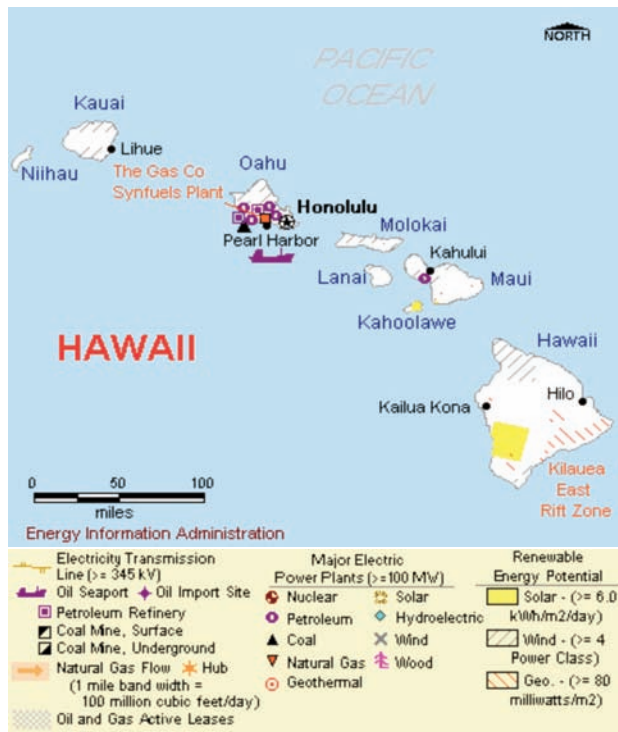
Source: Federal Highway Administration

5.2 POWER GENERATION

Oahu relies on fossil fuel powered electricity generation for more than 90% of its supply. Power generation is concentrated on the southern coast of the island, where there are two refineries, four oil-fired plants, the Gas Company synfuels plant (an emergency operator), the AES coal plant, and the H-POWER waste to energy facility. Power generation facilities on Oahu and the other islands are shown in Figure 5.1. Note that this figure shows only those power plants with a generation capacity of more than 100MW. Though Hawaii represents less than one half of one percent of the national population, it generates more than 20% of the country's oil-fired electricity, again highlighting Oahu's dependence on this fuel. Because of Hawaii's mild climate, there is little need for heating or air conditioning. This combined with little heavy industry means that per capita electricity consumption in Hawaii is among the lowest in the nation (Energy Information Administration, 2009).

Oahu's reliance on fossil fuels in energy terms has a corresponding dependence in mass terms. As detailed in Section 3, fossil fuel makes up a large portion of Oahu's overall inputs. The AES coal cogeneration plant is the only coal-fired power plant on the island and produces about 14% of the island's electricity (180 MW). Five to seven percent of the island's power comes from the H-POWER waste to energy facility, with the remaining 80% coming from six large-scale oil-fired sources (two are auxiliary). From a material flow point of view, all of these plants take in fuel, oxygen, and water, and emit carbon dioxide and other air emissions, water vapor and ash.

Figure 5.1 State energy profile of Hawai'i (Energy Information Administration, 2009)



5.2.1 AES coal plant

The AES plant burns nearly 900,000 tons of low sulfur coal (0.5-0.7%) annually. Through a contract with Constellation Energy, AES receives coal from Canada, Indonesia, Colombia or Australia. In addition, the plant uses as alternative fuels some 6,750 tons of tire-derived fuel from a nearby tire shredding operation run by Unitek, 5,400 tons of waste oil also processed by Unitek, and 530 tons of spent activated carbon (Chertow and Miyata, 2009). Of the 50,000 tons of fly ash produced by AES in 2005, 7,000 tons is used by Hawaiian Cement and the remainder is mixed with 20,000 tons of bottom ash and water and used to cap the PVT landfill (Parthasarathy et al., 2008; Chertow and Miyata, 2009).

5.2.2 H-POWER waste to energy plant

While the waste treatment and disposal functions of H-POWER will be discussed in the Waste section below, this section will focus on the power generation aspects of the facility. At full capacity, H-POWER generates 90 MW of electric power and reduces the mass of municipal solid waste (MSW) that is burned there by approximately 90% and the volume by 70% (see Figure 5.2). Despite this reduction, the plant generated 88,000 tons of ash in 2005-2006 that were disposed of in a special ash section of the Waimanalo Gulch landfill. During both pre-and post-combustion screening, 20,000 tons of metals are recovered each year, most of which is ferrous. The facility also uses approximately 5,000 tons of lime annually for pollution control measures.

AES coal-fired power plant

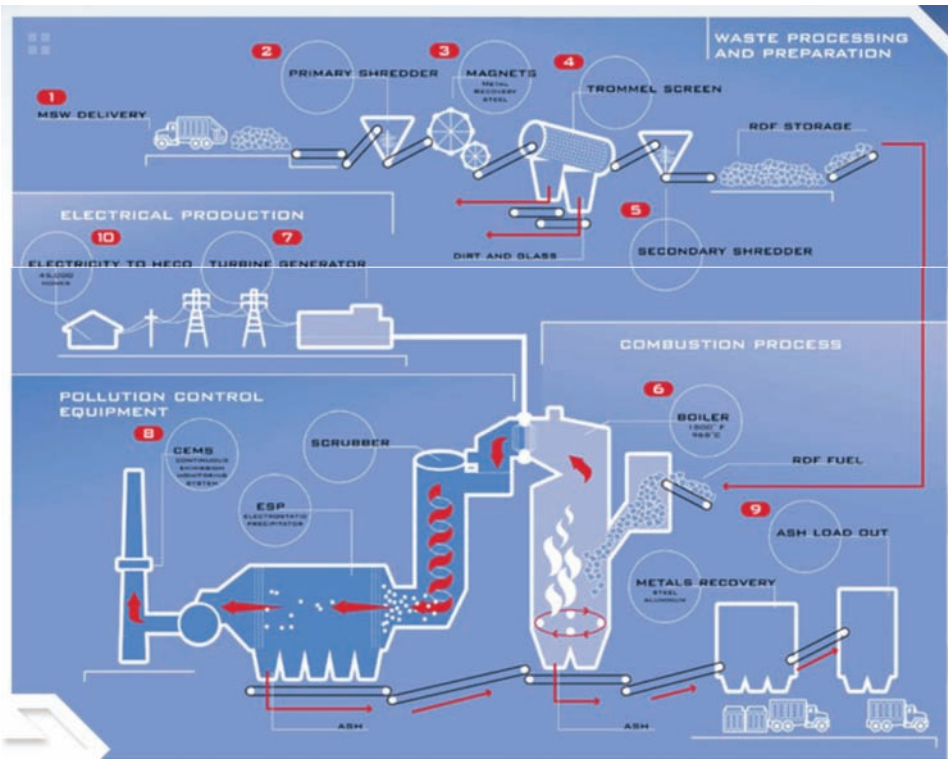


Source: Honolulu Star-Bulletin

H-POWER waste to energy plant



Figure 5.2 Process diagram for the H-POWER plant



Source: www.honolulupower.com/

Table 5.1 Operating data for H-POWER (tons)

	2005	2006
Solid Waste Processed	552,265	643,895
Unprocessable Waste Removed	5,891	4,894
Pre-combustion Ferrous Removed	12,748	14,445
Process Residue Removed	77,012	99,320
Ash Removed	84,349	92,052
Post-combustion Ferrous	4,135	5,401
Post-combustion Non-ferrous	1,648	2,030
Gross MWh Produced	336,472	386,960
Net MWh Sold	292,252	338,077
Lime Consumed	5,037	5,544

5.2.3 Oil-fired power generation

There are six major oil-fired power plants on Oahu. Three are owned by the Hawaiian Electric Company (HECO), with the plant at Kahe being the largest. Kalaeloa Partners (majority owned by PSEG) runs a single, combined-cycle cogeneration plant that uses low-sulfur fuel oil. It also sends steam to the Tesoro refinery, supplying approximately 90% of the refinery's external thermal requirements.

Kalaeloa Cogeneration Plant



Source: www.industcards.com

Firm Generating Capacity	
HECO power plants (oil)	
Honolulu.....	113 MW
Walau.....	500 MW
Kahe.....	650 MW
Dispersed Generation.....	30 MW
Independent Power Producers	
H-POWER (waste-to-energy)...	46 MW
Kalaeloa Partners, LP (oil).....	208 MW
AES-Hawaii (coal).....	180 MW
Total firm generating capacity	1,727 MW
Non-firm generation	
Tesoro.....	18.5 MW
Chevron.....	9.6 MW

The military has a great influence on the island's use of petroleum as a fuel. Military aircraft and Honolulu International Airport require a large amount of jet fuel, which is produced on the island from crude oil in the two refineries. Jet fuel represents only one distillate fraction from crude oil refining. Out of one barrel of crude oil imported into Oahu, 27% will produce jet fuel, 30% for gasoline and diesel and 7% for commercial and industrial uses. The remaining 36% will be used for electricity generation. There is then a delicate but fruitful relationship between the airlines, refineries and the Hawai'i Electric Company (HECO). Refining and utilizing 100% of a crude barrel on the island keeps costs down for everyone. Jet fuel can only be produced from the highest quality portion of the crude. As the refining process continues lower grades of fuel are extracted such as gasoline and diesel. A significant amount of waste oil remains at the end of the refining process. This waste oil is utilized as a cheap fuel for electricity generation.

There is currently no alternative for petroleum jet fuel. There are alternative liquid fuel sources for electricity generation and possibly for personal transportation. One issue is that when jet fuel is refined from crude oil, gasoline and waste oil are produced as co-products, so there is little impetus for deviation from the current arrangement. A capital investment in refining infrastructure would allow an improvement in the jet fuel yield; however, as long as there is demand for waste oil and gasoline, there is less of an incentive for such action.

5.3 TRANSPORTATION

Oahu is home to approximately 900,000 year-round residents and supported a flux of 4.7 million visitors in 2006 alone. All of these people need transportation. Thus, the transportation subsector represents a large impact on Oahu's economy and material flows. Most visitors use a rental car. In 2006, visitors spent \$794 million on rental vehicles, gasoline and parking (DBEDT, 2006).

Of close to 300,000 households on the island, approximately 37% own one automobile, 34% own 2 automobiles, and 16% of households own three or more automobiles (DBEDT, 2006). The remaining households do not own an automobile. In addition, there are 1,560 registered taxicabs on the island and thousands more commercial vehicles. The tourism sector heavily influences transportation, as rental cars make up a large portion of the total fleet.

State statistics report that there are 600,000 cars and light trucks on the island, including those scrapped or shipped off the island (DBEDT, 2006). This is an extremely large number of motor vehicles for a small island of only 600 square miles, and all of them are imported. In 2006, Schnitzer Steel processed 159,000 tons of steel, approximately half of which was automobile scrap directed to Schnitzer by the County. As the sole steel recycler on the island, all cars are either processed by Schnitzer Steel or shipped off island. Information about scrap shipped off the island prior to processing by Schnitzer was not available.

In addition to cars that have reached end-of-life, around 150,000 used rental fleet cars are shipped off the island every year. Fleet cars are disposed of when they reach an average of 20,000 miles traveled. An assumption was made that all of these cars are replaced, so that the rental fleet size stays constant.

Despite large influxes of new cars, the mass of the Oahu vehicle fleet actually decreased in 2006 by 40-80,000 tons, through the export of used cars and scrap. In addition to material flows in the form of physical automobiles, the transport sector accounts for nearly all of the non-military fuel use on the island, totaling some 900,000 tons of motor fuel (DBEDT, 2006).

Commercial and logistics companies also account for a significant portion of the transportation services provided on the island. The transportation process for each 40-foot container, including ocean shipping and trucking to warehouse and/or retail location, typically costs about \$11,000. There are brokerage firms, such as American Customs Brokerage, that broker the commodities entering the island. They take care of the paperwork and inspections, unless a logistics company is taking care of that component. Retailers solicit these brokers when they want products and the brokers ensure that certain items make it onto ships and arrive at the destination in time. Once containers arrive at Oahu's port, the trucking companies pick them up and distribute them throughout the island. Some of the containers are delivered directly to the retailer while others are taken to a warehouse and broken down into smaller units. These items are then stored for short periods of time while they are being distributed to the various retailers.

5.4 TOURISM

Quantifying the material flows of the tourism sector is complicated, as it is difficult to determine what portion of the goods and services on the island are consumed by tourists as opposed to residents. Tourists are also constantly importing and exporting materials in luggage. While it was not possible to estimate a total mass of material flows due to the tourism on the island, information for certain important subsectors is included here.

In 2006, Oahu's visitors spent a total of \$5.7 billion during their stay on the island, or nearly \$180 per person per day, of which \$40 was for shopping and \$30 was for food (DBEDT, 2006). Most of what tourists spend goes toward lodging, and hotels dominate the landscape of the large tourist centers. From the retail perspective, the top 25 shopping centers in Oahu house a total of 1892 tenants, occupying more than 10 million square feet of retail space available for lease (Pacific Business News, 2006). The public (non-store) areas of these shopping centers produce about 60,000 tons of solid waste per year cumulatively. This is exclusive of the amount of solid waste that each store produces because each store is responsible for waste removal using a third party contractor, such as Honolulu Disposal (Cofran, 2008).

The Sustainable Tourism Project of DBEDT was a large-scale assessment of the impacts of tourism growth, both positive and negative, and its reports contain much valuable information about material usage and waste generation due to visitors. Table 5.3 shows daily and per capita data for visitors as compared to residents.

Table 5.3 Summary of infrastructure demand, residents and visitors (DBEDT, 2005)

	Water	Sewer	Electric	Utility Gas	Solid Waste	Highway Gas & Diesel
Total Demand	(m gal)	(m gal)	(GWh)	(mmBtu)	(m lbs)	(m gal)
Residents	61,429	33,587	5,253	1,287,940	2,432	354
Visitors	11,856	8,022	1,944	1,521,260	421	52
Daily per capita demand	(gal)	(gal)	(kWh)	(Btu)	(lbs)	(gal)
Residents	139	76	12	3,000	5.5	0.8
Visitors	207	140	34	27,000	7.3	0.9

Hotels are another tourism subsector where material flows have been examined in detail. Essentially, there are two aspects of the hotel sector that are important for material flows. The first is hotel renovation and operations, examined in this section. The second is hotel construction, which is covered in the construction section (5.1) of this report. The top 25 hotels on Oahu contain a total of 26,800 rooms (Pacific Business News, 2006). These hotels have certain common amenities, including restaurants, gift shops/concessions, conference facilities, bars, pools, spas, and saunas/exercise facilities.

This report focuses on the material requirements of the hotel rooms, rather than these other common amenities. This was done because examining the hotel as a unit would require more time as many of the components of hotels are owned and operated independently (for example restaurants and concessions) and the hotels in

general do not keep track of material flows in these areas. The information described here was derived from interviews with the Ala Moana Hotel (Miho, 2008) and the Starwood Hotels & Resorts (Sue, 2008) and extrapolated to the entire hotel subsector.

The materials in a hotel room flow on several different cycles including daily, upon check out or request of the guest; weekly; annually; and every 8 to 10 years. The primary materials used daily in the hotel room unit are the liquid materials such as soap, shampoo, lotion and coffee. The packaging for the liquid materials is not recycled, instead it is sent for disposal. In addition, towels and linens are changed on a daily or on an as requested basis and are sent to an on-site or external laundry service for cleaning; their lifespan is about one year.

In addition to replacement and upkeep of soft goods within the hotel room unit, each hotel renovates its rooms every eight to ten years. At this time larger-scale stylistic changes are made to the hotel rooms. For this, the furniture and décor are completely overhauled. In the overhaul process there is a third party that picks up the discarded furniture and other room components. This third party sells what they are able to but most items, particularly things that are hard to resell such as mattresses, end up in landfills.

When the daily waste generation totals for hotel rooms are calculated, the top 25 hotels on Oahu contribute 5,050 tons per year of solid waste generated along with approximately 1.6 million gallons of liquid waste.

5.5 RESIDENTIAL AND COMMERCIAL CONSUMPTION

It was not possible to obtain direct measurements of all of the material bought and used by the island's many residents and businesses. Instead, these quantities were inferred by mass balance. Residential and commercial consumption can be thought of as all imports and material produced domestically that were not used by industry or the military.

Figure 5.3 Diagram of residential and commercial material use

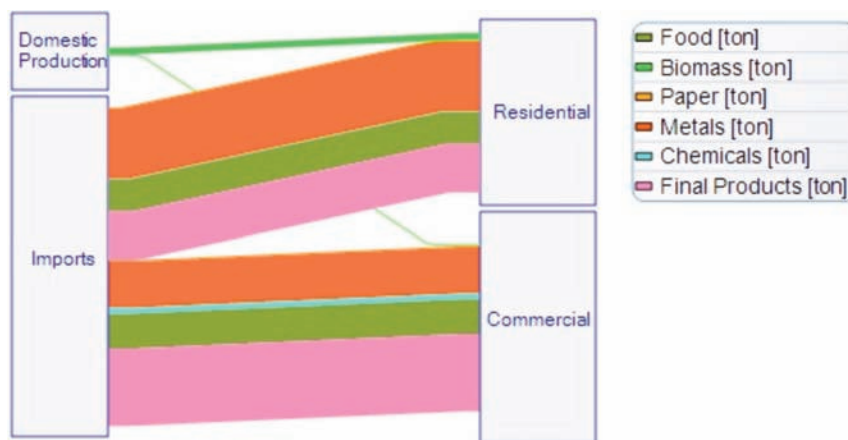


Figure 5.3 shows the relative use of different types of materials between residential and commercial sectors, as well as the source of that material. This excludes fossil

fuels that have been discussed in the power generation and transportation sections, as well as wood and minerals that were included in the construction section. The major categories used are metals, food, and final products. The flow of biomass from domestic production into residential and commercial consumption represents green waste from lawns and commercial property.

5.6 MILITARY

While material flows associated with military construction are discussed in section 5.1.2, above, the military is responsible for many other large scale inputs of material onto the island as well as significant levels of waste generation. The military plays a much larger role in the economy, in the environment, and in the material use of Oahu than it does in on areas in other parts of the country. Each branch of the military has at least one base on Oahu, and many branches (such as the Army) have more than one. The military also owns land outside of bases, which is used for training and other purposes. Figure 5.4 is a map of Oahu with all military holdings outlined in purple. These include many military land ‘buffers’ that are used by the military to uphold the Endangered Species Act and prevent conflict with neighbors by providing ‘buffer’ land between military activities and the civilian population (Godfrey, 2008). The military has landholdings totaling 85,000 acres, or 22.2% of the total land area of Oahu. This is a disproportionately large amount of land, considering that military members constitute less than 5% of the island’s population. When dependent family members and civilian employees are considered, the Department of Defense provides income for over 11% of the resident population (U.S. Census Bureau, 2007). Given these factors, it is clear that the military’s uses of land, activities, and funds plays a large role in the overall material flows on the island of Oahu.

Figure 5.4 Military areas of Oahu (in purple)



Outside of construction activities, the everyday operations of military facilities on the island require a variety of material inputs: food for on-site meals in “chow halls,” ammunition for training, and fuel and water for general operations. In this section, rough estimates of each material type are presented. These material flows are not comprehensive – there are many other materials used by the military on Oahu that could not be quantified for various reasons – but these can give a rough idea of the scale of material use at these military facilities.

5.6.1 Military food

For the Marines (Lotti, 2008) some 575,000 meals are served to the portion of the enlisted soldiers who lived on base in barracks over the course of a year. Each enlisted person is served three meals per day on the weekdays, and two meals per day on the weekends. Based on conversations with the facilities planner for the Marines, we estimate each meal to weigh 2 lbs. Since some of the foodstuffs are lost in preparation (for example, the potato peels are not served, nor are the chicken bones), we assume the mass required to prepare each meal is 3 lbs. In the Marines, there are 7,000 low-rank singles, of which 2,500-3,000 people eat in the chow hall. From this we can estimate total food served by the Marines last year amounted to 860 tons. We have data regarding how many people, per service, live in barracks. We assume that the same quantity of food per person is used by people living in the barracks regardless of service branch. Thus, we come to the conclusion that a total of 2167 tons of food is used in chow halls throughout the military, including 860 tons per year by Marines, 320 tons per year by Army, 970 tons per year by Navy, and 17 tons per year by Coast Guard (the Air Force does not have a barracks on the island).

It must be noted that most food on bases is not served in chow halls. Most military employees (with the exception of young, single people living in barracks) are serviced on-base by fast food, sit down restaurants, and commissaries. It was not possible to determine food quantities for these restaurants, nor for the commissaries.

Also of note is that Marine consumption seems greater (per size of the base) than Army consumption. This is because a greater portion of active duty members of the Army are older, and live with families or off-base. Marines tend to be mostly young, trained to be comfortable in rough environments, and housed disproportionately on-base.

5.6.2 Military ammunition use

Few services were willing to reveal ammunition use on base. The Marines were an exception, and they use 98 tons of ammunition per year (Lotti, 2008). Since the Marines and Army are involved in similar basic training, we can estimate Army ammunition use from this. We used enlisted person numbers for each branch from the 2006 Hawai'i Databook to find out how many more people were in the Army than Marines. We then estimated Army ammunition use (183 tons) from Marine ammunition use. The total use of ammunition is therefore approximately 280 tons, a very small flow in mass terms but with important implications. This does not include Navy and Air Force ammunition use. We are aware that these two services are involved in less ground combat training on the island but could not estimate their use.

5.6.3 Military fuel use

Fuel for the military is purchased primarily from companies in the Campbell Industrial Park and stored centrally by the Navy, which has the greatest storage capabilities of all the services. Some fuel is also brought in through Pearl Harbor. Fuel data were not available disaggregated by fuel type, but rather as an aggregated number, and so includes several different types of fuel that are used for aircraft and ships.

The following data for 2007 include JP5, JP8 and F76 fuel distributed from Pearl Harbor. When calculating fuel use by the military, the “Other” and “Foreign Vessels” categories were excluded. Fuel use by military, per military service branch:

Table 5.4 Military fuel use by service from Pearl Harbor

Service	Barrels	Gallons	Pounds	Tons
Air Force	1,703,143	71,532,000	486,417,600	243,210
Army	435,688	18,299,000	124,432,400	62,220
Marines	79,216	3,327,000	22,624,100	11,310
Other	316,864	13,308,000	90,496,300	45,250
Navy	1,227,847	51,570,000	35,0673,100	175,340
Foreign Vessels	11,824	4,991,000	33,936,100	16,970
Coast Guard	79,216	3,327,000	22,624,100	11,310

Source: Main (2008)

In addition, the Air Force has separate data for its jet fuel and ground fuel use (which includes, but is not limited to fuel sourced from Pearl Harbor, as presented in Table 5.3). Ground fuel data was only available for the Air Force, so fuel use included in Table 5.3 for the other services is based on relative size.

Table 5.5 Military fuel use by the Air Force in 2006

Fuel Type	Gallons
JP8	61.4 million
Diesel	250,000
Motor gasoline	40.6 million

Source: Lanier (2008)

5.6.4 Military water use

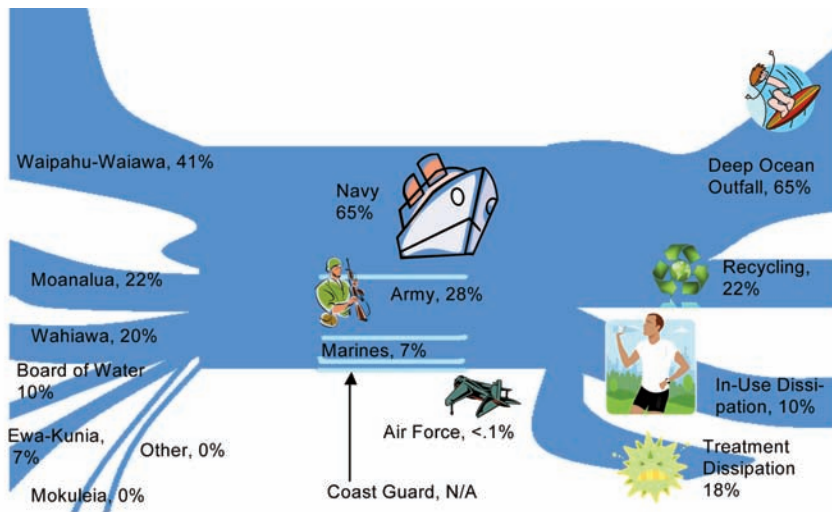
The majority of water used by military bases is extracted directly from aquifers, rather than purchased through the municipal water provider. The exceptions to this rule are Kaneohe Marine Base (because there is not an easily accessible aquifer), Fort DeRussy (since little water is used) and Bellows Air Force Recreation Area (which also uses very little water) (Usagawa, 2008). All individual permitted pumps operated by the military are required to report pumpage data to the state, but state regulators only

have Navy pumping data. Army numbers were estimated to be close to permitted amounts. Water use by service is calculated based on individual base metered water delivered from the Board of Water Supply, pumpage data from the state commission, and estimated pumpage data based on permit size. There is a problem with water-use data broken out by service – the Air Force is not allocated all of the water that it uses. The Air Force purchases some water from the Board of Water Supply, and additional water from the Navy. This report does not include data for the amount of water provided to the Air Force by the Navy, so Air Force use numbers reflect only Board of Water Supply provided water, and Navy use numbers appear higher than they are.

As there is so much concern over maintaining high water quality in the aquifers, no untreated (to a tertiary level) waste water is allowed to be discharged on the island. The Board of Water Supply, as well as the Navy and Marines dispose of treated sewer water in deep ocean disposal sites, far from the coast. This is expensive, especially for the Army whose water is used in the middle of the island (right on top of the purest aquifer on Oahu). As such, bases are incentivized to ‘recycle’ water by treating it to tertiary standards and reusing it to water golf courses, or to support local farming. For these reasons, over half of the water used at the Kaneohe Marine Corps Base, and all of the water used at Schofield Barracks is treated to high standards and reused for golf course management (Goo, 2008; Lotti, 2008). Ten percent of all municipal wastewater is also treated to tertiary levels and reused (after reverse osmosis desalinization) by power plants on the island – this water reclamation project may increase to encompass 20% of all sewage water on the island within the next few years (Goo, 2008).

In summary, on behalf of all military service branches, there is a water inflow of 38.6 Mm³/yr. About 75% of this is captured by the wastewater system, which has a water outflow of 29.7 Mm³/yr, of which 22%, or 6.5 Mm³/yr are recycled per year. Figure 5.8 shows a depiction of military water use on Oahu.

Figure 5.5 Annual water flows in the military

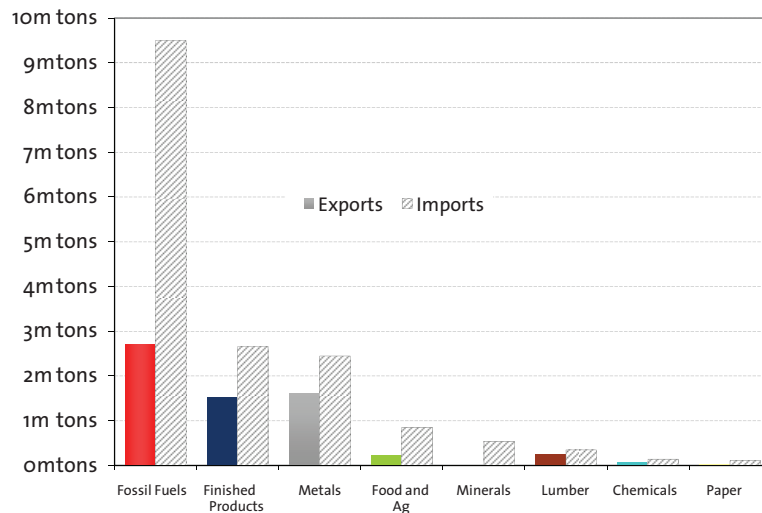


Source: Espinoza et al., 2008

Chapter 6: Exports

The majority of exports, 57% in all, are petroleum products shipped from the Chevron and Tesoro refineries at Barber's point (IWR, 2005). Much of this is shipped to the outer islands for direct consumption, mostly for transportation. This is not considered re-export as the crude oil is unloaded and transformed on Oahu before being shipped out. The remaining export shipments are largely food and farm products and waste materials (IWR, 2005). While the material throughput of Honolulu's airport is small compared to the ports, it is still an important gateway for products that are time-sensitive, such as cut flowers or mail. Taking into account both overseas and intrastate traffic, Oahu is a net exporter of both cargo (41,000 tons) and mail (1 ton) (HDoT, 2008).

Figure 6.1 Exports from Oahu compared to imports, by material category



While Oahu is highly dependent on imports for many of the island's needs, there are modest amounts of exports from the island as well. The great majority of these travel by ship; a breakdown of the island's major exports is shown in Figure 6.1

Considering non-petroleum exports, Matson shipping estimates that its top five exports by mass are:

1. Bottled water (desalinated – to Japan)
2. Household goods
3. Ginger
4. Pineapple
5. Livestock (to Oakland)

These estimates include re-export. For example, in 2003, nearly 998 TEU of bottled water was transported from Hawai'i Island to Oahu and then exported to Japan (Low, personal communication, 2008). Oahu is responsible for less than 8% of the beef production in the state of Hawai'i and after the Dole plantation completes its planned closure, large-scale pineapple production will cease. Historically, Oahu was a major exporter of agricultural goods, but with the collapse of the sugar and pineapple industries and Oahu's rising population, the island's net export of goods is nearly zero in almost every category.

It is important to note that Oahu exports some of its waste materials off the island for recycling. Hazardous waste is shipped to the West Coast of the U.S. and on to a special facility in Kansas. A significant amount of cardboard is backhauled by large retailers such as Sears, again to the mainland U.S. Metal scrap from Schnitzer Steel and other paper and plastic waste is also sold on the world market, usually to countries in East and Southeast Asia. For example, Island Recycling exported approximately 100 containers per month of recyclable materials in 2005-2006.

Chapter 7: Waste

Oahu's current issues with *opala* (Hawaiian for waste) are highly visible. Waste management is a contentious issue that often makes the nightly news and the daily newspapers. Certainly other cities and counties within the mainland United States face similar problems, but Oahu's economic mix, large population, mountainous terrain, and location in the middle of the Pacific Ocean make Oahu's waste management situation unique in the country.

The purpose of this section is to describe the system of waste flows on the island of Oahu. Both the benefits and the limitations of this systems approach are discussed, as well as the main issues with waste management on the island. The present analysis considers the following waste streams:

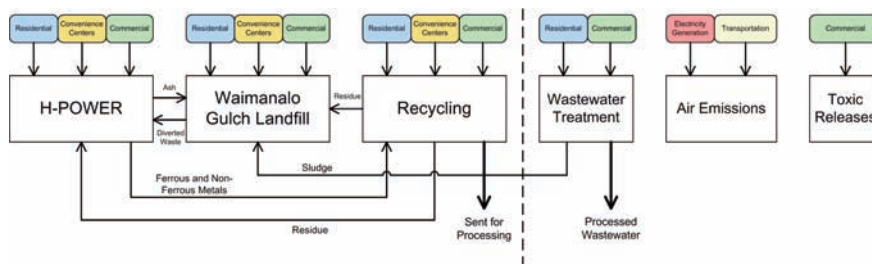
- *Solid wastes*: municipal solid waste (MSW), recyclable material, construction and demolition (C&D) waste, green waste, household hazardous waste (HHW), hazardous and non-hazardous industrial waste, sewage sludge, ash, discarded durable goods, end-of-life vehicles, and, toxics;
- *Liquid wastes*: wastewater, industrial discharges;
- *Air emissions*: sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO₂)

Waste management can be complex and the language used to describe it is often ambiguous. In this report, several aspects of Oahu's waste management system are examined. **Waste generation** occurs in all sectors: at residences, military bases, commercial facilities and businesses and represents the gross amount of material discarded, prior to any type of recycling. **Waste collection** represents the public municipal system of curbside pick-up that most residents experience, as well as commercial pick-up by private haulers and individuals taking their own waste to convenience centers, treatment and disposal facilities. Waste is brought to transfer stations, sorted, transferred to larger trucks, and then brought to treatment and disposal facilities. On Oahu, H-POWER is the only waste **treatment facility**, where waste is burned for electricity generation. **Final disposal** takes place at the landfill sites. **Recycling** takes place at any stage after waste generation: curbside pick-up, drop-off at convenience centers, commercial pick-up of sorted material, sorting and separation at transfer stations, and metal recovery at H-POWER are all examples of recycling considered in this report. Recycling also includes composting (or bioconversion) of Oahu's extensive quantities of green lawn and garden wastes, food waste, and other biodegradable land clearing materials. A schematic diagram of the system is shown in figure 7.1.

The most important source of information for this section was the report "Integrated Solid Waste Management Plan Update." It was prepared for the City and County of Honolulu in 2007 by R.W. Beck, an environmental consulting company. This report is detailed and current, with most of the data referring to fiscal year 2006. One of the primary components of this report is a waste characterization study

conducted by R.W. Beck. To estimate the waste stream composition, they collected a total of 100 samples of at least 200 pounds each. Fifty samples were collected at H-POWER and the remaining 50 samples were collected at the public landfill. The Refuse Division supplied the exact figures on the total quantities of solid waste that were disposed at the Landfill and H-POWER during FY 2006. R.W. Beck used its sampling method and refuse division data to calculate a mean and a 90% confidence interval for the total quantities of each category of material.

Figure 7.1 Schematic diagram of Oahu's waste management system



Source: Adapted from Oden et al. (2008)

While the R.W. Beck report is lengthy, the firm was asked to cover only solid wastes, whereas a systems approach would also include wastewater, and air emissions data. This is important as material can be transferred from solid to liquid form (as in the case of food becoming wastewater sludge) or from solid to gaseous form (as in the case of combustion of fossil fuels). The solid waste material flow estimates presented here are based on the mean values calculated by R.W. Beck, with appended recycling data gathered from personal communications and additional research. All additional calculations follow the principle of mass balance, so that the mass of waste that is generated should be equal to the mass of waste that is treated, disposed, or recycled.

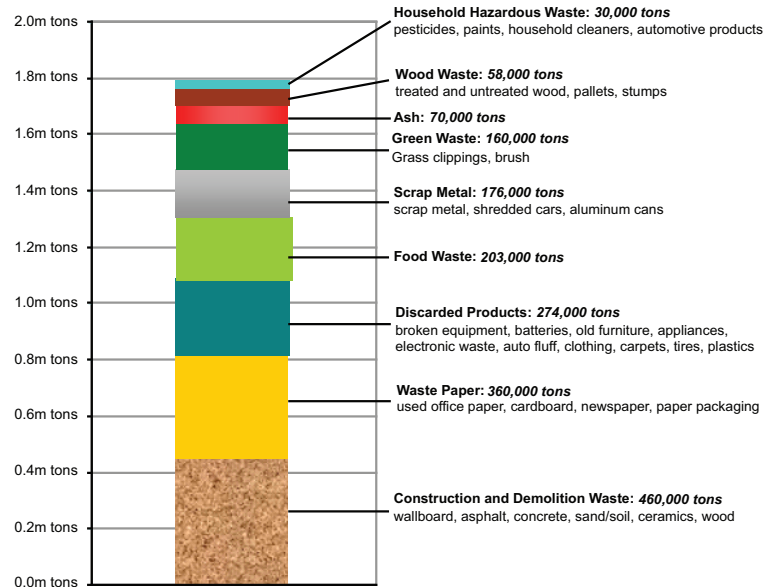
7.1 WASTE GENERATION AND COLLECTION

As they are tracked by both the City and County of Honolulu and the State of Hawai'i, municipal waste generation statistics are well-quantified and characterized. For other types of waste, such as construction and demolition (C&D) or recyclable materials, statistics are not as robust. The best estimate, counting all municipal, commercial, and industrial activities, is that 1.8 million tons of solid waste material are generated.

On Oahu, MSW is collected by public and private entities. Residential curbside waste is collected by the City and County of Honolulu, primarily from single-family homes and apartments, and is taken to transfer stations. The city also collects MSW from some multi-family units, and public sector facilities. Due to its status as a vacation destination, Hawai'i also produces much more waste than its baseline population would suggest. In 2000, tourists added nearly 6% to the de facto population of the island (DBEDT, 2006). This added population generates a

particular kind of waste stream: high in water and food wastes, extensive use of packaging such as plastic bags and bottles and aluminum cans, but low in household wastes such as glass, paper, or steel. The tourism industry is also the driver for other material streams such as construction & demolition and bulky wastes from hotels.

Figure 7.2 Waste Generation on Oahu, 2005-2006



The Refuse Division of the Department of Environmental Services of the City and County of Honolulu provides municipal solid waste collection once per week and recycling once per week for two-thirds of the single-family residences and some multi-family residences on the island of Oahu. The rest of the homes will be converted to curbside recycling by 2010 or when funding is available. According to the R.W. Beck report, almost 90% of all residential waste is delivered to H-POWER. The remaining fraction is disposed at the Waimanalo Gulch Landfill.

Green waste is collected twice a month and is sent to Hawaiian Earth Products for composting. The city also has special programs to collect household hazardous waste, white goods, tires, and bulky items, which need special handling or disposal restrictions. These special wastes are collected separately at the curb or received at convenience centers or transfer stations. End-of-life vehicles are sold via middlemen to metal yards where cars are stripped and the valuable metals and other materials are sorted and sold on to recyclers or sent for disposal. Prior to 2005, residential electronics were collected twice a year. This program was discontinued when local recyclers were no longer willing to accept these materials for free.

Commercial waste, generated by commercial, industrial, and military facilities, is collected primarily by private haulers and comprises 29% of all the waste hauled on the island. The major private hauler, Honolulu Disposal, operates its own transfer station

on Sand Island, on the south west side of Oahu. When commercial waste is received at the public transfer stations, haulers must pay a tipping fee of \$110.60 per ton plus 12% for recycling and a 35 cent-per-ton state surcharge. Tipping fees for commercial wastes at both H-POWER and the Waimanalo Gulch landfill are \$81 per ton plus a 12% surcharge for recycling programs and a 35 cent-per-ton state surcharge. As for recycling, restaurants, hotels, office buildings, and hospitals fall under the City's recycling ordinance, which requires mandatory recycling of several target materials. The city has also established treatment and disposal bans for items with alternative markets or end-uses, including green waste, corrugated cardboard, metals, auto batteries, and tires. The City further promotes commercial recycling through its Partnership for the Environment, which provides program assistance, education and training.

Six convenience center locations are operated by the Refuse Division where residents can bring waste, including green waste, white goods, tires, batteries, and propane tanks. Residents can drop off a maximum of two loads of waste per day for free at any of these locations. Commercial waste is strictly prohibited from the convenience centers. Many of the materials received at convenience centers would also be suitable for curbside residential waste collection. Waste is separated into combustible, non-combustible, yard waste and recyclable waste, and is sorted and transferred to the appropriate disposal/recycling site. The majority of waste received at the convenience centers was non-combustible waste and over 99% was sent to landfill. The composition of waste differs from center to center; overall, non-combustible waste, green waste, and tires are responsible for 75% of the waste delivered to convenience centers.

In addition to these conventional solid wastes, Oahu's institutions and industries produced roughly two million pounds of toxics in 2006. These are reported to the Toxics Release Inventory (TRI) run by the USEPA, shown in Table 7.1

In addition to these solid and liquid wastes, the various actors on the island released significant masses of air pollutants into the atmosphere. In 2006, the power generation sector was responsible for 10 million tons of CO₂, 24,000 tons of SO₂, and 32,000 tons of NO_x emissions in the state, the majority of which originated on Oahu. Power generation was the largest contributor of CO₂ emissions to the total statewide inventory, which was estimated at 30 million tons of CO₂ equivalent. Thus, air emissions are much larger than solid waste emissions on a mass basis.

7.2 TRANSFER STATIONS

There are three public transfer stations on the island at Kapa'a, Keehi, and Kawaihoa. After collection, approximately two-thirds of City waste is brought to these transfer stations to be sorted, and then transferred to larger trailer trucks. If the waste is combustible, it is sent to H-POWER and if it is non-combustible, it is sent to the Waimanalo Gulch Landfill, with the remainder brought directly to a disposal site. Commercial waste is collected by private haulers and either taken directly for final disposal or transported to the transfer stations and then brought either to H-POWER or to the private landfill. Residents may also bring their waste to the transfer stations for disposal at no charge. A total of 216,832 metric tons of combustible refuse and 28,325 metric tons of non-combustible refuse were delivered to the transfer stations during FY 2006.

Table 7.1 All chemicals reported to be disposed or otherwise released both on-site and off-site (in pounds), for facilities in all industries, under the federal Toxics Release Inventory program, Honolulu County, Hawaii, 2006. Note: Numbers may not add due to major rounding.

Chemical	On-site Disposal	Off-site Disposal	Total
1,2,4-TRIMETHYLBENZENE	3,059	473	3,532
1,3-BUTADIENE	1,272	0	1,272
AMMONIA	21,884	0	21,884
BARIUM COMPOUNDS	58	46,162	46,220
BENZENE	8,193	41	8,234
BENZO(G,H,I)PERYLENE	1	0	1
CERTAIN GLYCOL ETHERS	27,391	0	27,391
CHLORINE	4	0	4
CHLORODIFLUOROMETHANE	68	0	68
COPPER	31,487	0	31,487
CYCLOHEXANE	8,819	31	8,851
DIOXIN/ DIOXIN-LIKE COMPOUNDS (grams)	3	0	4
ETHYLBENZENE	2,896	224	3,120
ETHYLENE	30,905	0	30,905
HYDROCHLORIC ACID	295,682	0	295,682
LEAD	62,862	18,358	81,220
LEAD COMPOUNDS	2,340	2,406	4,747
MANGANESE	2	29	32
MANGANESE COMPOUNDS	34	24,372	24,407
MERCURY	10	0	10
MERCURY COMPOUNDS	47	48	95
METHANOL	772	0	772
METHYL TERT-BUTYL ETHER	268	0	268
N-BUTYL ALCOHOL	55,327	273	55,600
N-HEXANE	34,286	174	34,460
NAPHTHALENE	1,637	128	1,766
NICKEL COMPOUNDS	64,401	1,190	65,591
NITRATE COMPOUNDS	325,507	0	325,507
POLYCYCLIC AROMATIC COMPOUNDS	259	1	260
PROPYLENE	67,118	0	67,118
SULFURIC ACID	736,555	0	736,555
TETRACHLOROETHYLENE	84	0	84
TOLUENE	13,424	161	13,586
TRICHLOROFLUOROMETHANE	157	0	157
XYLENE (MIXED ISOMERS)	31,923	664	32,588
ZINC COMPOUNDS	156	114,470	114,627
TOTAL	1,828,904	209,213	2,038,118

Source: Yale University

Two private transfer stations are located on the island: one is owned by Honolulu Disposal, the largest commercial waste hauler, and the other is owned by Island Demo. The Honolulu Disposal station accepts municipal solid waste that was collected by their trucks. The Island Demo station receives only construction and demolition debris.



Source: Yale University

7.3 REUSE AND RECYCLING ACTIVITIES

About a third of the waste generated on Oahu is recovered, recycled, or reused by various private businesses and waste brokers on the island (R.W. Beck, 2007b). Traditional recyclables such as paper, metal scrap, and household bottles and cans are largely exported, mostly to the mainland U.S. and Asia. Some large retailers backhaul packaging waste to the west coast of the United States in containers that they own, but this constitutes a small percentage of the whole. In total, nearly 500,000 tons of materials are recycled on-island.

7.3.1 Municipal recycling

The Department of Environmental Services is currently spearheading a number of initiatives to promote recycling, including recycling fundraisers, community recycling bins, HI-5 redemption centers for deposit containers, curbside recycling, green waste recycling/composting, business recycling, condo recycling, computer recycling, and the Discover Recycling Fair. Furthermore, numerous private sector entities are also engaged in recycling, including Hawaiian Earth Products, Schnitzer Steel, Reynolds Recycling, and others.

On Oahu there are essentially four primary ways for private residences to recycle goods: (1) Curbside recycling, (2) Community Recycling Bins, (3) Convenience Centers, and (4) Private recycling drop off centers.

In October of 2007, a curbside collection pilot program was launched in Mililani and Hawai'i Kai to collect recyclables from residences. Households are provided color coded bins to deposit general refuse, mixed recyclables, and green waste. Between the fall of 2008 and the summer of 2010, the City and County of Honolulu plans to expand this program island-wide (Honolulu ENV, 2008c).

A private recycling drop-off center run by Reynolds Recycling



Source: Yale University

A program is already in place to use community recycling bins to assist in the interim period before the expansion is completed. More than 90 of these bins are already placed in schools all over the island and the program is expanding. Schools receive a payment for the recyclables that are collected in the bins on their campuses and more than \$1 million has already been disbursed (Honolulu ENV, 2008b).

7.3.2 Commercial recycling

A number of private companies also collect recyclable materials from the residential sector in addition to the activities undertaken by the City and County of Honolulu. These companies report the amounts of material they recycle or treat to the Department of Environmental Services. Reynolds recycling is among the largest: it has 25 redemption centers on the island, where aluminum cans, glass and plastic bottles are collected. At five of these locations scrap metal is collected, which includes #1 and #2 copper wire, aluminum rims, aluminum foil, aluminum scrap, and Spam™ and Vienna™ cans. Reynolds Recycling also operates reverse vending machines to deposit recyclables.

The recycling floor at Honolulu Recovery Systems



Source: Yale University

Table 7.2 Commercial recyclers on Oahu

Base Yard Hawaii	New or recycled (in new condition) construction materials, equipment, office furniture
Battery Bill's	Car batteries
Cartridge World	Inkjet and laser toner cartridge remanufacturing (refill)
C.M. Recycling	Non-ferrous metals: aluminum, brass, copper, stainless steel
EcoFeed, Inc.	Food/wet waste, processed into animal feed
Enviroservices	Computer hardware (householders welcome to drop off for a fee) – Commercial call for pick-up
Exide Battery Corp.	Car batteries
Han's Metals	Non-ferrous metals: aluminum, brass, copper, stainless steel
Hawaii Mail Box Systems	Polystyrene: loose-fill
Hawaii Open Source Education Foundation	Computers and peripherals
Hagadone Printers	Paper (through a take-back program)
Hawaiian Earth Products	Untreated wood: wooden pallets; Yard trimmings: green waste
Haztech	Computer hardware (commercial only)
Honolulu Recovery Systems	Aluminum, Cardboard, Glass bottles and jars, Paper: computer, newspaper, white and colored ledger
Interstate Battery of Hawaii	Car batteries
Island Recycling	Aluminum, Cardboard, Glass bottles and jars, Non-ferrous metals: aluminum, brass, copper, stainless steel, Paper: computer, newspaper, white and colored ledger, wooden pallets
Lenox Metals	Non-ferrous metals: aluminum, brass, copper, stainless steel, computer hardware, Paper: white ledger, baled cardboard
Linen Recovery Hawaii	Used damaged linen: Remanufactured into usable items such as pillow cases, napkins, aprons, etc.
Oahu Metal & Supply	Non-ferrous metals: aluminum, brass, copper, stainless steel
Okuda Metal	Non-ferrous metals: aluminum, brass, copper, stainless steel
Pacific Commercial Services	Computer hardware (householders welcome to drop off for a fee) – Commercial call for pick-up
Pacific Environmental Corporation (PENCO)	Computer hardware (commercial only) – call for pick-up
Philip Services Corp.	Motor oil/solvents, Computer hardware (commercial only) – call for pick-up
RRR Recycling Services Hawaii	Redemption Center for deposit beverage containers (glass, plastic, and aluminum), Paper: white ledger, newspaper, corrugated cardboard
Re-use Hawaii	Construction/ building materials
Refrigerant Recycling	Appliances and Freon
Reynolds Recycling, Inc.	Non-ferrous metals: aluminum, brass, copper, stainless steel, glass
SD Systems Inc.	Computer hardware (commercial and household), Paper: white ledger, newspaper, corrugated cardboard
Safeway Stores	Plastic bags
Schnitzer Steel Hawaii Corp.	Appliances, ferrous metals
Shred Ex/Confidential Records Destruction	Paper: Pick up and destroy confidential records and recycle the paper product.
Shred It	Paper: Pick up and destroy confidential records and recycle the paper product.
Sun Home Metal	Ferrous metals
T & N Services	Computer hardware (commercial and household)
The UPS Store	Polystyrene: loose-fill
Unitek Solvent Services	Tires, Motor Oil/Solvents

Source: Honolulu ENV

Schnitzer Steel is the major metals recycling company on the island. It is located within Campbell Industrial Park. It collects and processes automobile bodies and hulks, pipes, beams, posts, cables, wires, cast iron, motor blocks, and bicycles. It also purchases the metal that is extracted from the municipal solid waste at H-POWER. Unlike other metal recyclers on Oahu, Schnitzer Steel separates and processes the metal on the island, which helps to generate local jobs. In addition to its metals recycling business, Schnitzer Steel has partnered with the National Oceanic and Atmospheric Administration (NOAA) and other government agencies and businesses for a “Marine Debris to Energy Partnership.” The purpose of this program is to remove and recycle marine debris in Hawai‘i that threatens marine ecosystems. Derelict fishing gear hauled by fishing boats is brought to land where it is taken to Schnitzer Steel to be stored and chopped into small pieces for incineration at H-POWER to create electricity.

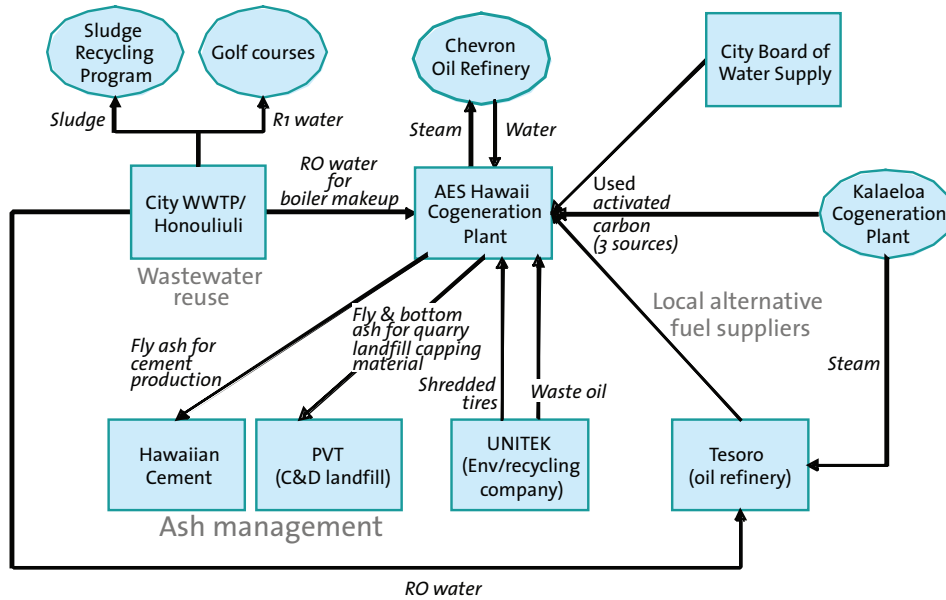
7.3.3 Industrial recycling

Some 210,000 tons of inorganic minerals are used as landfill cap, structural fill (material that is compacted and used as a base for further building), and road base on the island. This is especially important in Oahu since local quarries have limited resources and/or permit restrictions, and alternate sources for aggregate need to be found. Curiously, while the federal government allows recycled aggregate in federal roads as well as on-site crushing of concrete, the state and city governments prohibit recycled aggregate in their roads.

The AES coal power plant engages in the recycling of some waste materials for electricity generation. As mentioned above in section 5.2, the plant uses 6,750 tons of tire-derived fuel from a nearby tire shredding operation run by Unitek, 5,400 tons of waste oil also processed by Unitek, and more than 500 tons of spent activated carbon from three sources: a nearby wastewater treatment plant, Kalaeloa cogeneration plant, and the Tesoro oil refinery, as alternative fuels (Chertow and Miyata, 2009).

As shown in figure 7.2 below, an interesting phenomenon has occurred with the AES coal power plant playing a critical role. Eleven enterprises in or near the Campbell Industrial Park were found to be exchanging nine different materials across firms including steam, reverse osmosis (RO) water as well as reclaimed (R1) water, waste oil, tires, used activated carbon, and ash. This phenomenon, known as “industrial symbiosis,” creates both economic and environmental benefits. The two largest environmental benefits of this collective industrial approach to reuse and recovery were found to be conservation of primary materials and reduced landfilling (Chertow and Miyata, 2009). Annual landfill space savings for just one of the waste streams, 70,000 tons of ash, is equivalent to 51,400 m³. That this alternative business model with so many linkages emerged in Honolulu in a quiet and gradual way, the extent to which is not generally known, indicates that it has some very useful characteristics in this setting (Chertow, 2007).

Figure 7.2 An industrial symbiosis network based in the Campbell Industrial Park



7.3.4 Composting and green waste

Green waste, in practice, is defined in a variety of ways, but is primarily comprised of lawn clippings and plant debris. Green waste is one of the only materials that is generated, collected, processed and reused on Oahu. R.W. Beck reports that it is one of the largest components of the waste stream with over 200,000 tons generated and, of that, approximately 160,000 tons handled in the waste system for 2005-2006. (Some 40,000 tons of green waste is also left on lawns or composted privately and does not enter the waste management system.) The City collects green waste, but it is composted at Hawaiian Earth Products, a large-scale composter that recycles clean yard trimmings, untreated wood waste (pallets, crates, spools), non-lead paint treated wood waste, fruit and vegetable waste from supermarkets and processing plants, and borate treated lumber. Hawaiian Earth Products sells soil conditioners, compost, and mulches from the materials that have been generated and collected on island. The company has two locations, at Kailua and Campbell Industrial Park. There are concerns that current compost markets are saturated and that market development is needed both for green waste and sludge.

Finished compost at Hawaiian Earth Products



Source: Yale University

Chipping brush and wood into mulch



Source: Yale University

7.4 MILITARY WASTE GENERATION AND RECYCLING

The many military bases operate their own waste management systems. Some are completely self-contained, from waste generation to landfilling all on-base, while others use commercial waste haulers or private recyclers to manage certain waste streams under contract.

This section details military waste generation and recycling and reuse activities. In general, it is difficult to collect consistent information across all of the different branches of the armed services on the island. For MSW, most bases send their waste to H-POWER or to Waimanalo Gulch landfill; however, the Marine Corps operates its own landfill at Kaneohe Bay (table 7.3). Demolition waste is not considered a base waste by the military, since demolition is contracted to outside sources, although it is an important component of waste generation by the military (see section 5.1.2). Hazardous waste is generated for some services, but is a small percentage of total waste weight. In general, hazardous waste is shipped off of the island for treatment in either Washington or California.



Source: Yale University

Most recycling is either shipped off-island directly, or sent to recycling companies on the island that process and bale materials and then ship them off-island. With the exception of the Air Force, the services contract with in-country recycling centers for recycling sales. The Air Force, on the other hand, has direct contracts with recycled material purchasers abroad. As such, the Air Force is responsible for all of its own baling and only sells in bulk. Air Force personnel plan to work with commissaries across the island to improve cardboard recycling. They are currently using recycled glass as a concrete component. The Air Force also has a rock crusher and tub grinder for dealing with tree and wood waste on-site (Twilligear, 2008; Lotti, 2008; Lanier, 2008).

Table 7.3 Breakdown of waste at the Marine Corps Kaneohe Bay Landfill (tons)

Month	Trash	Wood/ Green Waste	Cover/ Fill Received	Concrete Debris	WWTP Sludge
July 2006	134.0	23.5	70.0	0.0	0.0
August 2006	175.5	42.5	273.0	0.0	21.0
September 2006	163.0	10.0	148.0	217.0	0.0
October 2006	182.0	19.0	89.0	208.0	8.0
November 2006	161.0	15.0	848.0	0.0	0.0
December 2006	169.0	27.0	195.0	0.0	0.0
January 2007	157.5	17.0	75.0	0.0	0.0
February 2007	152.5	21.0	125.0	0.0	0.0
March 2007	218.0	24.5	255.0	0.0	0.0
April 2007	164.5	33.0	20.0	0.0	0.0
May 2007	173.0	34.0	200.0	0.0	0.0
June 2007	180.0	31.0	43.5	0.0	0.0
TOTALS	2,030.0	297.5	2,342.0	425.0	29.0

Steps have been taken towards improving material reuse and recycling in the military overall, but these steps have been hampered by the small size of the material streams at each individual base. In the case of recycling, the Marines and Air Force, in particular, have undertaken extensive recycling programs to reduce their flow of waste to landfills (Lotti, 2008; Peterson, 2008). The Air Force has a large recycling program that bundles goods in bulk to deal directly with purchasers of recyclables to get the highest price. With the exception of glass and some metals, the Air Force ships all recyclables off of Oahu. There is not much of a market for glass recycling, but many bottles can be returned for deposits and sold. Metals from construction demolition go through the Hickam Recycling Center and are sold to companies on Oahu or off-island depending on where the highest bidder is located. The other recyclables – newspaper, paper, cardboard, and aluminum cans – are shipped back to the mainland United States or to Asia (Lanier 2008, Petersen 2008). While the practice of shipping back to the mainland U.S. or Asia generates revenue for the military recycling programs, it requires shipping of products and consumption of fuel. To the extent these resources could be recycled and reused on the island, there would be less fragmentation and more opportunity to manage the resources overall.

Military wastewater undergoes tertiary treatment with the Army and Marines and both services use some of the discharged water from the treatment plant to irrigate fields and golf courses (Goo, 2008, Lotti, 2008). The rest of the water is currently pumped into the Pearl Harbor Aquifer to recharge the lens. The Army hopes to sell some of the discharged water for diversified agriculture.

In addition to the reuse and recycling of concrete by Actus and Forest City during demolition and subsequent construction of new homes (see section 5.1.2), the Marines attempt to reuse some materials from their maintenance and upgrading projects. The furniture inside the barracks must be changed every seven years. The Marines work with several local charitable groups to put the old furniture to use after it is taken out of the barracks (Lotti, 2008).

Another issue is asphalt, imported to Oahu to meet the high demand by the military. The military services are constantly repairing roads on their bases and the

Air Force is continually repaving runways. Large quantities of asphalt are needed for these maintenance and repair projects. It is costly, must be shipped a long distance, and is not currently reused, but is land filled. Asphalt remains one of the major material loop closure problems that could likely be addressed, especially since about 80% of asphalt pavement is recycled nationwide (Andersson-Skold *et al.*, 2007).

Another major challenge in closing material loops is that information about specific materials is not centralized for the island of Oahu. Fuel and water are the two exceptions to this. Hawai'i is the hub of the Pacific for the military, so it is difficult to disaggregate the military operations in the region and get Oahu-specific information for purchasing of food, consumable goods, and other minor flows. Furthermore, it is uncommon for military branches to disaggregate use data by base, as most administrative decisions are made in Washington, D.C. Purchasing contracts (for clothing, food, and so forth) are determined centrally and are made with large companies for the entirety of the services. Items are then shipped from these companies all over the country to different bases. This leaves little opportunity for locally sourcing materials and closing local material loops.

The military services on Oahu are working to improve their sustainability. Some services, notably the Army, have had problems with their environmental rapport on Oahu. The Army has several National Environmental Protection Act (NEPA) lawsuits related to the environmental and public nuisance aspect of shooting ranges. The activity of the military on sacred lands (as this constitutes much of the land owned by armed services) has also angered native Hawaiians. The DoD has hired consultants to work to improve the military's sustainability. There are some beneficial policies regarding purchasing – the military is required to select the most environmentally preferable material if possible (Lanier, 2008). Yet, environmental decisions are not the only factors in selecting materials. In the military, quality, strategic importance, and cost are very important considerations in selecting materials.

While it is instructive to look at the military as part of the island system, recommendations for future sustainability efforts become challenging. The military services aim to increase their environmental sustainability, but decisions are more affected by security, safety, and financial issues than environmental issues. Oahu's role as a staging and refueling station for military ships and planes in the Pacific further increases the military's material use on the island. Fuel and other materials must be shipped onto Oahu, but are often consumed off-island by troops or other military operations in the Pacific. Because of separate organizational structures, it is often difficult for individual branches of the military to collaborate on environmental programs. Key opportunities discussed in this section would be 1) asphalt 2) adding contract terms for construction projects that specify waste diversion and recycling rather than landfill 3) water reuse for irrigation activities.

7.5 WASTE TREATMENT AND DISPOSAL

7.5.1 H-POWER

H-POWER is a waste-to-energy facility that is operated by Covanta Energy and located within Campbell Industrial Park in Kapolei, Hawai'i. It has been in operation since 1990. In FY 2006, this facility received approximately 756,000 tons of municipal solid waste. As H-POWER is operating at full capacity, one-fifth of this MSW (154,000 tons) was by-pass material and was sent to the landfill. Approximately 20,000 tons of metal and 79,000 tons of non-combustible material were screened out; the remaining 500,000 tons of MSW were processed into refuse derived fuel (RDF) that was used to generate electricity. The ash and residue from incineration is delivered to the Waimanalo Gulch Landfill (Smith, 2008; R.W. Beck, 2007b).

For the past 12 years, H-POWER has processed over 1,800 tons of non-hazardous MSW per day. The energy produced is sold to the Hawaiian Electric Company. Five to seven percent of Oahu's electricity is produced at H-POWER. In FY 2006, H-POWER generated 320 million kilowatt hours (kWh) of electricity and nearly \$35 million in revenues. According to H-POWER, their waste-to-energy process displaces the use of 800,000 barrels of oil per year. Rodney Smith, the facility business manager at H-POWER, has mentioned that the facility currently has very little reserve capacity and the company has begun a planning and permitting process to add a third boiler by 2011 (Smith, 2008).



Source: Yale University

Ferrous and non-ferrous metals are extracted from the municipal solid waste before and after incineration. Magnets are used to collect the ferrous materials and eddy currents are used to collect non-ferrous metals. Approximately 20,000 tons of non-ferrous metals were collected at H-POWER in FY2006 and the sale of this metal generated nearly \$1.5 million (Smith, 2008).

Green waste is completely banned from landfill disposal but can be sent to H-POWER in amounts less than 10% per load. Despite this restriction, an estimated 80,000 tons is thought to be disposed of in this way.

7.5.2 Waimanalo Gulch landfill

The Waimanalo Gulch Landfill, which occupies over 200 acres of land in Kapolei, has been in operation since September 1989. It is owned by the City and operated under contract by Waste Management, Inc. The city operates the scales. The landfill accepts two types of municipal solid waste: (1) noncombustible MSW and (2) ash, residue and overflow from H-POWER. Materials that are not accepted at the landfill include some recyclables from non-residential sources (i.e., corrugated cardboard, ferrous/non-ferrous metal objects), liquid waste, medical waste without proper sterilization, and toxic/hazardous waste.

During FY 2006, the landfill received 330,000 tons of municipal solid waste, which consisted of 184,000 tons of wastes originally headed to the landfill and 154,000 tons of wastes which were rerouted from H-POWER. Of this incoming MSW, about 22 percent of the incoming waste was non-combustible residential waste delivered by the Refuse Division, and 16% was from convenience centers (R.W. Beck, 2007b). In addition, the landfill received 79,000 tons of non-combustible residues screened at the H-POWER facility, 88,000 tons of ash, and 40,000 tons of wastewater treatment biosolids (sludge). The total amount disposed at the landfill in 2005-2006 was therefore about 500,000 tons of material.

In order to relieve pressure on the landfill, H-POWER plans to add a third boiler to its waste-to-energy plant, but construction will not be completed until 2011 or 2012. While the landfill was originally slated to close on May 1, 2008, it is currently operating under a permit extension to July 31, 2012, after the expansion of H-POWER. A program to ship 100,000 tons of wrapped and baled municipal solid waste to the mainland has also been in discussion for several years and was set to commence on July 1, 2009; however, the bid to Hawaiian Waste Systems was rejected after months of challenges and the start date has been delayed. The City and County have also applied for permits to increase reuse of green waste and food waste on the island, as well as to recycle H-POWER ash and residue (Honolulu Advertiser, 2009).

7.5.3 PVT landfill

Outside of the public system, approximately 200,000 tons of C&D waste and petroleum-contaminated soil is disposed annually at the private PVT landfill, along with 50,000 tons of ash from the AES plant, which is used to cap the landfill. More recent estimates of the amount of incoming material are significantly higher; this may be due to the recent spate of demolition projects on the island. Of the C&D waste delivered to PVT, managers estimate that approximately 8% is asphalt, 20-25% is concrete, and 10-20% is sand, rock, and dirt. The C&D waste that is disposed of at PVT constitutes approximately 80% of all C&D waste on the island; the remainder is treated and disposed via the public system. C&D waste is a large portion by mass of the total waste stream of the island and, unlike many other waste streams; contains some materials that have a local market. Residents can drop off C&D waste at the Waimanalo Gulch landfill, but businesses are required to use recycling contractors or dispose of waste at the PVT landfill.

Many useful materials become mixed into the C&D stream and then require disposal at the PVT landfill because numerous demolition projects make use of an

excavator that simply crushes all of the materials of a house (and its contents), creating a heterogeneous mixture of C&D waste from which it is difficult to extract useful materials. These materials include wood (treated and untreated), metals (plumbing pipes and fixtures, door and window frames), plastic (plumbing, rain gutters), vinyl (doors, windows, siding, flooring tiles), glass, carpet, ceramic (tile, toilets, sinks), rubber, mineral rock (granite and marble), gypsum board; furniture, mattresses, paint, and various liquids (cleaners, solvents, etc).

7.5.4 Wastewater treatment

The City and County of Honolulu treats more than 90 percent of Oahu's wastewater (excluding Hawaii Kai WWTP and military facilities). The Department of Environmental Services manages nine wastewater treatment plants and its tributaries using an island-wide Supervisory Control and Data Acquisition (SCADA) system. This is a computer system that constantly monitors the 70 wastewater pump stations, nine wastewater treatment plants, and four preliminary treatment facilities on the island. The wastewater treatment facilities have a combined outflow of more than 158 million cubic meters or about 41 billion gallons annually (105-110 million gallons daily) into both freshwater and ocean outlets (Honolulu ENV, 2008a).

Honouliuli Water Recycling Facility, located in Ewa, has generated 16.5 million cubic meters of recycled water every year (or about 13 million gallons per day) for non-drinking uses since 2000. About 5/6 of the recycled water, 13.8 million cubic meters, is treated using standard processes up to UV disinfection; this is used for irrigation mostly for golf courses. A reverse osmosis (RO) process generates another one-sixth of the recycled water that is treated to a level of purity that is suitable for industrial uses. This comes at a cost, however, as RO processes have high energy requirements, particularly for electricity.

Table 7.4 Wastewater treatment (Honolulu ENV, 2008a) and Water recycling (Usagawa, 2008)

CY2006		MGD	Mm ³ /yr	Notes
Wastewater Treatment Plants	Sand Island	69	95.20	Deep ocean outfall
	Waimanalo	1	0.83	Injection well
	Honouliuli	26	35.87	Deep ocean outfall
	Kahuku & Paalaa Kai	0	0.36	Injection well
	Kailua Regional	13	17.94	Deep ocean outfall
	Wahiawa	2	2.48	Freshwater outfall
	Waianae	4	4.95	Deep ocean outfall
	Total Wastewater	114	157.63	
Water Recycling	Honouliuli Water Recycling Facility (WRF)	12	16.56	Treatment plant, community parks, golf courses, landscaping and industrial users

Most of the reclaimed water is used for golf course irrigation; the rest is treated to a higher standard and is used in industrial applications. Biosolids are generated during the wastewater treatment process and comprise about 5% of Oahu's total solid

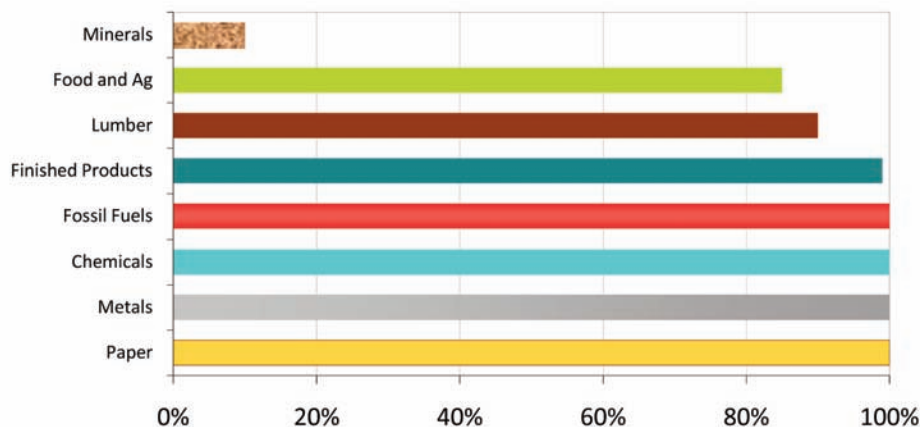
waste. Honolulu currently landfills the biosolids but is considering reuse options. It has developed a partnership with Synagro, a company that will digest, dewater and heat-dry approximately 20,000 tons of biosolids generated from the Sand Island WWTP (half of the total) to be used as fertilizer pellets. Digesters on wastewater treatment plants are also a viable source for generating energy. Since 1998, the Navy facility in Kalaeloa had composted green waste with biosolids from the Honouliuli WWTP to produce soil additives and compost (approximately 10,000 tons in 2005). Due to changes in Navy policies, however, this facility stopped accepting material from the city but still processes biosolids generated by the Navy.

Chapter 8: Issues and Opportunities

8.1 MATERIAL DEPENDENCE AND IMPORT SUBSTITUTION

Oahu has a strong dependence on imports for nearly every category of goods. As shown clearly in figure 8.1, Oahu's dependence on foreign goods is variable but in general quite high, ranging from 10% for construction minerals, to 100% for fossil fuels. In many cases, however, there are unused or underutilized resources on the island that could serve to displace at least some portion of these imports. The opportunities are particularly attractive in the cases of construction minerals, energy, and food.

Figure 8.1 Material dependence of Oahu on various types of imported goods



8.1.1 Construction minerals

Excluding water, inorganic minerals such as sand and gravel for construction are almost always the largest material flow by mass for any large system. This was found to be the case both for Hawai'i Island (as seen in figure 1.1) and Oahu. Though Oahu has three domestic quarries, these do not fulfill the demand of the island's construction industry, and the concrete industry is forced to import some aggregate and a large quantity of sand. One company currently recycles nearly 100,000 tons of C&D waste into concrete and fill, but is limited in the applications to which it can put this recycled material. City highway regulations have placed a cap of 30% recycled aggregate for road base construction and 10% glass for limited road construction projects (R.W. Beck, 2007b).

There is still a large supply of waste inorganic minerals that could be safely utilized. Both the Island Demo transfer station that handles C&D waste and the PVT landfill could potentially process or separate and use/sell valuable construction

material, though the mixed state of most incoming waste currently presents challenges. Revisiting construction and demolition specifications and permit rules could increase C&D waste recovery and lead the island toward greater self-sufficiency while reducing pressure on domestic sources for this important material category. Ash and crumb rubber are two additional materials that could be reused.

In part due to Hawaii's container deposit law, Oahu businesses recover 20,000 tons of glass annually. An additional 16,000 tons (mostly non-container glass) is sent for waste treatment and disposal. Though limited amounts of glass are processed to fines and used in construction projects, there are virtually no economically viable disposal or recycling options for glass handlers on Oahu. The consultancy R.W. Beck (2007b) recommended an expansion in the permitted uses of glass in construction in order to create a local market for this material.

8.1.2 Energy

Hawaii has no fossil fuel resources of any type. Article XI, section 8 of the Hawaii constitution specifically discourages the construction of nuclear power plants. The only natural available energy is renewable, and Hawaii as a state has been early in meeting required renewable energy portfolio standards. Most of the renewable energy, however, is generated on the other islands with a negligible amount generated on Oahu. Generating electricity from renewable sources avoids fossil fuel imports that would otherwise be necessary, and so has significant material implications for the island. Oahu imports 880,000 tons of coal for electricity generation each year; 94% remains on Oahu, and 6% is shipped to Hawaii Island. H-POWER provides the largest source of indigenous energy to Oahu, with a capacity of approximately 50 MW generated from local waste. The island is heavily dependent on imported petroleum for power generation and transportation fuel; the interruption of fuel imports currently poses one of the most critical dangers to the island's economy. Efficiency measures and conservation must be considered as short-term (and often low-cost) solutions to curtail growing demand and long-term strategies for energy sustainability. Although the focus of this study was on material flows rather than energy, the Yale Center for Industrial Ecology has done extensive analysis on how Hawaii Island could reduce its level of fossil fuel dependency (which is comparable to that of Oahu) from over 80% to only 31% of primary energy demand (Johnson *et al.*, 2007).

Waste oil and recovered tires are high heat content materials currently burned for electricity in the AES plant that could be used to a greater degree to displace coal imports. An estimated 10,500 tons of tires are shipped off-island for processing on the U.S. mainland, depriving Oahu of a valuable energy and material resource (R.W. Beck, 2007b). Approximately 5,400 tons of waste fuel oil is collected and burned at AES. Another 3,900 tons of waste cooking oil is converted into biodiesel by the Pacific Biodiesel operation in Honolulu, which is then sold to island residents and businesses.

Great attention has been awarded to the prospect of growing biofuels on Oahu. The Rocky Mountain Institute has identified 150 km² of Oahu as prime biofuel cropland and an additional 67 km² as restricted use or non-prime. Approximately 7,000 km² of cropland would be required to replace Oahu's gasoline demand with

ethanol (RMI, 2006). This area is almost 50 times greater than the prime agricultural land available and almost five times greater than the total land area of Oahu. So there is a large discrepancy between the energy demand and the energy that could be made available using current biofuel technology. Any significant effort to produce biofuels on Oahu would also place greater demand on freshwater resources, but some of the irrigation infrastructure needed for sugarcane production is still intact (RMI, 2006).

Oahu is less than ideal for large-scale wind farming. The mountain ridges act to shield the majority of the island from potential wind resources. Limited areas at the top of each mountain ridge do receive sufficient wind densities for power generation with National Renewable Energy Laboratory (NREL) ratings of 6 or 7 at 50 meters of elevation. Turbines are not generally built on land with NREL ratings lower than 4 or 5. So there is limited potential for wind farming on Oahu, however the terrain is inhospitable, remote and aesthetically valued. Even if the entire island displayed sufficient wind power density for electricity generation, which it does not, it would require about 75% of the land area of Oahu to meet current electricity demand.

Solar radiation on Oahu is greater at the shore line where the sunlight is not obstructed by the mountains. The shoreline regions receive approximately 240 W/m² of solar radiation, which is fairly high. These regions are where most of the population is and some residents have installed photovoltaic panels on their homes in order to offset their electricity purchases.

Considering solar power, there is a small (and growing) use of photovoltaic panels for electricity generation, but most of the solar energy that is harnessed is for hot water heating. There are 24,000 solar water heating systems on Oahu covering approximately 10% of structures. A solar water heater is simply a heat exchanger mounted on the roof of a home designed to transfer heat from the sun to water circulating through the device. Their installation is being promoted by local government and the electric utility. These systems reduce the demand for heat from conventional hot water heaters, which operate using electricity or natural gas, and thus reduce both greenhouse gas emissions and fossil fuel imports.

8.1.3 Food

More than 90% of Oahu's food demand is being met by imports. As with fuel, consistent supplies of food are essential for sustaining the daily lives of island residents in the case of a large-scale disruption to trade. Oahu has a total of 521 km² of agricultural land, 283 of which are currently in use. An estimated 55% of the fallow land in use is considered to be "prime agricultural lands" once used in monoculture operations (HDoA, 2004). There is a great deal of potential for agricultural expansion, particularly with renewed interest in achieving food and energy self-sufficiency (Sustainability Task Force, 2008), but the competitive opportunities for both food and biofuel crop cultivation present serious issues for such a densely populated island.

Barriers to the expansion of agriculture include providing consistent water supply through improved irrigation systems and committing to sufficient growing quantities so that food wholesalers and retailers can transition toward reliance on consistent local supplies. A white paper released by Hawaii's Department of Agriculture

indicated that many imported crops have the potential to be replaced by locally grown varieties and proposed that Hawai'i could realistically become self-sufficient in producing much of its current food supply with the appropriate assistance. It must be noted, however, that this would require serious changes in dietary preferences and agricultural infrastructure. In addition, thought must be given ahead of time to reuse of agricultural by-products so they could be cycled rather than disposed.

A key barrier to the development of the aquaculture (fish farming) industry in Hawai'i is the competitive disadvantage caused by the cost of importing fishmeal. There are many instances worldwide of fish farming using vegetable feed, and according to the Marine Finfish Department at Hawaii's Oceanic Institute, everything from papaya waste to macadamia nut shells to discarded fly agar is being investigated to identify alternative sources of imported fishmeal for aquaculture (Laidley, 2008).

There are not very many native resources available for extraction on Oahu, however the areas that bear the most potential are the expansion of agriculture and aquaculture as well as the harnessing of renewable energy resources such as solar. Agriculture and aquaculture do not face physical barriers to expansion as much as organizational, political, and cultural ones and can offer great potential increases in food security and possibly energy supply. Bearing in mind existing energy technologies, there is no way currently to satisfy Oahu's sizeable energy demands without reliance on fossil fuels. In the long run, however, this represents a dangerous dependence for an island, and reducing the demand for fossil fuel imports should be a priority.

8.2 WASTE UTILIZATIONS

In some ways, Oahu's waste management system works very well. Through commercial recycling, nearly 34% of the total waste stream is diverted. H-POWER supplies 5-7% of the island's electricity and treats roughly two-thirds of the MSW, thus prolonging the life of the landfill. Progressive organic waste regulations require much of the food waste to be composted along with the island's green waste. This comprehensive composting system provides a source of low-cost fertilizer for farmers and in turn results in less methane generation at the landfill and better burn rates at H-POWER. There are, however, several opportunities to enhance the waste management system as elucidated by the MFA results, some of which are currently being undertaken by the City, and some which have yet to be considered.

8.2.1 Residential recycling

In 2007, the City began a pilot program for residential curbside pickup of recyclables. Prior to this, the only recycling option for residents was to bring material to the convenience centers. In terms of collection and waste diversion rates, the pilot was largely successful and curbside recycling is now being expanded to the entire island. A comprehensive, island-wide program is projected to divert an additional 48,000 tons of green waste and 27,000 tons of recyclables from the municipal landfill (Honolulu ENV, 2008c).

8.2.2 Processing and sorting at treatment and disposal sites

Currently, no entity is extracting metals from the waste that is directed to the municipal landfill. One issue is whether it is possible for the City, or another entity, to sort out metals before entering the landfill. A small pilot study that was performed by Waste Management of Hawai'i for the City and County of Honolulu determined that several tons per day of metal (or slightly less than one percent of all incoming material) is disposed of at the Waimanalo Gulch landfill that is easily recoverable using demonstrated technologies (Oden *et al.*, 2008). Island Demo transfer station does extract some metal from its waste stream, generating \$500,000 to \$1 million in revenues annually.

8.2.3 Materials recycling versus energy recovery

One of the most debated issues surrounding material flows on Oahu is to what extent materials should be shipped off of the island for recycling versus finding new uses for used materials on the island. A study commissioned by the Department of Environmental Services, for example, found that in the case of wastepaper, the many global lifecycle energy and greenhouse gas benefits of material recycling over energy recovery were principally accrued off-island and did not contribute much to on-island sustainability (R.W. Beck, 2007a).

8.2.4 Reuse opportunities

According to the R.W. Beck waste report (2006), nearly 19,000 tons of material were reused on the island in 2005 in addition to the 600,000 tons recycled. Most of the reusable items were clothes donated to the island's numerous thrift stores.

The conversion and use section of the MFA revealed additional opportunities for materials reuse. Most of the hotels on the island undergo a complete renovation every ten years, during which they discard all furniture and fixtures. In addition, all linens and towels are replaced annually. Considering the largest 25 hotels on the island, these renovations produce solid waste equivalent to 4,700 tons per year. The discarded materials are collected by a third party hotel liquidator that resells some furniture but also landfills a substantial amount, particularly items that are difficult to resell such as mattresses (Parthasarathy *et al.*, 2008).

For usable furniture and appliances, there are several businesses on Oahu that accept used items (and refurbish them if needed) for resale or donation to island community and non-profit groups, thus avoiding disposal fees. Other businesses serve as material exchanges for used or surplus building materials. The Hawai'i Department of Health has long encouraged contractors to make use of these services in order to conserve landfill space and improve material efficiency (HDoH, 2008). If remanufacture or reuse of furniture and other wood products is not possible due to quality concerns, the next best option would be to send these to H-POWER for conversion to electricity, given the high energy content of wood. H-POWER currently charges \$81 per ton flat rate tipping fee (not including surcharges) for private haulers, which is identical to the landfill's tipping fee. Introducing a fee scale for materials with high heat content may improve the economics of this option.

Mattresses can be another valuable resource, being nearly 60% by weight of steel coils with the remainder readily burnable materials such as wood and synthetic textiles. For those mattresses that cannot be reused, shredding and separation by a private business or transfer station may be economical in a period of high scrap prices and contribute to waste reduction at the landfill. The stream of used linens and towels would be appropriate for remanufacturing (as is done now for some portion by Linens Recovery Hawaii), rag recycling, or waste-to-energy, rather than landfilling.

8.2.5 Organic materials

Expanding partnerships between wastewater treatment plants (WWTPs) and fertilizer manufacturers could divert an additional 41,000 tons of biosolids from the municipal landfill, though transport of such a quantity of biosolids may be problematic for traffic and public health reasons. Pelletized biosolids have many potential uses (the primary one being fertilizer and soil conditioner) and could be used on Oahu, on the other islands, or exported.

The R.W. Beck waste report suggested increasing the use of untreated wood waste and gypsum wallboard from construction projects in composting operations. The MFA reveals that there are about 18,000 tons of untreated wood entering the waste management system, all of which could be used after minimal treatment to substitute for coal at the AES power plant. Some of this wood waste is used pallets, which can also be refurbished by companies such as Island Recycling, or composted by Hawaiian Earth Products.

8.2.6 Military reuse and recycling

In 2006, the military recycled an estimated 16% of the waste material that was generated. One significant barrier to increased recycling in the military is the lack of communication and coordination among waste management officers in the different branches, with each handling its waste in a slightly different way. The Air Force has direct contacts with companies abroad and bales and ships all of its own material; the other three branches contract with on-island waste brokers. The Air Force also processes some waste on-site: glass cullet is incorporated into cement and may be used as pipe bed material, and plant waste is mulched. The various branches have many common material and service requirements but have not created joint management strategies because of control and security concerns. The Navy operates a recycling facility at Pearl Harbor that occasionally takes in material from the other branches, but these deliveries are sporadic. Given the large amount of land that the military controls on Oahu, programs such as the Navy's use of sewage sludge and green waste as soil additives (currently idle) could be revived on a larger scale. The military has now established a coordinating committee across branches with the idea of improving waste management and recycling practices as well as procurement (Killian, 2009).

8.2.7 Backhauling opportunities

Of great importance to material flows on the island is the fact that all of the containers arriving at Oahu are full but more than two thirds of containers generally leave empty.

The commercial sector currently backhauls an estimated 12,000 tons of old corrugated cardboard (OCC) to the mainland U.S. and discards an additional 29,400 tons. Through cooperative programs among the large retailers, a significant portion of the discarded OCC may be diverted from incineration and disposal. R.W. Beck also suggests commercial backhauling of plastic film, which currently amounts to 31,700 tons of commercial discards. Historically, however, three companies were described as having gone bankrupt previously trying to backhaul cardboard (Strom, 2009).

8.3 LEGISLATIVE DRIVERS

Many of the constraints to the current system of waste management on Oahu are economic, resulting from the island's remote location, high land and energy prices, and intermediate-sized market. There are, however, some legislative drivers that greatly influence the current system and which may be examined for potential changes that could effect waste reutilization and minimization. Title 11, Chapter 58.1 of the Hawai'i Administrative Rules governs solid waste management in the state, primarily outlining permit and reporting requirements. The City Department of Transportation Services writes the design and construction specifications for road constructions projects on Oahu, which have restrictions on the amounts and uses of recycled aggregate and glass, as discussed above. Careful consideration could be given to altering these restrictions within safety limits, which may help to foster an important end-market for these secondary materials.

In 2006, nearly 90,000 tons of ash were delivered to the municipal landfill from H-POWER and most of the 70,000 tons of coal ash from the AES power plant is used as landfill cap. Some of this ash may be able to be diverted for other beneficial uses with proper permits from the Hawai'i Department of Health, which must be assured that such use is protective of human health and the environment.

Oahu's waste management issues, while unusual in many respects, are certainly not unique, and many other cities and states in the U.S. have passed innovative legislation to reduce waste generation. One such regulation that has stimulated local recyclers and secondary materials markets is a Massachusetts ban on certain C&D wastes including asphalt, concrete, brick, metals, and wood (Chertow, 2008). Such a regulation would divert a combined 94,000 tons of materials from Oahu's landfills, assuming an 80% efficient ban.

8.4 SUMMARY

Table 8.1 presents a summary of the opportunities for materials management discussed above, with mass estimates for potential increases in import substitution or waste diversion. As these opportunities are not all mutually exclusive, no sum is given. Ranges are based on material availability and feasible recovery rates.

Table 8.1 Potential options for Oahu material flows

Reduce imports through....	Qty Displaced ('000 tons)
Increased recovery of useful construction materials by the Island Demo transfer station and the PVT landfill, which is currently restricted by operating permits	65-125
Increased recovery of glass by private and municipal recyclers and increased use of glass in public and private construction projects	20-35 ^a
On-island production of a significant quantity of ethanol or biodiesel for motor fuel to replace imported gasoline	10-20 ^b
Expansion of renewable electricity generation to 10%, from its current negligible level to replace imported crude oil, in accordance with the Hawai'i Clean Energy Initiative	140-170 ^b
Greatly expanding and diversifying the domestic supply of food on the island to replace 5-20% of imported food, using fallow but productive agricultural lands abandoned by plantations and old farms	35-140

Utilize wastes more fully by....	
Expanding the pilot curbside recycling program to cover the entire island, with regular pick-up of paper, glass, bottles and cans, and green waste	70-80
Enacting a system to screen incoming waste at the Waimanalo Gulch and PVT landfills and extract useful metals	10-20
Encouraging a system of reuse of furniture, textiles, fixtures, and usable construction pieces from hotel renovations	3-5
Expanding existing military programs for reuse and recycling, spreading best practices from each base to all of the other bases and cooperating on collection programs	3-5 ^c
Organizing large commercial entities to collect, aggregate, and backhaul corrugated cardboard and plastic film in otherwise empty containers to the mainland	30-50
Expanding on existing partnerships, increase the use of wastewater treatment sludge as a potential fertilizer	30-40
Collecting, screening, and shredding wood waste for use in the AES power plant	15-25 ^a
Enabling the expansion of capacity to process tires that are now being treated as waste into tire-derived fuel for use at the AES power plant or other applications	10-12

Consider legislation that would....	
Allow road beds to be up to 50% recycled construction materials	50-150
Allow up to 30% ash content in concrete	30-60
Ban landfilling construction and demolition waste, as has been enacted in several other states to reduce the overall strain on local landfills	85-105 ^d

^a Sum of import substitution and waste diversion

^b Assuming current levels of consumption and no additional imports are required for alternative production

^c Assuming that the military increases its recycling rate to the average of ~35%

^d Assuming that this does not result in increased illegal dumping

One theme that could be derived from the options in table 8.1 is a focus on green buildings and construction. This would include using recycled materials in roads and concrete, recycling construction and demolition waste as much as possible (which can be incentivized by banning this waste from landfills), creating a local market for recycled glass by increasing its use in public construction projects, and enabling effective reuse of furniture and other items from hotels. Some of these options overlap, but all in all, this would reduce imports by more than 100,000 tons of material per year and reduce the overall amount of waste that would need to be disposed by approximately 10% from current levels.

Another theme is increasing self-sufficiency on the island by producing more food via agriculture and aquaculture, and beginning to produce biofuels using old plantation lands. In the catastrophic event of a cessation in shipping to the island for whatever reason, increasing self-sufficiency in food and fuel would allow for more of a buffer for residents to subsist on before normal service resumed. In addition, increasing the production of food and fuel to the maximum levels discussed in this report would reduce total imports by more than 200,000 tons per year.

A final theme is fully utilizing all waste materials, either for use on the island or for sale to international scrap markets. The primary purpose of this category of activities is to reduce the burden on waste treatment (H-POWER) as well as the public landfill. Aggressively enacting all of the waste utilization options presented here would decrease total waste generation by approximately 200,000 tons and would increase the amount of on-island reuse and recycling that takes place by about 40%, from 440,000 tons to over 600,000 tons.

This report does not prioritize one option over another, but simply describes these opportunities so that citizens, government, and business leaders can compare them and use the quantitative estimates to make informed decisions.

CONCLUSIONS

The major conclusions of this report are straightforward. There are many opportunities for Oahu to increase material self-sufficiency. This can be done through a combination of increasing the amount of local materials available, decreasing demand for materials, and enhancing the cycling of all materials, both imported and local. Understanding what these materials are and how they flow through the system underlies coordinated decision-making for the people of Oahu.

This report comes at a time when there is a lot of public interest and activity in sustainability issues on the island. A great deal of recent investment by prominent individuals, NGOs, and government officials has focused on moving Hawai'i towards sustainability. Several recent government initiatives have focused on promoting alternative sources of energy in particular, such as The Hawai'i Clean Energy Initiative. Many of these initiatives will have significant system-wide benefits for the island and implications for issues of dependency and waste management. The goal of this report has been to provide a full-view picture of the material-based challenges to Oahu's sustainability, and the many interconnections and impacts that material flows have on other systems (energy, economic) that we are more used to considering.

References

- Andersson-Skold, Y., K. Andersson, B. Lind, A. Claesson, L. Larsson, P. Suer, and T. Jacobson. 2007. Coal Tar-Containing Asphalt: Resource or Hazardous Waste? *Journal of Industrial Ecology* 11(4): 99-116.
- Ashton, W. and M. Chertow. 2008. *Puerto Rico's Industrial Legacy: Finding a Path to Sustainability. Final Report of the 'Puerto Rico: An Island of Sustainability' Project 2001-2008*. New Haven: Yale University.
- Boylan, P. 2009. Trash exports may start in July. *Honolulu Advertiser* [Honolulu], March 5, 2009, section.
- Chertow, M. R. 2007. "Uncovering" industrial symbiosis. *Journal of Industrial Ecology* 11(1): 11-30.
- _____. 2008. Municipal Solid Waste: Building Stronger Connections to Jobs and the Economy. In *Agenda for a Sustainable America*, edited by J. Dernbach: (in press).
- Chertow, M. R. and Y. Miyata. 2009. Assessing collective firm behavior: Comparing industrial symbiosis with possible alternatives for individual companies in Oahu, Hawaii'i. *Business Strategy and the Environment* forthcoming.
- Cofran, F. 2008. Ala Moana Hotel. Personal Communication.
- Creps, R. 2008. Grace Pacific Corporation. Personal Communication.
- CWRM. 2005. *2004 Hawaii Water Use Survey and Report*. Honolulu: Hawaii Commission on Water Resource Management, Department of Land and Natural Resources.
- DBEDT. 2005. *Sustainable Tourism Project, Modeling Summary Report*. Honolulu: Hawaii Department of Business, Economic Development, and Tourism.
- DBEDT. 2006. *State of Hawaii Data Book 2005*. Honolulu: Hawaii Department of Business, Economic Development, and Tourism.
- Deschenes, P. J. and M. Chertow. 2004. An island approach to industrial ecology: towards sustainability in the island context. *Journal of Environmental Planning and Management* 47(2): 201-217.
- Eckelman, M. J. and M. R. Chertow. 2009. Using material flow analysis to illuminate long-term waste management solutions in Oahu, HI, USA. *Journal of Industrial Ecology*.
- Energy Information Administration. 2009. State Energy Profiles: Hawaii. http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=HI. Accessed April 10, 2009.

- Espinoza, F., A. Heinemann, and L. Sima. 2008. *Material flow analysis for the island of Oahu: Military sector*. New Haven: Yale University (unpublished).
- Famely, J., E. Gladek, and C. Ziemba. 2008. *Material flows on the island of Oahu: Imports, exports, and resource extraction*. New Haven: Yale University (unpublished).
- Fernandes, J. D. a. A. 2002. 2002 National Lodging Forecast, Ernst and Young LLP.
- Friel, L. 2008. Matson Shipping. Personal Communication.
- Fugate, E. 2008. Life cycle energy analysis of Hawai'i Island water systems. Paper presented at Gordon Research Conference on Industrial Ecology, New London, NH.
- Godfrey, J. 2008. *Oahu Conservation Partnership and the Army Compatible Use Buffer Program*. Online presentation, Chief of the Environmental Division of the Directorate of Public Works for the U.S. Army Garrison, Hawaii.
- Goo, A. 2008. U.S. Army. Personal Communication.
- HDoA. 2004. *Agricultural water use and development plan*. Honolulu, HI: Hawaii Department of Agriculture.
- HDoH. 2008. *Minimizing Construction & Demolition Waste*. Honolulu: Hawaii Department of Health.
- HDoT. 2008. *State of Hawaii Airport Activity Statistics by Calendar Year*. Honolulu: Hawaii Department of Transportation; Airports Division.
- Honolulu Advertiser. 2009. City should expedite waste-shipping plans. *Honolulu Advertiser* [Honolulu], July 1, 2009, section.
- Honolulu BWS. 2008. *Oahu Water Management Plan Overview*. Honolulu: City and County of Honolulu Board of Water Supply.
- Honolulu DPP. 2006. *Monthly Bulletin – Building Permits* Honolulu: City and County of Honolulu Department of Planning and Permitting.
- Honolulu ENV. 2008a. Wastewater. <http://envhonolulu.org>. Accessed August 25 2008.
- Honolulu ENV. 2008b. Community Recycling Bins. http://envhonolulu.org/solid_waste/community_recycling_centers.html. Accessed April 20 2008.
- Honolulu ENV. 2008c. *Curbside recycling pilot program evaluation*. Honolulu: City and County of Honolulu Department of Environmental Services.
- Houseknecht, M. 2006. *Waste management on the Big Island: Mapping a vision for an economically and ecologically sustainable Hawai'i*. Hilo, HI: The Kohala Center.
- Houseknecht, M., C. Kim, and A. Whitman. 2006. *Material flows on the island of Hawai'i*. Hilo, HI: The Kohala Center.

- Houseknecht, M., C. Kim, and A. Whitman. 2007. Material flows on the island of Hawai'i. Hilo, HI: The Kohala Center.
- Hunt, C. D., Jr. . 2004. *Ground-Water Quality and its Relation to Land Use on Oahu, Hawai'i 2000-01, Water-Resources Investigations Report 03-4305*. Reston, CA: United States Geological Survey.
- IWR. 2005. *Waterborne Commerce of the United States, Calendar Year 2005; Part 4-Waterways and Harbors Pacific Coast, Alaska and Hawaii*. Alexandria, VA: Institute for Water Resources, U.S. Army Corps of Engineers.
- Johnson, J., D. Leistra, J. Opton-Himmel, and M. Smith. 2006. *Hawaii County baseline energy analysis*. Hilo, HI: The Kohala Center.
- Johnson, J., M. Davies, C. Gagne, Z. Hausfather, D. Lippert, and M. Chertow. 2007. *Analysis and Recommendations for the Hawai'i County Energy Sustainability Plan*. Hilo, HI: The Kohala Center.
- Kaufman, S., N. Goldstein, K. Millrath, and N. Themelis. 2004. The state of garbage in America. *BioCycle* 45(1): 31-41.
- Kennedy, C., J. Cuddihy, and J. Engel-Yan. 2007. The changing metabolism of cities. *Journal of Industrial Ecology* 11(2): 43-59.
- Keoleian, G. A., S. Blanchard, and P. Reppe. 2000. Life-cycle energy, costs, and strategies for improving a single-family house. *Journal of Industrial Ecology* 4(2): 135-156.
- Killian, H. 2009. Colonel, U.S. Army, Personal Communication.
- Kitaoka, H. 2008. Grace Pacific Corporation. Personal Communication.
- Laidley, C. 2008. Hawai'i Oceanic Institute. Personal Communication.
- Lanier, R. 2008. U.S. Air Force, Hickam Air Force Base. Personal Communication.
- Lotti, R. 2008. U.S. Marine Corps, Kaneohe Bay, Director of Facilities Management. Personal Communication.
- Miho, D. 2008. Ala Moana Hotel. Personal Communication.
- NASS. 2005. *Hawaii Statistics*. National Agricultural Statistics Service.
- Nichols, B. 2008. Actus Lend Lease. Personal Communication.
- Oden, M., J. Park, and K. Zaidel. 2008. *Management of opala on the island of Oahu*. New Haven: Yale University (unpublished).
- OMB. 2003. *Circular No. A-76, revised*. Office of Management and Budget.
- Pacific Business News. 2006. *Honolulu Book of Lists '06*.

- Parthasarathy, T., H. Gilbert, and N. Arabshahi. 2008. *Material flows on the island of Oahu: Private sector*. New Haven: Yale University (unpublished).
- Pascua, F. 2008. Hawai'i Department of Transportation. Personal Communication.
- Peterson, M. 2008. U.S. Air Force, Hickam Air Force Base. Personal Communication.
- Prentice, J. 2008. Hawaiian Dredging Corporation. Personal Communication.
- R.W. Beck. 2006. *Solid Waste Management Plan*. Honolulu: City and County of Honolulu Department of Environmental Services.
- R.W. Beck. 2007a. *Comparison of select materials and energy recycling scenarios*. Honolulu: City and County of Honolulu Department of Environmental Services.
- R.W. Beck. 2007b. *Integrated solid waste management plan update*. Honolulu: City and County of Honolulu Department of Environmental Services.
- RMI. 2006. *Hawaii biofuels summit briefing book*. Hilo, HI: Rocky Mountain Institute.
- Schaefers, A. 2008. Operator Cites Shortage of Construction Materials. *Honolulu Star Bulletin* [Honolulu], March 30, 2008, section.
- Slick, K. 2008. U.S. Air Force, Hickam Air Force Base. Personal Communication.
- Smith, R. 2008. H-POWER. Personal Communication.
- Stannard, D. E. 1989. *Before the Horror: The Population of Hawai'i on the Eve of Western Contact*. Honolulu: Social Science Research Institute, University of Hawaii.
- Strom, J. 2009. Enterprise Hawai'i, Personal Communication.
- Sue, N. 2008. Sheraton Waikiki, Director of Purchasing. Personal Communication.
- Sustainability Task Force. 2008. *Hawai'i 2050 Sustainability Plan*. Honolulu: State of Hawai'i.
- Turn, S. Q., V. Keffer, and M. Staackmann. 2002. *Biomass and Bioenergy Resource Assessment*. Honolulu: Hawaii Department of Business, Economic Development, and Tourism.
- Twilligear, M. 2008. U.S. Air Force, Hickham Air Force Base, Recycling Program Manager. Personal Communication.
- U.S. Census Bureau. 2007. *Honolulu County*.
- U.S. Census Bureau American Fact Finder U.S. Geographic Comparison Table. 2000.
- U.S. EPA. 2007. *Mucipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2006*. Washington, DC: U.S. Environmental Protection Agency.

Usagawa, B. 2008. City and County of Honolulu Board of Water Supply. Personal Communication.

USGS. 2007. 2005 *Minerals Yearbook – Hawaii*. Reston, VA: United States Geological Survey.

USGS. 2009. *Pacific Island Water Science Center*. Reston, VA: United States Geological Survey.

Wurlitzer, D. 2008. Hawaiian Cement. Personal Communication.

Yap, B. 2008. Forget sugar and pineapples; Hawaii plans to export 100,000 tons of trash. *The Associated Press* [Honolulu], July 14, 2008.

Biosketches of Authors

Marian Chertow is Associate Professor and Director of the Industrial Environmental Management Program at the Yale School of Forestry & Environmental Studies. Her teaching and research focus on industrial ecology, business/environment issues, waste management, and environmental technology innovation. Her most recent research involves the study of industrial symbiosis – geographically-based exchanges of energy, water, and material by-products within networks of businesses. She is on the founding faculty of the Masters of Science in Environmental Management Program at the National University of Singapore and is a Visiting Professor at Nankai University's National Center for Innovation Research on Circular Economy in China.

Matthew Eckelman is an Associate Research Scientist in Environmental Engineering at Yale and works with the Yale Center for Industrial Ecology. His research examines the life cycle environmental impacts of industrial production and trade, as well as regional sustainability issues. Prior to this, he worked with the Massachusetts State Executive Office of Environmental Affairs and Design that Matters, a non-profit product design company, and was a Peace Corps science instructor in southern Nepal.

Yale Center for Industrial Ecology

The Center for Industrial Ecology at the Yale School of Forestry & Environmental Studies was established in September 1998 to provide an organizational focus for research in industrial ecology. The Center brings together Yale staff, students, visiting scholars, and practitioners to develop new knowledge at the forefront of the field. Research is carried out in collaboration with other segments of the Yale community, other academic institutions, and international partners. Faculty research interests include, among others, the theoretical basis of industrial ecology, the cycles of materials, technological change and the environment, eco-industrial urban development, industrial symbiosis, and product and producer policy issues.

cie.research.yale.edu

PUBLICATION SERIES

Yale School of Forestry & Environmental Studies

To capture exciting environmental projects at Yale of interest to a broad professional audience, the Yale School of Forestry & Environmental Studies Publication Series issues selected work by Yale faculty, students and colleagues each year in the form of books, bulletins, working papers and reports. All publications since 1995 are available for order as bound copies or as free downloadable pdfs at our online bookstore at www.yale.edu/environment.yale.edu/publications. Publications are produced using a print-on-demand system and printed on 100% recycled paper. For further information or inquiries, contact Jane Coppock, Editor of the F&ES Publication Series, at jane.coppock@yale.edu.

Yale School of Forestry
& Environmental Studies
PUBLICATION SERIES

195 Prospect Street
New Haven, Connecticut 06511
USA