Hawaii Energy Strategy Project 2: Fossil Energy Review

TASK II
FOSSIL ENERGY IN HAWAII

Prepared for

State of Hawaii
Department of Business, Economic Development & Tourism,
Energy Division

by

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Hawaii Energy Strategy Project 2, Fossil Energy Review

Task II. Fossil Energy in Hawaii

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Contents

Tables

Figures

Abbreviations, Acronyms, and Measures

AAGR	average annual growth rate in percentage terms
ADO	automotive diesel oil
AES	Applied Energy Services (Hawaii)
ANS	Alaska North Slope (crude oil)
API	degrees of API (American Petroleum Institute); API gravity.
ASEAN	Association of South East Asian Nations
bcf	billion cubic feet
b/d	barrels per day
boe	barrels of (crude) oil equivalent
Btu	British thermal unit
BTX	benzene, toluene, xylene; BTX raffinate: the material remaining after aromatics extraction
CAT REF	catalytic reformer
CDU	crude distillation unit
cf	cubic feet
cf/d	cubic feet per day
c.i.f.	cost, insurance, freight
CIS	Commonwealth of Independent States (former Soviet Union)
CNG	compressed natural gas
CPE	centrally planned economies
d	day
dwt	deadweight tons
EC	European Community
ETBE	ethyl tertiary butyl ether
FBC	fluidized bed combustors
FCC	fluid catalytic cracker
FGD	flue gas desulfurization
f.o.b.	free on board (f.o.b.t.: free on board and trimmed)
gPB/l	grams of lead (Pb) per liter
GSP	gross state product
GW	gigawatts (1,000,000 kilowatts)
HDC	hydrocracker
HGI	Hardgrove grindability index
HGO	heavy vacuum gasoil (also HVVGO)
HSFO	high-sulfur fuel oil
HVAC	heating, ventilating, and air-conditioning
HVVGO	heavy vacuum gasoil
IDO	industrial diesel oil
IEA	International Energy Agency (Paris)
IGCC	integrated gasification combined cycle

kg	kilogram (2.205 pounds)
km	kilometer (0.62 miles)
kW	kilowatt (1,000 watts)
kWh	kilowatt-hours
l	liter (1.057 U.S. quarts)
lb	pound
LCO	light cycle oil
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LRG	liquefied refinery gas
LSFO	low-sulfur fuel oil
LSWR	low-sulfur waxy resid
LTVGO	light vacuum gasoil
m	thousand
mb	thousand barrels
mb/d	thousand barrels per day
MDO	marine diesel oil
MITI	Ministry of International Trade and Industry (Japan)
mm	million
mmb	million barrels
mmb/d	million barrels per day
mmcf/d	million cubic feet per day
mmt	million tons
mmtoe	million tons of oil equivalent
MON	motor octane number
MTBE	methyl tertiary butyl ether
MW	megawatts (= 1,000 kW)
NGL	natural gas liquids
OECD	Organisation for Economic Cooperation and Development
OPA 90	Oil Pollution Act of 1990 (U.S.)
OPEC	Organization of Petroleum Exporting Countries
OTEC	ocean thermal energy conversion
PADD-V	Petroleum Administration for Defense District V (Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington)
PCF	pulverized coal fired (power plant)
PCI	pulverized coal injection
PNG	Papua New Guinea
RCC	resid catalytic cracker
RDS	resid desulfurizer
resid	residual oil; also called heavy oil, bunker fuel, bottoms, etc.
RON	research octane number
RP ratio	reserves-to-production ratio
RVP	Reid vapor pressure
RVPBI	Reid vapor pressure blending index

t	ton (U.S. short ton)
tcf	trillion cubic feet
TEL	tetraethyl lead
TFI	transport fuels index (East-West Center)
toe	tons of oil equivalent
UAE	United Arab Emirates
VB	vacuum bottoms
VDU	vacuum distillation unit
VGO	vacuum gas oil
VR	vacuum resid
y	year

Introduction

During the course of the Hawaii Energy Strategy (HES) Project 2, a number of individuals and organizations have asked questions about and given commentary on our work. Many of the questions and comments dealt with alternative fuels, conservation, and environmental externalities. Many—though not all—of the comments came from people who did not understand the scope of our work and the scope of the work performed by other consultant groups. These people were frustrated by our apparent unwillingness to delve more deeply into the feasibility of alternatives, renewables, and conservation. Some felt that we were biased because we made bold statements to the effect that oil was cheap and a superior source of energy. They felt that we should add externality costs to the price of oil, and then assess the economic feasibility of alternatives. At the outset, we would like to make clear what this report on fossil energy in Hawaii does and does not do. We are HES Project 2, which is the Fossil Energy Review. We do not assess the potential for alternative and renewable energy resource development and deployment in Hawaii. HES Project 3 will analyze alternative energy sources. We do not calculate how much energy (regardless of source) could be saved through conservation and efficiency gains. HES Project 4 is assigned the analysis of demand-side management (DSM) strategies in the power sector. Additionally, HES Project 5 will assess prospects for conservation and alternative fuels in ground transport. We do not attempt to predict the date of a future oil price shock or calculate its impacts on the economy, nor can we accurately predict how certain energy security measures, such as a strategic petroleum reserve, would benefit various economic sectors under price spike conditions. We do not integrate the myriad findings of other groups; we do not recommend *the* energy policy for Hawaii. If we could do all of these things within the span of a year or so, we would be almost supernaturally clever, and the HES project as a whole would be essentially complete.

Then would come the difficult part: adoption and implementation. Even if the data on Hawaii's energy situation were perfect, the analyses were thorough and thoughtful, and the integration exercises were complete, Hawaii still would not have an energy policy. Attempts are being made at every stage of the HES to gain public input and support, but if the result of the HES project is a series of recommendations requiring changes in public policy and taxation, then a new round of public hearings will be necessary to consider these changes from a public point of view.

In this Task II (*Fossil Energy in Hawaii*) of the HES Project 2, we refer often to findings presented in Task I (*World and Regional Fossil Energy Dynamics*). In Task I, we explain what fossil energy is, what it does, who has it, who uses it for what purpose, and how long supplies may be expected to last given current exploitation rates. We assess fossil energy resources, reserves, quality, processing and transport considerations, relative prices, uses, substitutability, and environmental trends affecting fossil energy use. We attempt to demystify the fossil energy industry. We explain at length the oil refining process and which chemical properties define which products, partly in order to discuss the capabilities and limitations of Hawaii's oil industry in a meaningful way. We also try to familiarize readers with the concept of jointly produced products; that is, refining crude oil results in a slate of output products, chiefly gasoline, naphtha, jet fuel, diesel, and fuel oil. Within the limits of technology, the output slate can be modified to better meet local demand. But it is not possible to make *only* jet fuel, or *only* gasoline.

In Task II, we establish a baseline for evaluating energy use in Hawaii, and examine key energy and economic indicators. We provide a detailed look at fossil energy imports by type, current and possible sources of oil, gas and coal, quality considerations, and processing/transformation. We present time series data on petroleum product consumption by end-use sector, though we caution the reader that the data is imperfect. We discuss fuel substitutability to identify those end-use categories that are most easily switched to other fuels. We then define and analyze sequential scenarios of fuel substitution in Hawaii and their impacts on patterns of demand. We also discuss energy security—what it means to

Hawaii, what it means to neighboring economies, whether it is possible to achieve energy security.

Task III (*Greenfield Options*) covers the greenfield options, the potentials and drawbacks of fossil fuels not widely used in Hawaii. (The term "greenfield" is used in industry to describe new areas or technologies.) The heart of the task is an assessment of coal technology options and implications for the State of Hawaii, which has been undertaken by the Environmental Assessment and Information Sciences Division of Argonne National Laboratory as subcontractors to the East-West Center. Task III also explores the possibilities for liquefied natural gas (LNG) use in Hawaii.

Finally, Task IV (*Scenario Development and Analysis*) is devoted to analysis of key future scenarios jointly developed by the East-West Center and the Energy Division of the Department of Business, Economic Development, & Tourism.

Fossil energy provides by far the bulk of Hawaii's energy needs, and as Task I establishes, fossil energy remains, for most purposes, the cheapest and most flexible source of energy. Oil price shocks are always a possibility in the future, but it appears that the next-cheapest alternative may be unconventional oil resources such as Latin American or Canadian heavy oil. For the time period covered in the HES analysis (extending to 2014) it seems unlikely—in a free-market economy—that base case oil prices will rise to the point that alternatives and renewables will be able to make serious inroads into oil demand, and it seems also unlikely that one or more oil price shocks could change the fundamental economics of the situation.

This is not to say that our efforts to diversify fuel sources, promote renewable energy, and use energy more efficiently are useless or to no avail. As Task I also establishes, oil is indeed a finite resource, and even though reserves are at an all-time high, we are consuming this finite resource at a fairly good clip.

We will be candid about our bias: we believe in free-market economics and feel that the simplest, and most essential, role for government is to establish standards protecting the common good (public health, safety, education, welfare, defense, environmental protection, civil liberties, and so forth) and rely on the marketplace to find the most cost-efficient pathways to those public policy goals. It is possible that additional regulations will be required in Hawaii to achieve public policy goals concerning energy; it is possible that additional taxes and/or tax incentives will be required. It is not our responsibility (thankfully) to indicate support for, initiate, or carry out such programs; what we wish to point out is that we have worked with many governments around the world that practice some sort of energy market regulation, and we observe that the trend worldwide is toward *de*-regulation and privatization. If Hawaii moves toward greater regulation, it will be moving against the worldwide trend, and it should be forewarned that instituting new regulations and expanding bureaucracies to administer such regulations will be costly and politically unpopular.

I. Current Energy Utilization Patterns and Trends

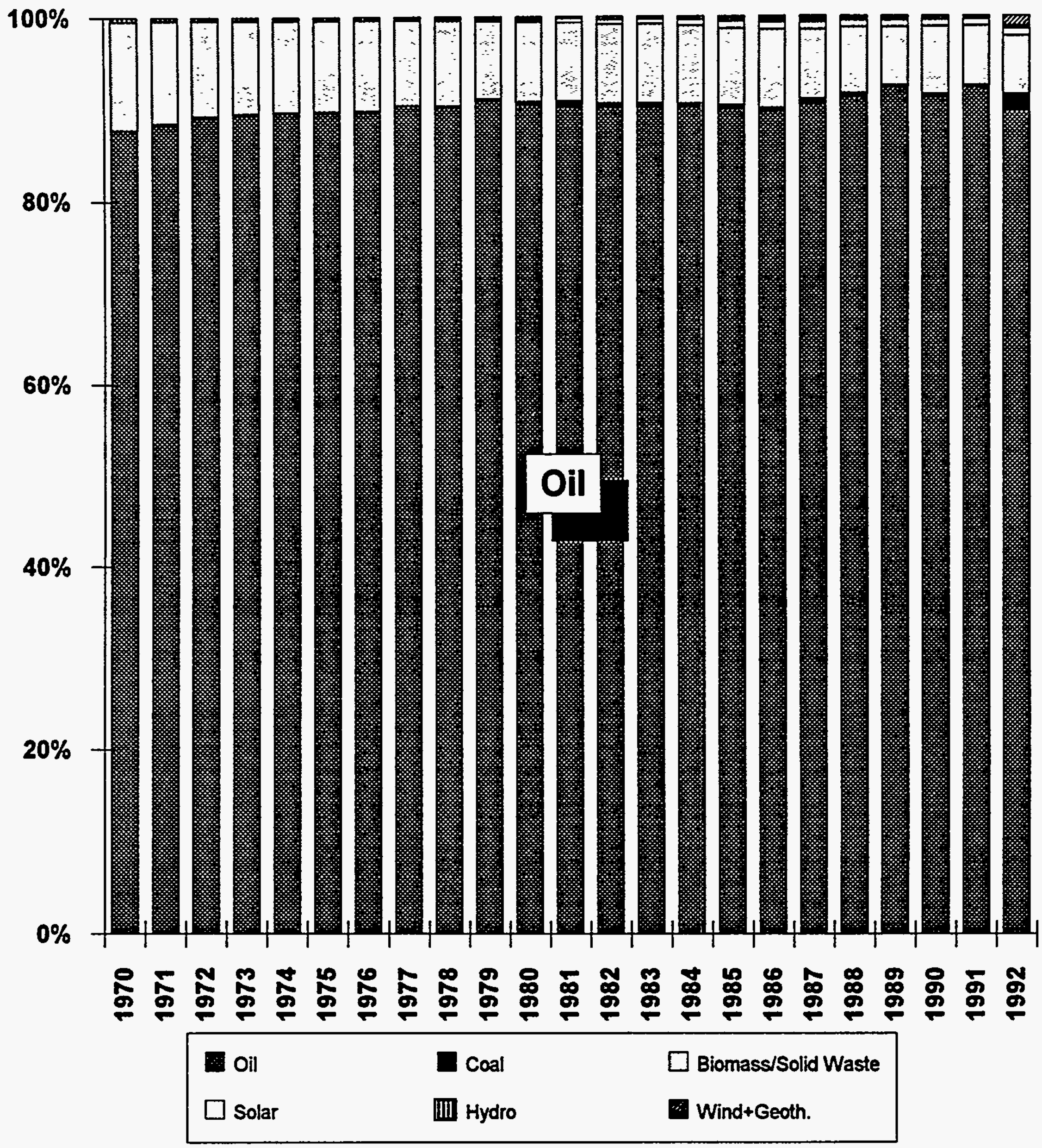
A. Primary Energy Use and Oil Dependence

1. What is Oil Dependence?

What does it mean to be oil-dependent? Does it mean that one-third, or one-half, or two-thirds of your primary energy comes from oil? Or is it that, regardless of the total percentage of oil in your energy mix, you must rely on *imports* of oil, having inadequate supplies of your own? Or is it that the structure of your energy demand dictates that oil *must* be used, with few opportunities for substitution? Or perhaps "oil-dependence" refers more to a feeling, a state of mind, a nagging unease that energy security is compromised because oil plays too large a role in the energy mix?

Under almost any definition, Hawaii is hugely oil-dependent. This is the case, and has remained the case, despite many millions of dollars and person-hours spent on alternative energy research, development, and deployment. Figure 1 displays the structure of Hawaiian primary energy use by type, 1970-92. This single chart says a great deal about energy in Hawaii. Over the past twenty-three years, oil overwhelmingly has dominated the energy scene, with a share of around 90 percent of total energy. This period of time witnessed two major oil price shocks in the 1970s, a price collapse in 1986, a major spill of one of Hawaii's mainstay crudes (the *Exxon Valdez* spill in Alaska), and war in the Persian Gulf. Yet throughout it all, oil use has grown. What can explain this? Is it a conspiracy by the oil companies? Are they so direly in need of money that losing the Hawaii market (which represents almost 0.008 percent of the U.S. oil market) would deal them a crippling blow? Or are we all just recalcitrant, digging in our heels and refusing to use alternatives even when they are available?

Figure 1. Structure of Hawaii's Primary Energy Demand by Type, 1970-92



2. The Changes in Hawaii's Energy Structure

The State of Hawaii has long recognized its dependence on oil and has taken many steps to diversify sources. It is not obvious from inspecting Figure 1, but it can be said that progress has been made. First, the share of oil is not *increasing*. Preliminary estimates for 1992 place oil's share at 89.6 percent, the lowest percentage since 1974. Statistics indicate that oil's share in 1991 was as high as 92.2 percent. As Figure 2 shows, total energy demand continues to grow, so holding oil's share down to 90 percent is, in a sense, an accomplishment. Hawaii may be likened to a swimmer, swimming against the current of oil: we must swim forward steadily just to avoid falling behind, and if we wish to move faster against the current, we must either change the current or strengthen our swimming skills. From Hawaii's position in the world energy market, there is little the state can do to change the current of world events. We cannot force the world to change and then benefit from the economies of scale captured by larger economies. The state's efforts must focus on improving our swimming skills; that is, making improvements in energy conservation and efficiency of use, encouraging cost-effective fuel substitution, and moving to develop alternative energy resources.

The second area where progress has been made is in diversification of non-oil energy. Figure 3 pulls the non-oil energy components out of the previous figure—where they were so dwarfed by oil that they were indistinguishable from one another—and presents them individually so the amount of diversification is quite clear. Biomass is the dominant alternative, though it can be seen that the role of bagasse has dwindled as Hawaii's sugar industry has contracted. Hydropower has offered a fairly stable amount of energy, but it's potential is limited by the number of suitable rivers. By the late 1970s, however, new energy sources began to make their entrance: first solar and coal, then wind and geothermal and solid waste. Coal use surged in late 1992 with the startup of the Applied Energy Services' (AES) coal-fired power plant and will show up even more dramatically in 1993, the first full year of operation for the 180-megawatt AES plant at Barbers Point.

Figure 2. Energy Use by Type in Hawaii, 1970-92

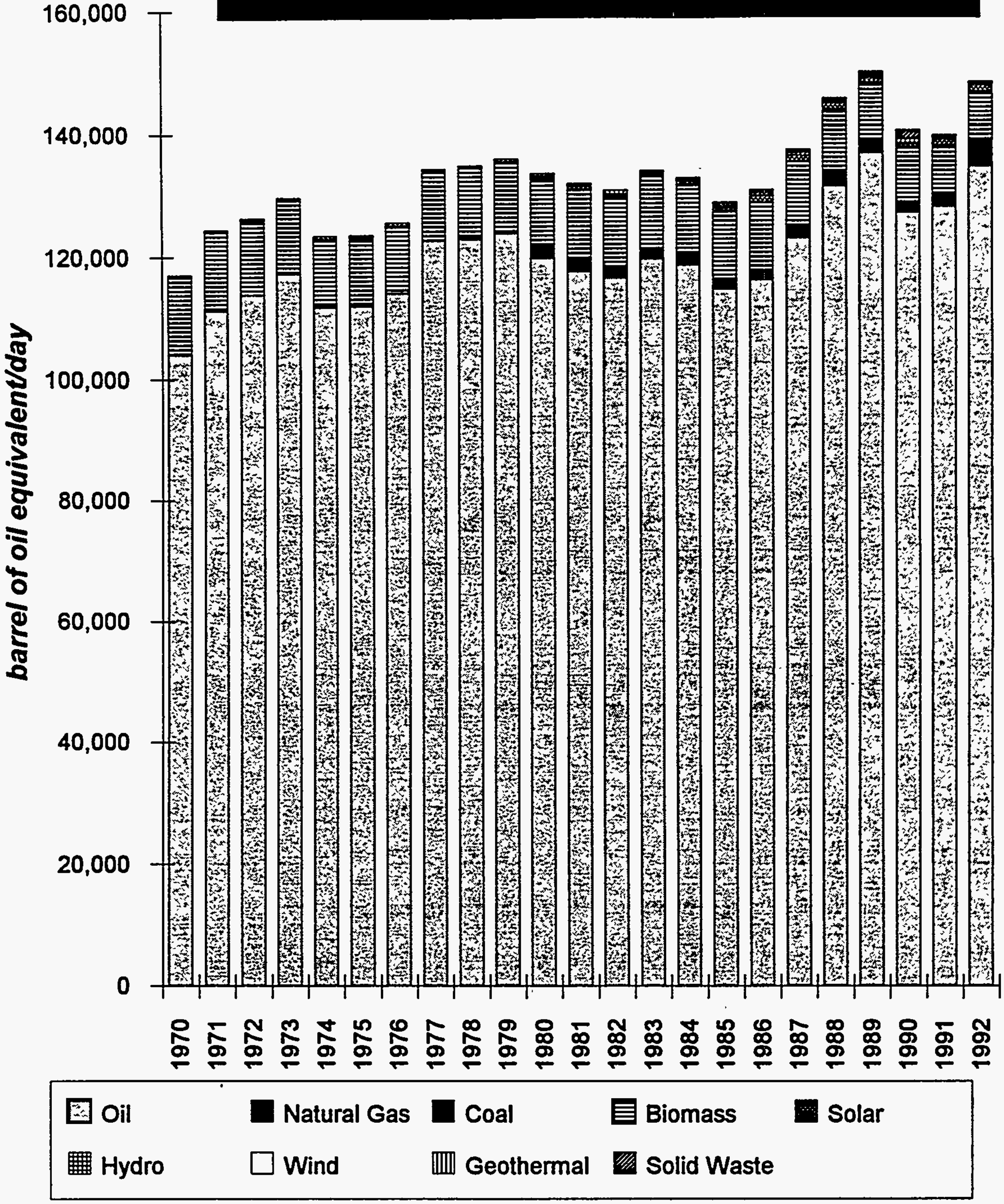
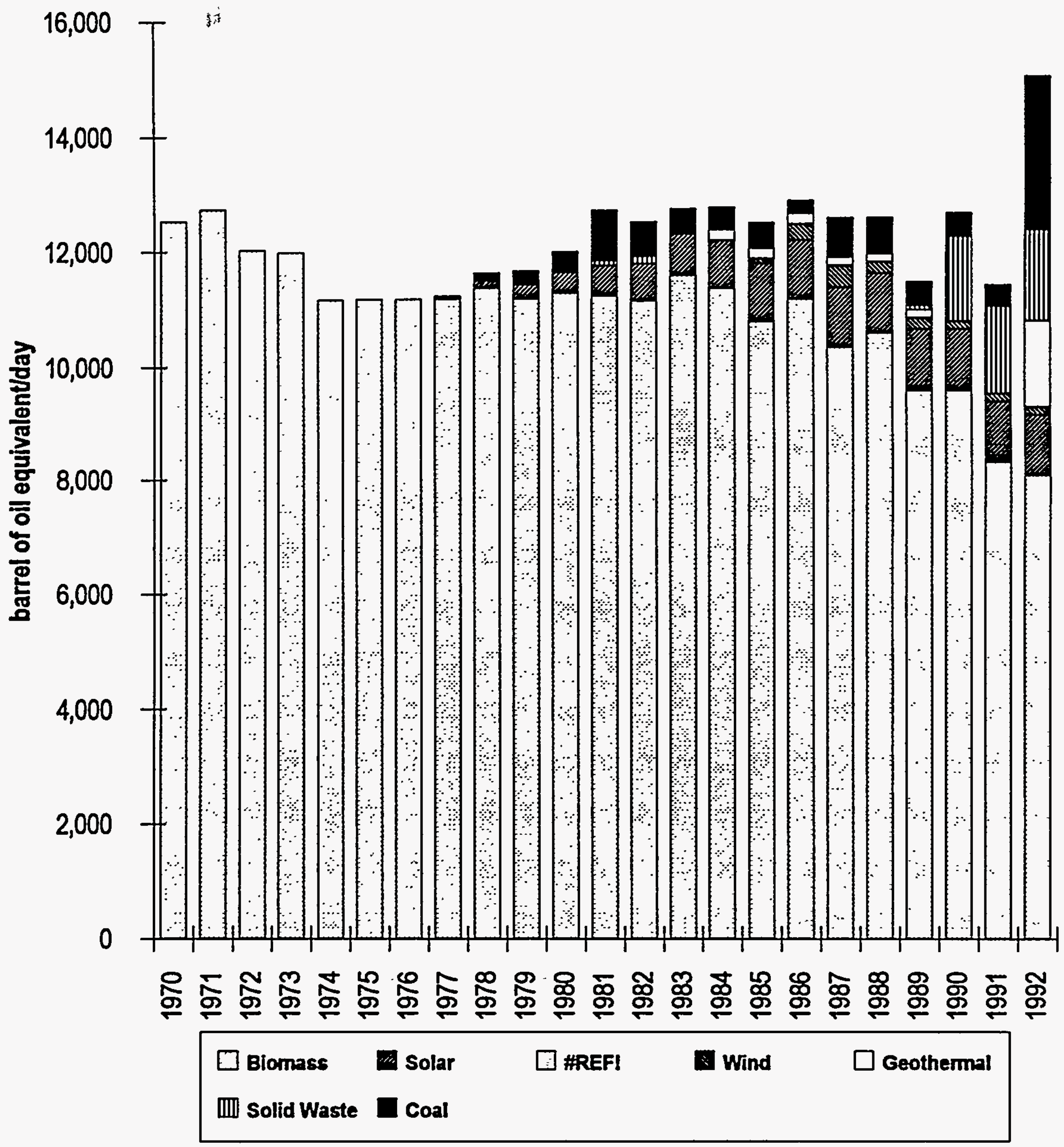


Figure 3. Non-Oil Energy Sources in Hawaii, 1970-1992



Hawaii's overall energy structure is presented numerically in Table 1; the previous figures are derived from this data series. Despite the progress made in promoting non-oil energy, oil remains Hawaii's chief fuel. The United States as a whole is considered an oil-dependent economy. Japan is considered even more oil-dependent, particularly since almost all of its oil supply is imported. In comparison to Hawaii, what role does oil play in the energy demand pattern of these two countries? Figure 4 answers this question. In the United States as a whole, oil accounts for 40 percent of the primary energy mix. In Japan, oil's share is around 57 percent. Natural gas, coal, nuclear, and hydro all play a much larger role in these countries than in Hawaii. Among the oil-dependent economies, Hawaii can claim to be a leader. The reasons for this are myriad and complex; the situation cannot be explained by theories about a conspiracy by "Big Oil." We will discuss the reasons further in Chapter III (Substitutability of Fuels) below.

B. Energy and Oil Intensities

Energy is *the* vital input for economic activity and growth. Without energy, our economies would grind to a halt. We have established that Hawaii's economy is highly dependent on oil and energy. When reductions in energy use are accomplished through increases in efficiency, the economy may continue to expand despite reductions in energy use. When a short-term event, such as an oil price shock, causes a drop in energy use, there may be temporary reductions in economic output as well. So, while the connection between energy input and economic output is not necessarily one-to-one, the links are nonetheless extremely strong, and at this point in history it is not possible to make severe changes in one without affecting the other. A sharp drop in energy use may cut more than fat from the system; at some point, it may cut into the meat of the economy.

1. External Events and Energy Use in Hawaii

There does appear to be some price sensitivity in Hawaii's oil market, though perhaps not a great deal. Figure 5 traces the course of oil and total energy demand in Hawaii since

Table 1. Hawaii's Overall Energy Structure, 1970-92

Barrels of Oil Equivalent per Day

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Oil	93,224	100,623	103,223	105,817	100,336	100,894	101,907	108,552	110,386	119,550	117,205	118,367	117,758	120,730	119,591	115,294	116,962	123,477	134,002	139,520	135,174	139,456	133,761
Coal	0	0	0	0	0	0	0	28	130	240	359	871	592	442	394	445	231	693	629	406	415	373	2,677
Biomass	12,530	12,735	12,037	11,996	11,174	11,178	11,178	11,178	11,364	11,178	11,271	11,220	11,141	11,574	11,348	10,779	11,163	10,332	10,576	9,554	9,554	8,289	8,050
Solar	0	0	0	0	0	0	0	28	130	240	359	521	632	711	824	993	1,008	1,021	1,021	1,086	1,090	1,071	1,078
Hydro	512	419	419	466	466	419	466	419	419	419	419	343	509	413	363	457	492	450	458	474	498	466	497
Wind	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	281	384	195	195	135	143	135
Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	186	186	186	140	140	140	0	0	1,524
Solid Waste	0	0	0	0	0	0	0	0	0	0	0	93	140	0	0	0	0	0	0	69	1,453	1,528	1,555
Total	106,266	113,778	115,679	118,279	111,976	112,491	113,551	120,204	122,429	131,628	129,612	131,414	130,771	133,870	132,707	128,234	130,324	136,497	147,022	151,443	148,319	151,325	149,276

% of Total By Type

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Oil	87.7	88.4	89.2	89.5	89.6	89.7	89.7	90.3	90.2	90.8	90.4	90.1	90.0	90.2	90.1	89.9	89.7	90.5	91.1	92.1	91.1	92.2	89.6
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.7	0.5	0.3	0.3	0.3	0.2	0.5	0.4	0.3	0.3	0.2	1.8
Biomass	11.8	11.2	10.4	10.1	10.0	9.9	9.8	9.3	9.3	8.5	8.7	8.5	8.5	8.6	8.6	8.4	8.6	7.6	7.2	6.3	6.4	5.5	5.4
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.5	0.6	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7
Hydro	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1
Geothermal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	1.0
Solid Waste	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: DBED State Data Book, issues from 1970-1991. 1991 is preliminary from State Energy Resources Coordinator Report.

Unpublished HSPA data used for biomass figures 1989-92. Unpublished H-Power data used for MSW figures.

Oil figures are converted into barrels of oil equivalent/day from product demand totals, State Energy Resources Coordinator's Report 1992, supplemented by EWC.

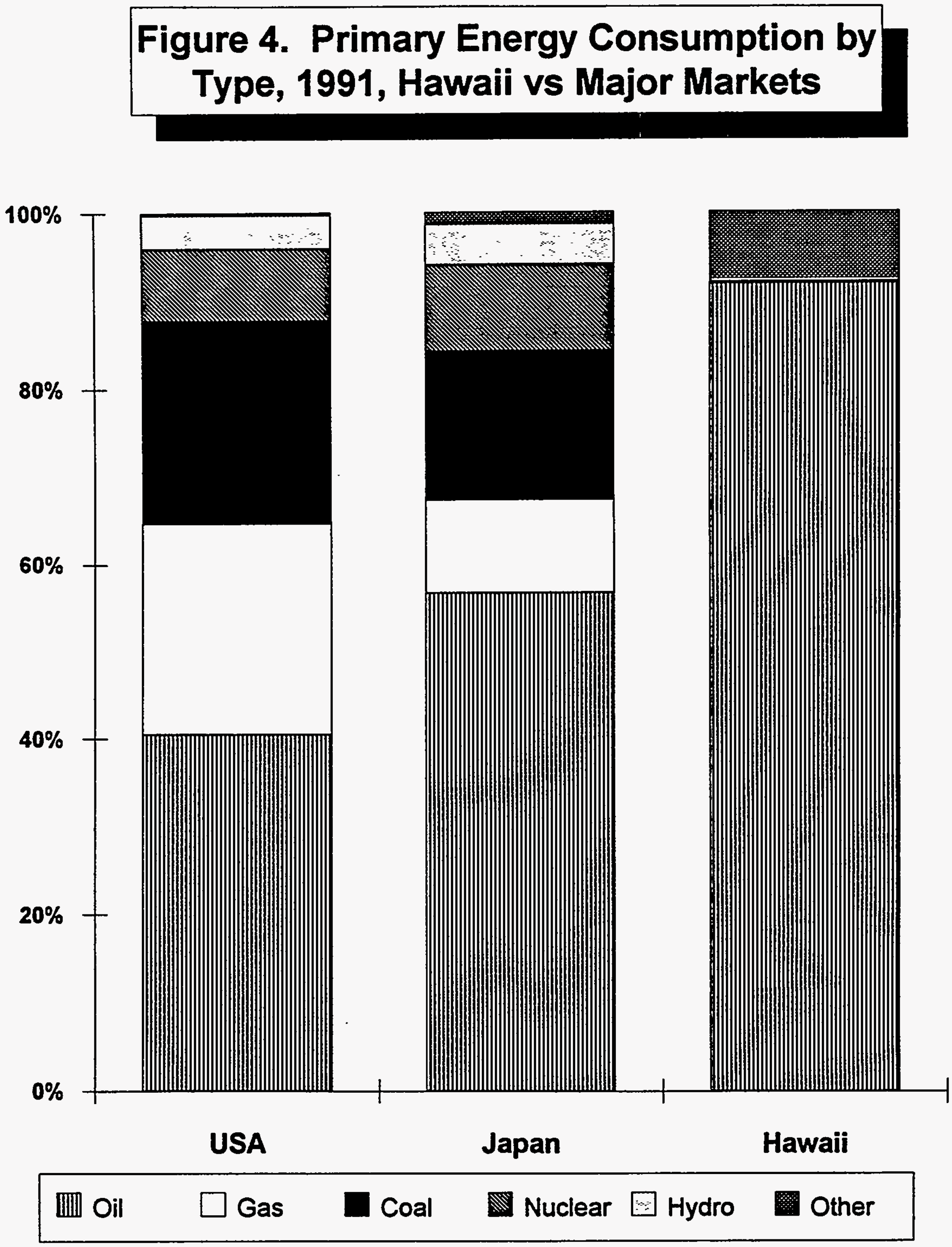
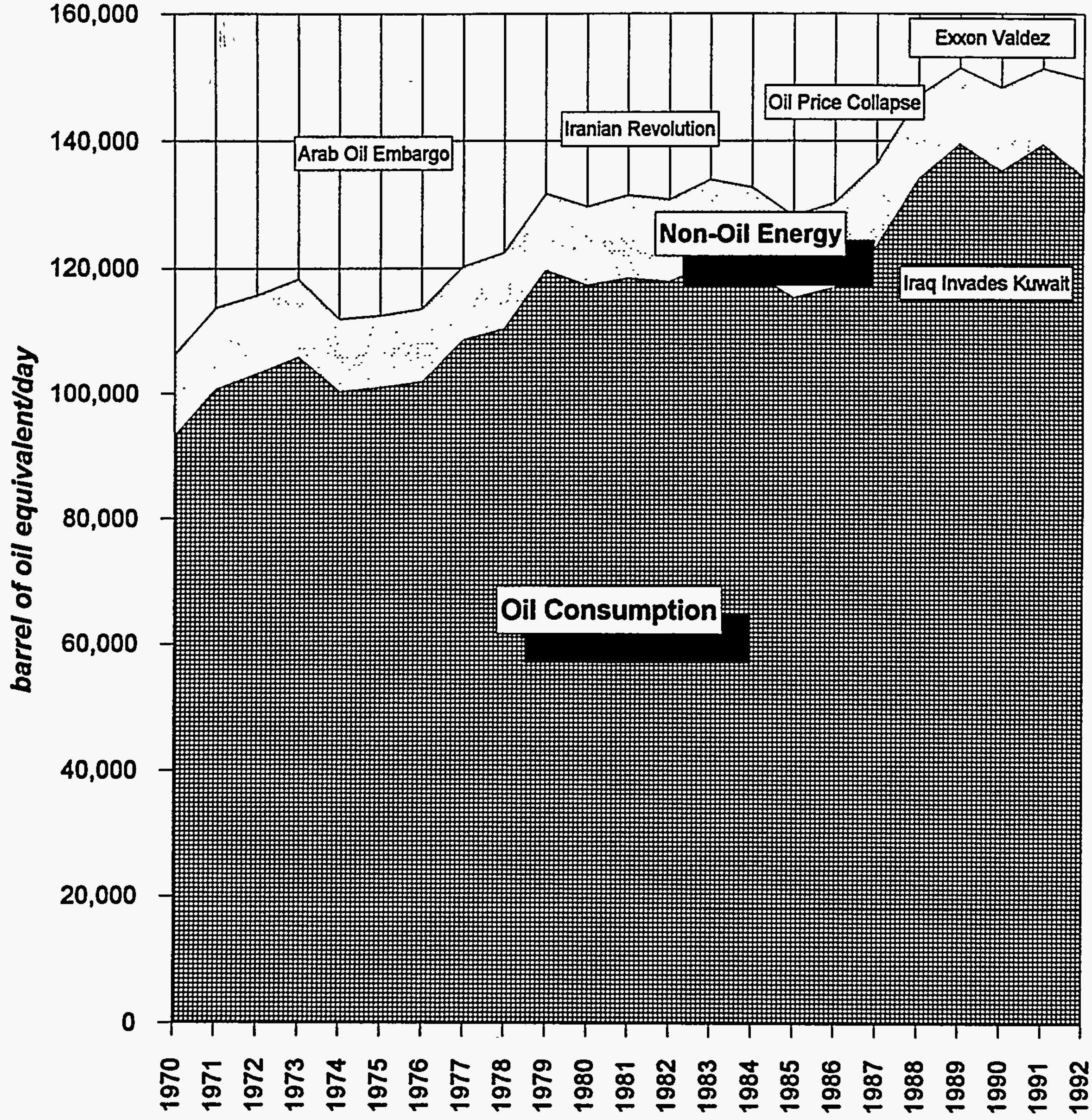


Figure 4. Primary Energy Consumption by Type, 1991, Hawaii vs Major Markets
100%
80%
60%
40%
20%
0%
USA
Japan
Hawaii
Oil
Gas
Coal
Nuclear
Hydro
Other

Figure 5. Major World Events and the Overall Trend in Hawaii Oil and Non-Oil Energy Consumption, 1970-92



1970, relating demand to key events in the world oil market. The first oil price shock occurred in conjunction with the Arab-Israeli War of 1973-74. Internationally, the price of oil went from around three dollars per barrel ($3/b) to $5/b, then to over $11/b in rapid succession. Oil demand dropped in Hawaii by around 5 percent from 1973 to 1974. Did non-oil substitutes leap in to take up the slack? Referring back to Table 1 and Figure 3, it can be seen that they did not. In fact, non-oil energy use also actually decreased. The mid-1970s was a period of economic recession; the drop in oil demand was largely a function of economic downturn, not conservation, fuel switching, or efficiency gains.

The economy began to recover late in the decade, and oil demand began to expand, when the Iranian Revolution in 1979 sparked the second oil price shock. International prices doubled from $17/b to $34/b and approached $40/b on the spot market. Oil consumption in Hawaii dropped between 1979 and 1980, but only by around 2 percent. After this second price shock, however, *non-oil* energy use did not decrease; the first oil price shock changed the psychology of the market, and by the time the second shock hit, there were more non-oil sources ready for deployment. In Hawaii, the 1970s laid the groundwork for the expanded use of alternatives in the 1980s: solar, wind, geothermal, solid waste, and coal.

Price volatility works in both directions, however. The OPEC members were largely in disarray during the 1980s and found themselves unable to support the high price levels. Prices had remained at around $28/b during the 1983-85 period. Worldwide, demand for OPEC oil fell during the first half of the 1980s. There were three main causes: worldwide conservation, fuel switching, and development of oil resources in non-OPEC regions (such as Alaska and the North Sea.) In 1986, the price of oil collapsed, falling to around $12/b in the second quarter. In some areas, spot prices were below $10/b. As discussed in Task I of this report, these prices in real terms were the cheapest the world had seen since before the Arab oil embargo of 1973-74. Somewhat unsurprisingly, oil use began to grow, increasing by over 5 percent between 1986 and 1987, then by over 8 percent between 1987 and 1988, then by another 4 percent in the next year before levelling off. The *Exxon Valdez* oil spill in March 1989 caused a only slight upward price movement, but it had a major impact on consumer perceptions. In 1990, Iraq invaded Kuwait, causing oil prices to move up to around $28 from a prior level of only around $17. Operation "Desert Storm" was over quickly in early 1991; prices soon subsided and have remained in the $15-$20 range ever since—which, we emphasize once again, is cheaper than pre-1974 prices in real terms.

2. Key Economic and Energy/Electricity Indicators

While it may appear that little progress has been made in reducing oil dependence, it is clear that energy and oil are being used more effectively in the Hawaii economy. One of the simplest ways to measure oil and energy intensity in the economy as a whole is to measure the amount of energy or oil needed to produce a unit of economic output, such as the gross state product (GSP). Key energy and economic indicators, 1970 to 1979 and 1980 to 1992, are presented in Tables 2 and 3. Figure 6 measures the amount of oil and the amount of total energy, in thousand barrels of oil equivalent per day (mboe/d), that were consumed in producing each unit of one million dollars GSP (in constant 1982 dollars.) The downward trend is a strong indicator of increased efficiency. In 1970, around 10,000 barrels of oil equivalent per day (boe/d) were consumed for each million dollars GSP; by 1986, the figure had fallen to around 7,000 boe/d. GSP output grew at average annual rates of around 4.4 percent during the 1970s, while energy use grew by only 1.5 percent per year. In the 1980s, the GSP increased at rates of 3.1 percent per year, while energy demand grew at 1.4 percent per year.

The oil price collapse in 1986 may have set back some of the efficiency gains, since demand rose significantly, but in general the trend is down. There is a slight divergence visible, however, in 1992 between oil and non-oil intensity. It is known that in this year, a considerable amount of coal entered the power sector, displacing some oil; it is not known whether this has actually reversed the efficiency trend, however, since there is some debate about the accuracy of the interim GSP figures for 1992. The 1992 GSP figures used were derived from estimates of tourist arrivals that are still a topic of debate, since in 1992 there was a change in the survey used aboard incoming aircraft to measure tourist

Figure 6. Oil and Overall Energy Intensity in the Hawaii Economy, 1970-92

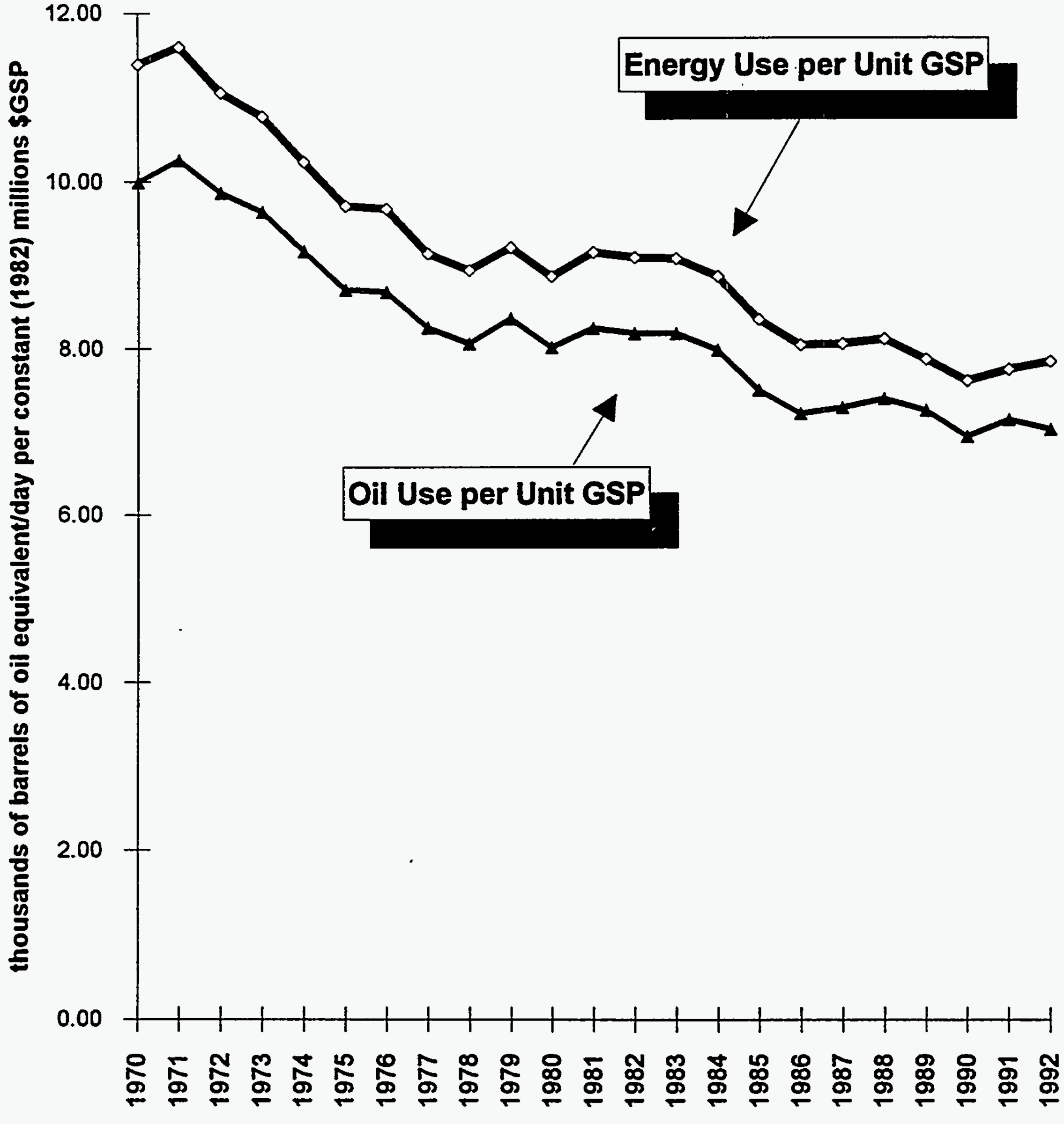


Table 2. Key Energy and Economic Indicators in Hawaii, 1970-79

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	AAGR 1970-79
Constant (1982) million $GSP	9,325	9,807	10,465	10,982	10,949	11,597	11,746	13,168	13,706	14,309	4.38%
Energy Use (mboe/d)	117,119	124,450	126,366	129,749	123,470	123,518	125,614	134,283	134,841	135,921	1.50%
Population	798,600	833,100	869,800	901,300	923,700	943,500	970,300	992,300	1,014,300	1,042,700	2.70%
GSP/Capita	$11,676	$11,771	$12,031	$12,185	$11,853	$12,291	$12,106	$13,270	$13,513	$13,723	1.63%
Energy Use (boe/d) per Capita	146.7	149.4	145.3	144.0	133.7	130.9	129.5	135.3	132.9	130.4	-1.17%
Utility Electricity Sales (MWh)	3,758,094	4,167,127	4,562,568	4,867,850	5,113,906	5,334,755	5,615,210	5,831,610	6,004,891	6,197,426	5.13%
KWh/Capita	4,706	5,002	5,246	5,401	5,536	5,654	5,787	5,877	5,920	5,944	2.36%

Trends in Key Indicators, 1970=1

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
GSP (1982$)	1	1.05	1.12	1.18	1.17	1.24	1.26	1.41	1.47	1.53
Energy Use	1	1.06	1.08	1.11	1.05	1.05	1.07	1.15	1.15	1.16
Population	1	1.04	1.09	1.13	1.16	1.18	1.22	1.24	1.27	1.31
GSP/Capita	1	1.01	1.03	1.04	1.02	1.05	1.04	1.14	1.16	1.18
Energy/Capita	1	1.02	0.99	0.98	0.91	0.89	0.88	0.92	0.91	0.89
Electricity Sales	1	1.11	1.21	1.30	1.36	1.42	1.49	1.55	1.60	1.65
Electricity/Capita	1	1.06	1.11	1.15	1.18	1.20	1.23	1.25	1.26	1.26

Source: Population and GSP figures per DBEDT, State of Hawaii Data Book (various issues). Energy data supplemented by EWC estimates
mboe/d = thousand barrels oil equivalent/day

Table 3. Key Energy and Economic Indicators in Hawaii, 1980-92

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	AAGR 1980-89	AAGR 1990-92
Constant (1982) million $GSP	14,639	14,384	14,412	14,778	15,006	15,394	16,241	16,976	18,155	19,280	19,526	19,573	19,084	3.11%	-1.14%
Energy Use (mboe/d)	133,504	131,828	130,783	133,894	132,680	128,679	130,622	136,497	147,022	151,443	148,319	151,325	149,276	1.41%	0.32%
Population	1,054,300	1,062,500	1,084,600	1,109,300	1,130,600	1,138,000	1,167,500	1,186,600	1,200,600	1,245,500	1,257,600	1,277,600	1,300,600	1.87%	1.70%
GSP/Capita	$13,885	$13,538	$13,288	13,322	13,273	13,527	13,911	14,306	15,122	15,480	15,526	15,320	14,674	1.22%	-2.78%
Energy Use (boe/d) per Capita	126.6	124.1	120.6	120.7	117.4	113.1	111.9	115.0	122.5	121.6	117.9	118.4	114.8	-0.45%	-1.35%
Utility Electricity Sales (MWh)	6,345,531	6,424,016	6,332,707	6,425,578	6,606,255	6,635,158	7,025,739	7,298,178	7,719,029	7,970,360	8,311,536	8,524,088	8,666,889	2.57%	2.12%
KWh/Capita	6,019	6,046	5,839	5,792	5,843	5,831	6,018	6,150	6,429	6,399	6,609	6,672	6,664	0.68%	0.41%

Trends in Key Indicators, 1970=1

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
GSP (1982$)	1.57	1.54	1.55	1.58	1.61	1.65	1.74	1.82	1.95	2.07	2.09	2.10	2.05
Energy Use	1.14	1.13	1.12	1.14	1.13	1.10	1.12	1.17	1.26	1.29	1.27	1.29	1.27
Population	1.32	1.33	1.36	1.39	1.42	1.42	1.46	1.49	1.50	1.56	1.57	1.60	1.63
GSP/Capita	1.19	1.16	1.14	1.14	1.14	1.16	1.19	1.23	1.30	1.33	1.33	1.31	1.26
Energy/Capita	0.86	0.85	0.82	0.82	0.80	0.77	0.76	0.78	0.83	0.83	0.80	0.81	0.78
Electricity Sales	1.69	1.71	1.69	1.71	1.76	1.77	1.87	1.94	2.05	2.12	2.21	2.27	2.31
Electricity/Capita	1.28	1.28	1.24	1.23	1.24	1.24	1.28	1.31	1.37	1.36	1.40	1.42	1.42

Source: Population and GSP figures per DBEDT, State of Hawaii Data Book (various issues). Energy data supplemented by EWC estimates

mboe/d = thousand barrels of oil equivalent per day.

AAGR = average annual growth rate (%).

arrivals/returning resident arrivals. If the figures are correct, then the GSP declined by 1.1 percent per year between 1990 and 1992, while energy demand grew at a rate of 0.3 percent, and this translates into the higher energy:GSP ratio.

By indexing the key energy and economic indicators against 1970 as a base year, it is possible to see the longer term trends. Figure 7 depicts these trends. GSP growth was sluggish in the early 1970s, picked up in the late 1970s, fell off again after the 1979-80 oil price shock, then began to expand again during the latter half of the 1980s before levelling off in the 1989-92 period. The growth in GSP, however, has been more rapid than growth in population and energy use. Accordingly, GSP per capita and GSP per unit energy consumed have increased. Population growth has outstripped energy demand growth, so per-capita energy use has declined. In 1970, per-capita energy use stood at around 147 boe/d. During the decade, this dropped at rates averaging around 1.2 percent per year, so that by 1979 the figure had fallen to around 130 boe/d. The decline continued at average annual rates of around 0.5 percent during the 1980s, resulting in a per-capita energy use figure of around 122 boe/d by 1989. The estimates for 1992 place the figure at around 115 boe/d.

In contrast, electricity intensity has been on an upward trend. Figure 8 displays trends in electricity and economic indicators. Utility electricity sales grew at the rapid rate of 5.1 percent per year during the 1970s and around 2.6 percent per year during the 1980s. The rates of growth in electricity sales outpaced both population growth and GSP growth over the past two decades. Electricity consumption per capita increased from around 4,700 kilowatt-hours per capita (kWh/capita) in 1970 to over 5,940 kWh/capita in 1979, reaching 6,400 kWh/capita in 1989 and an apparent 6,664 kWh/capita in 1992. Since electricity is such a major user of fossil energy and is an important form of consumer energy, a separate section below is devoted to the electric power sector.

C. Utilization by Economic Sector

It is clear that Hawaii is vitally dependent on petroleum. Since petroleum lends itself so well to the production of liquid transport fuels, it should surprise no one that the bulk of

Figure 7. Trends in Key Energy and Economic Indicators in Hawaii, 1970-92

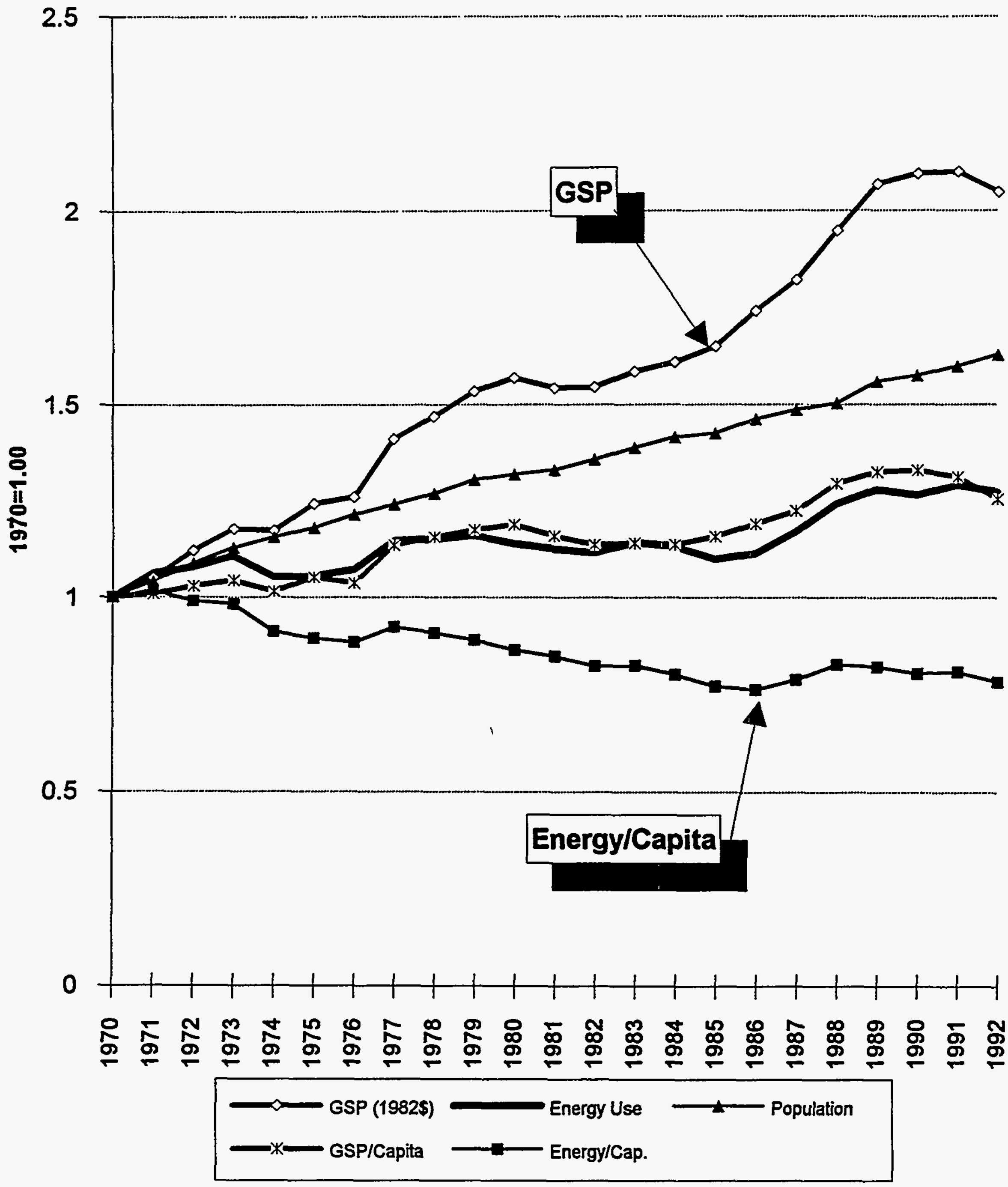
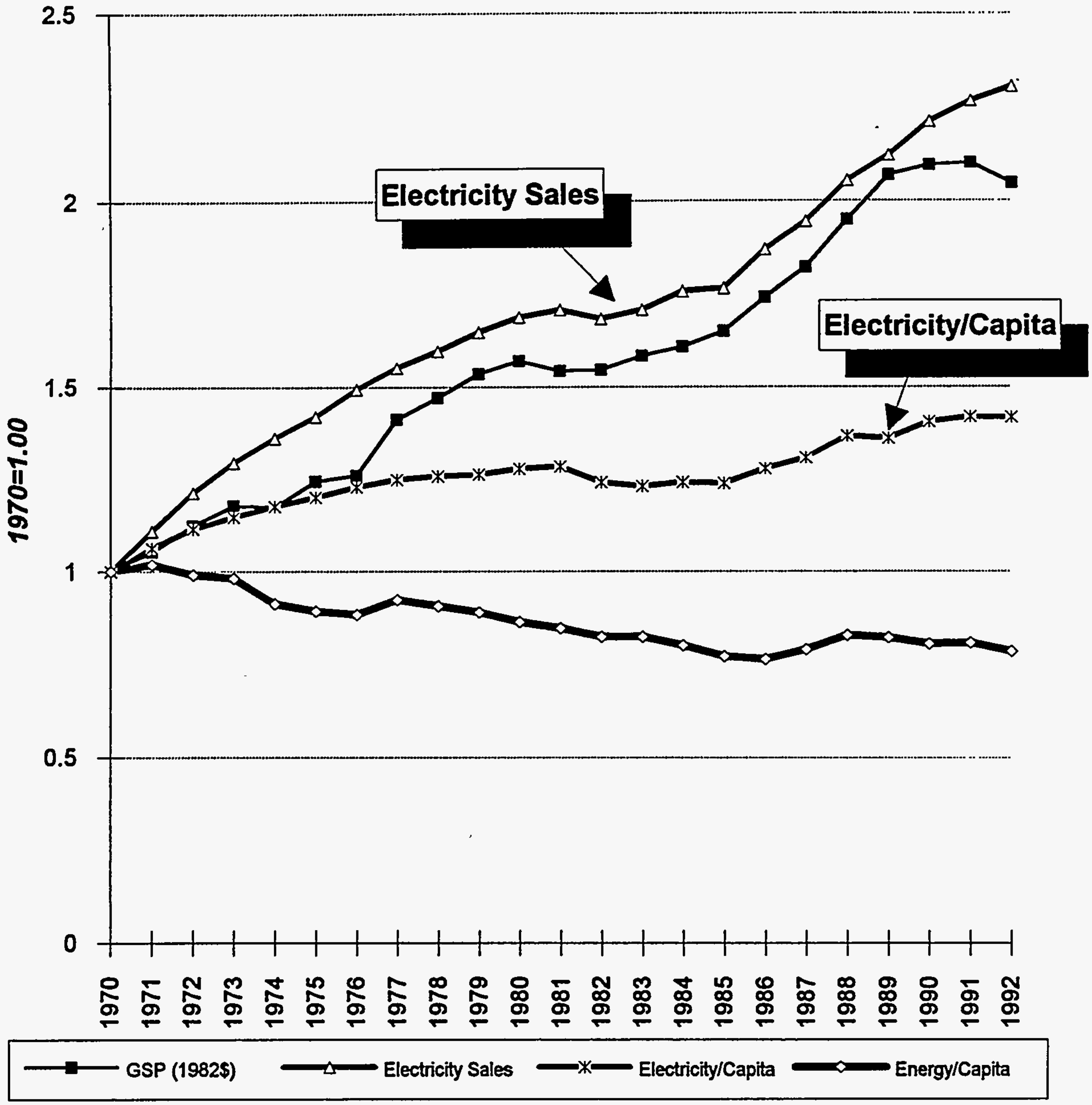


Figure 8. Trends in Key Electricity/Economic Indicators in Hawaii, 1970-92



Hawaii's energy use takes place in the transport sector. Figure 9 illustrates the dominance of the transport sector in the overall end-use picture, with numerical data presented in Table 4. The transport sector generally accounts for 50-60 percent of Hawaii's energy use, followed by the industrial sector with a share of around 25 percent, the commercial sector (10-15 percent in recent years), and the residential sector (around 10 percent). Total energy inputs to electricity production are also disaggregated from the totals; around 30 percent of the energy use goes toward producing electricity. If we combine the electricity sector with the transport sector, we account for around 80 percent of Hawaii's energy use.

The importance of these end-use sectors cannot be overstated when the ultimate goal is developing an energy strategy that involves conservation, efficiency improvements, and fuel substitution. We *must* know where the energy is going to be able to identify appropriate targets for future demand-side management (DSM) or fuel substitution strategies. We *must* know where the energy is going in order to determine the constituencies that may be affected by changes in energy policy and/or prices. It is common-sensical that not all energy uses are easily interconvertible; within the framework of Hawaii's energy market, which ones are? And where are our state's efforts best spent? For example, we can see that the residential sector is responsible for only around 10 percent of Hawaii's energy use, and Hawaii is widely noted as the lowest residential energy user in the nation (largely because there is no home-heating demand). Should the cornerstone of our energy policy be home energy conservation? Probably not. We do feel that residential energy conservation is a worthwhile facet of any energy policy, but residential energy consumers will not be able to change Hawaii's energy problems on their own. In terms of setting priorities and having an actual impact on total energy use, it seems clear that the state will have to look to making improvements in the larger end-use sectors.

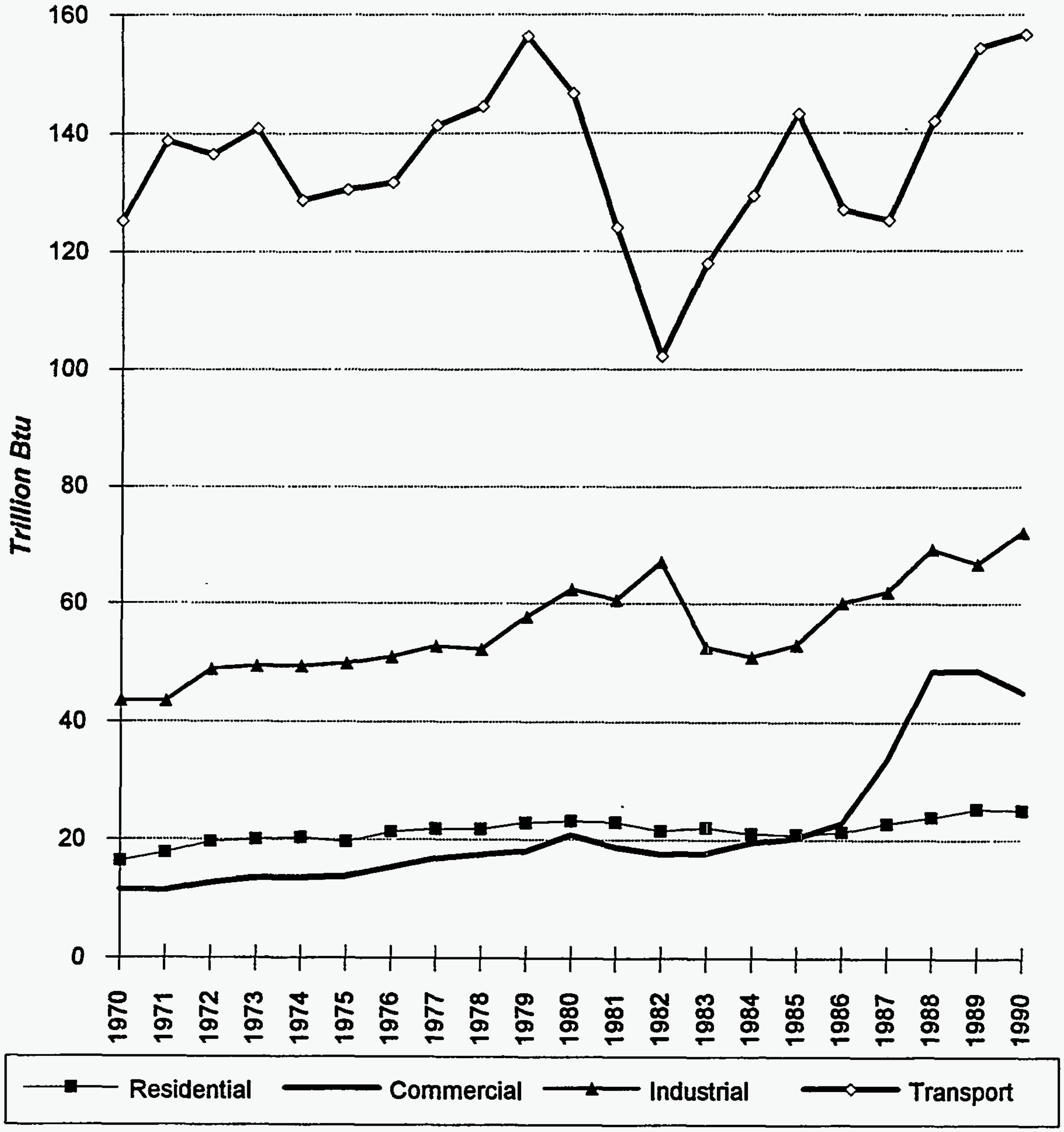
In the pages that follow, we will trace the course of petroleum product consumption and end-use patterns for each main fuel and sector, then we will examine end-use patterns by county. We will adopt 1992 as a base year for analysis in Chapter III (Substitutability of Fuels) below.

Table 4. Consumption of Energy by End Use Sector in Hawaii, 1970-90
(trillion Btu)

							% Shares by Sector					
	Residential	Commercial	Industrial	Transport	*Input to Electricity*	TOTAL	Resid.	Comm'l	Ind.	Transp.	*Input to Electricity*	% Share, Transp+Elec
1970	16.4	11.6	43.6	125.3	43.2	196.9	8%	6%	22%	64%	22%	86%
1971	17.8	11.4	43.5	138.8	47.7	211.5	8%	5%	21%	66%	23%	88%
1972	19.6	12.7	48.9	136.5	54.1	217.7	9%	6%	22%	63%	25%	88%
1973	20	13.5	49.4	140.9	55.6	223.8	9%	6%	22%	63%	25%	88%
1974	20.3	13.5	49.4	128.7	57.5	211.9	10%	6%	23%	61%	27%	88%
1975	19.6	13.8	49.9	130.5	58.8	213.8	9%	6%	23%	61%	28%	89%
1976	21.3	15.3	51	131.7	62.5	219.3	10%	7%	23%	60%	28%	89%
1977	21.8	16.8	52.7	141.3	65.2	232.6	9%	7%	23%	61%	28%	89%
1978	21.8	17.4	52.2	144.6	66.8	236	9%	7%	22%	61%	28%	90%
1979	22.9	18.1	57.8	156.4	67.7	255.2	9%	7%	23%	61%	27%	88%
1980	23.2	20.8	62.4	146.7	69.7	253.1	9%	8%	25%	58%	28%	85%
1981	23	18.8	60.6	124.1	69.9	226.5	10%	8%	27%	55%	31%	86%
1982	21.5	17.6	67.1	102.2	66.9	208.4	10%	8%	32%	49%	32%	81%
1983	22.1	17.8	52.6	117.9	68.6	210.4	11%	8%	25%	56%	33%	89%
1984	21	19.5	50.9	129.3	70.6	220.7	10%	9%	23%	59%	32%	91%
1985	20.9	20.3	53	143.3	70	237.5	9%	9%	22%	60%	29%	90%
1986	21.3	22.8	60.2	126.9	72.9	231.2	9%	10%	26%	55%	32%	86%
1987	22.8	33.7	62	125.1	76.6	243.6	9%	14%	25%	51%	31%	83%
1988	23.9	48.6	69.3	142	81.9	283.8	8%	17%	24%	50%	29%	79%
1989	25.3	48.8	66.8	154.4	85.8	295.3	9%	17%	23%	52%	29%	81%
1990	25.1	45.1	72.2	156.6	86.1	299	8%	15%	24%	52%	29%	81%

Source: DBET State of Hawaii Databook, citing USDOE/EIA "State Energy Data Report, Consumption Estimates, 1960-1990," (May 1992) pp106-110

Figure 9. Energy Consumption by End-Use Sector in Hawaii, 1970-90



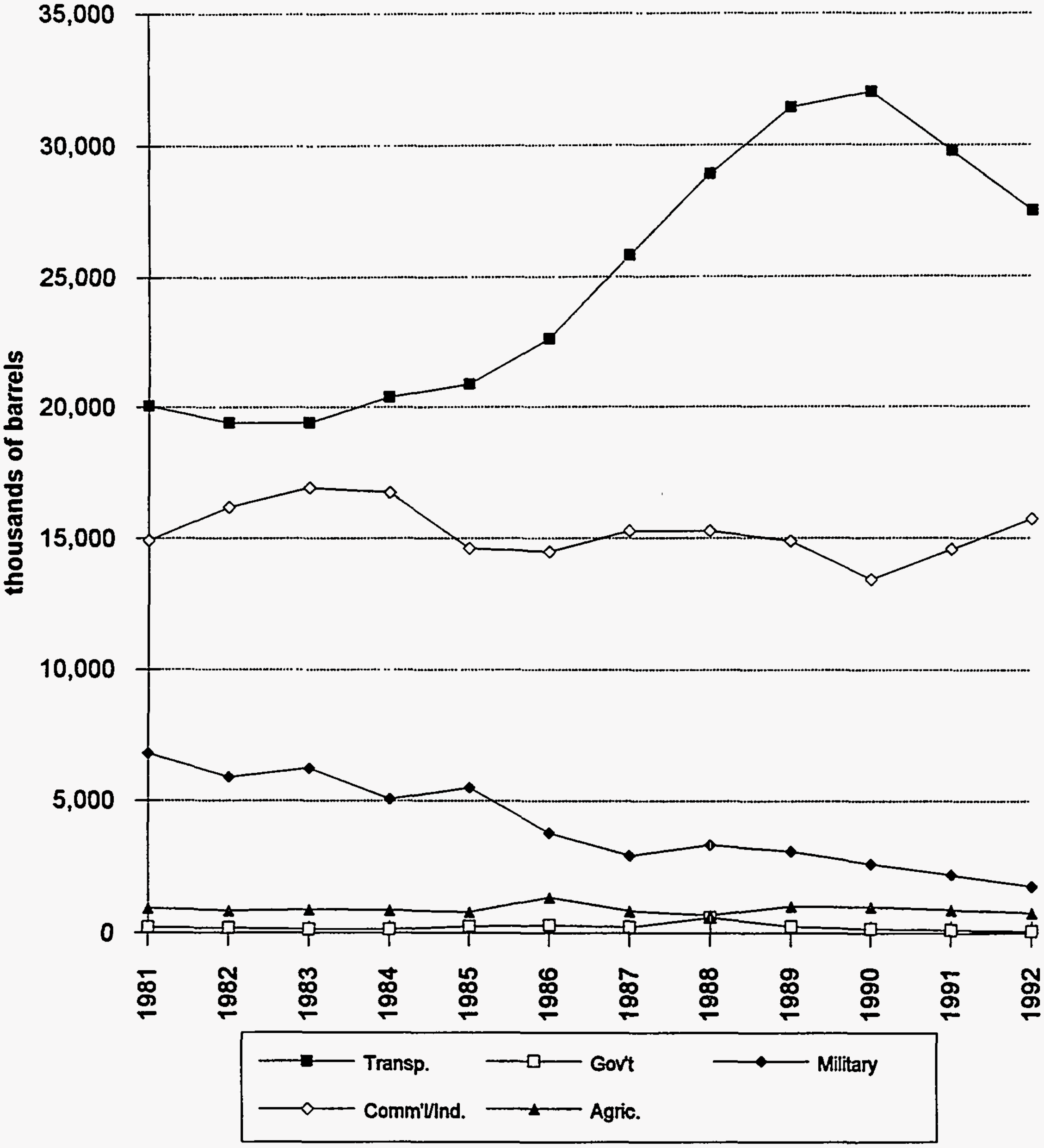
Source: DBEDT State Databook, citing USDOE/EIA

1. Trends in Oil Consumption by End-Use Sector

State of Hawaii energy data is disaggregated into slightly different end-use sectors than those used by the U.S. Department of Energy/Energy Information Administration (USDOE/EIA), which were presented above. Hawaii's end-use categories employed here are transport, commercial/industrial, agriculture, military, and government. For the purposes of this analysis, gasoline and diesel fuel sold on military base exchanges is included in Hawaii's transport sector rather than the military sector, since much of this fuel is used by military personnel, their dependents, and affiliated civilians for personal uses. It can be argued that *all* of this fuel is for personal use, because it is used in privately owned (not government) vehicles. The series used for the following charts was missing complete data for 1991; this year is excluded from the series except in the case of Figure 10, where 1991 is assumed a straight-line interpolation between 1990 and 1992. The overall picture is fairly consistent, however, with a dominant transport sector followed in importance by the commercial/industrial sector (which includes fuel used in the generation of electric power), followed more distantly by the military, with the government and agricultural sectors representing relatively minor amounts of oil consumption. The trend in total consumption by sector is depicted in Figure 11.

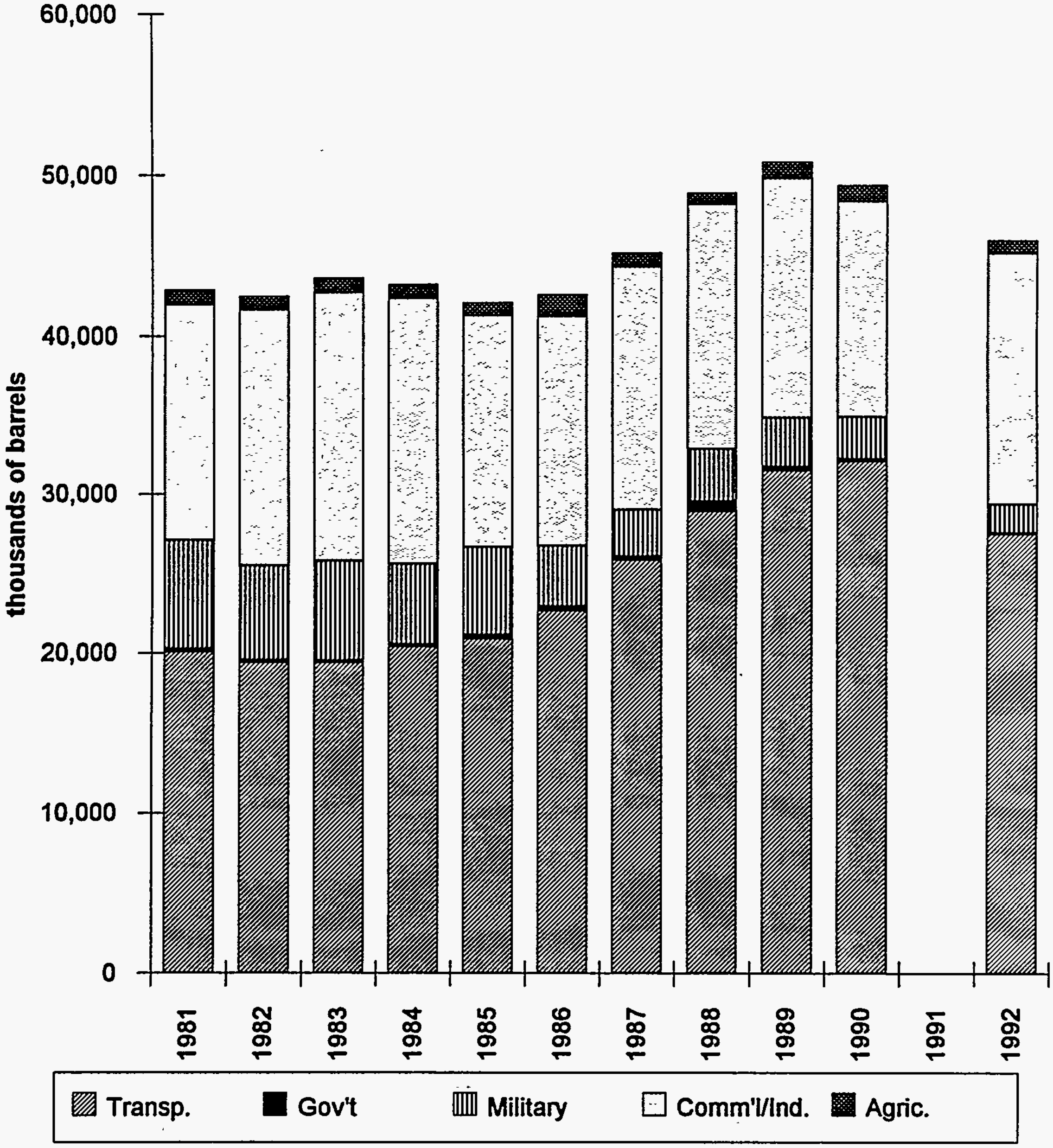
Looking at the four main petroleum products—gasoline, aviation fuels, diesel, and fuel oil—reveals more about Hawaii's oil end uses. Figure 12 presents gasoline consumption by end use. Predictably, the transport sector accounts for the vast majority of gasoline use, though other sectors also use modest amounts. Aviation fuels, presented in Figure 13, are the preeminent transport fuels for Hawaii. The civilian transport sector accounts for the lion's share of fuel use, though the military is also a major consumer of aviation fuels. The military also is the sole consumer of naphtha-type jet fuel, which, having the majority of its constituents in the naphtha boiling range rather than the kerosene boiling range, is a more volatile fuel than commercial jet fuel. This volatility can be a safety hazard, and the military is in fact switching away from naphtha-type jet fuel in favor of kerojet. In the early years depicted in the figure, approximately 15 percent to 20 percent of the aviation fuel was

Figure 10. Trends in Oil Consumption by End Use Sector, 1981-92



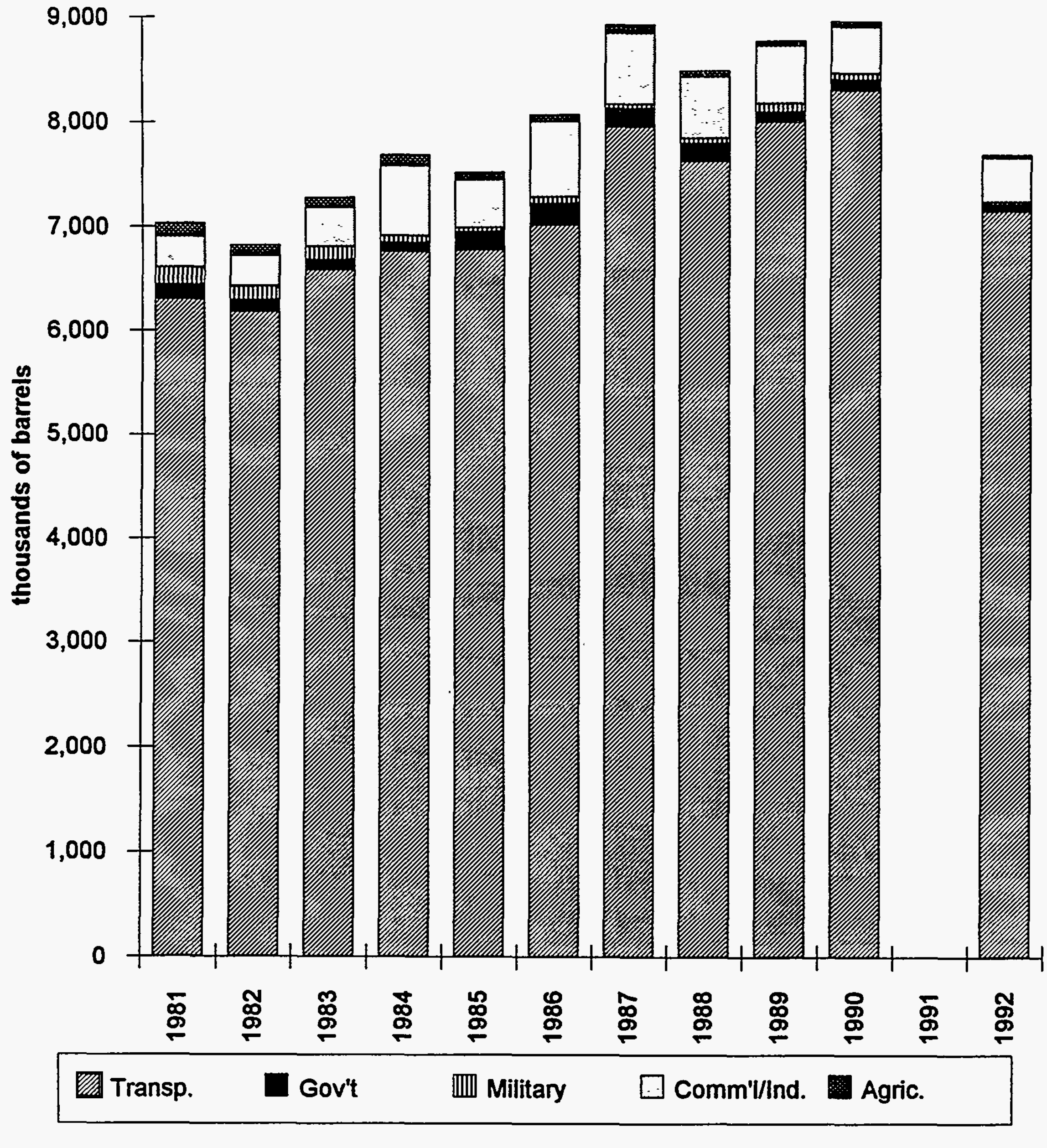
Note: 1991 is included through straight-line interpolation

Figure 11. Oil Products Consumption by End Use Sector, 1981-92



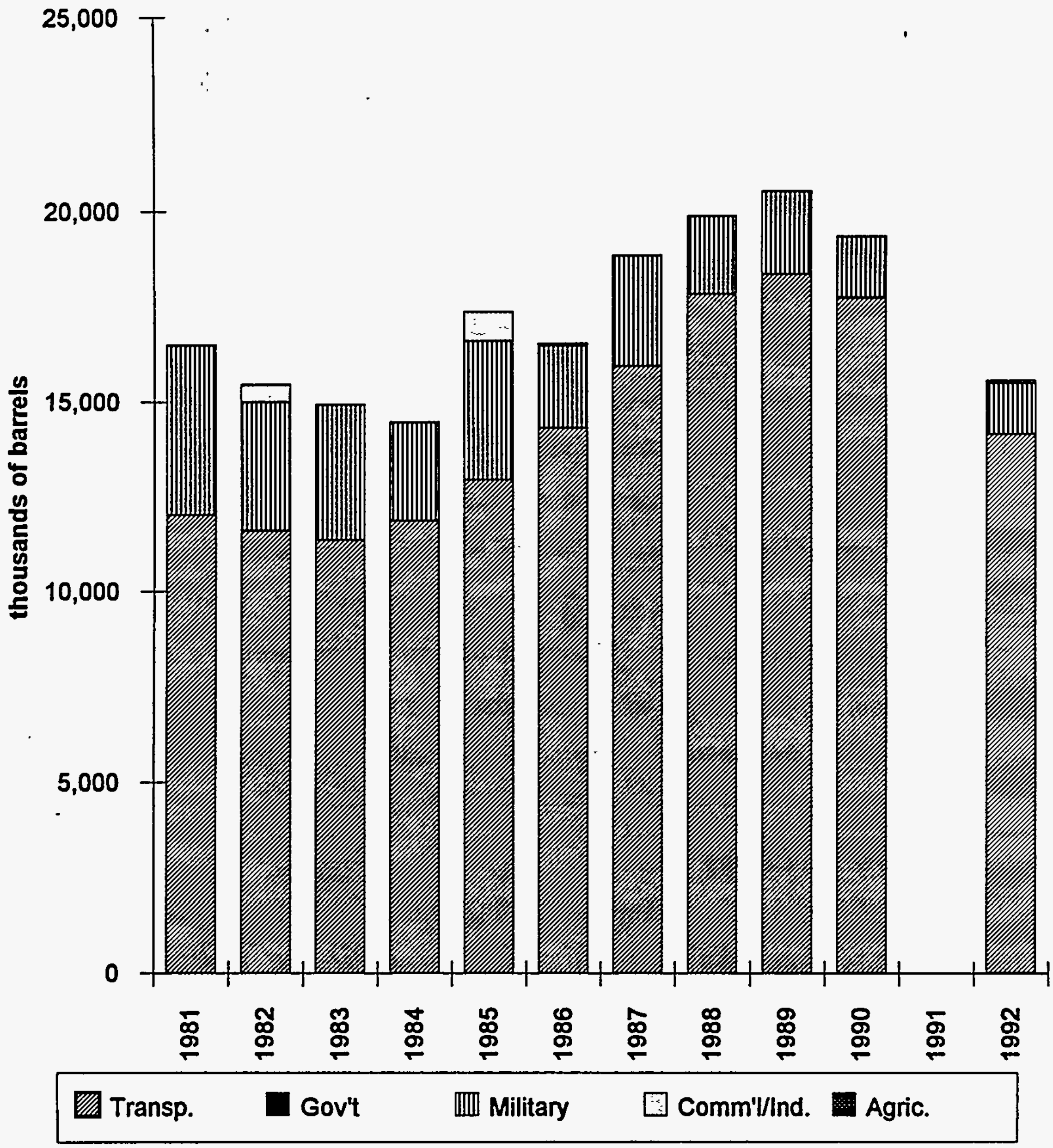
Note: 1991 data not available in consistent format

Figure 12. Gasoline Consumption by End Use Sector, 1981-92



Note: 1991 data not available in consistent format

Figure 13. Aviation Fuels Consumption by End Use Sector, 1981-92



Note: 1991 data not available in consistent format

naphtha-type jet used by the military; in 1992, the phaseout of this fuel was nearly complete, with naphtha-type jet accounting for less than 1 percent of total aviation fuels used.

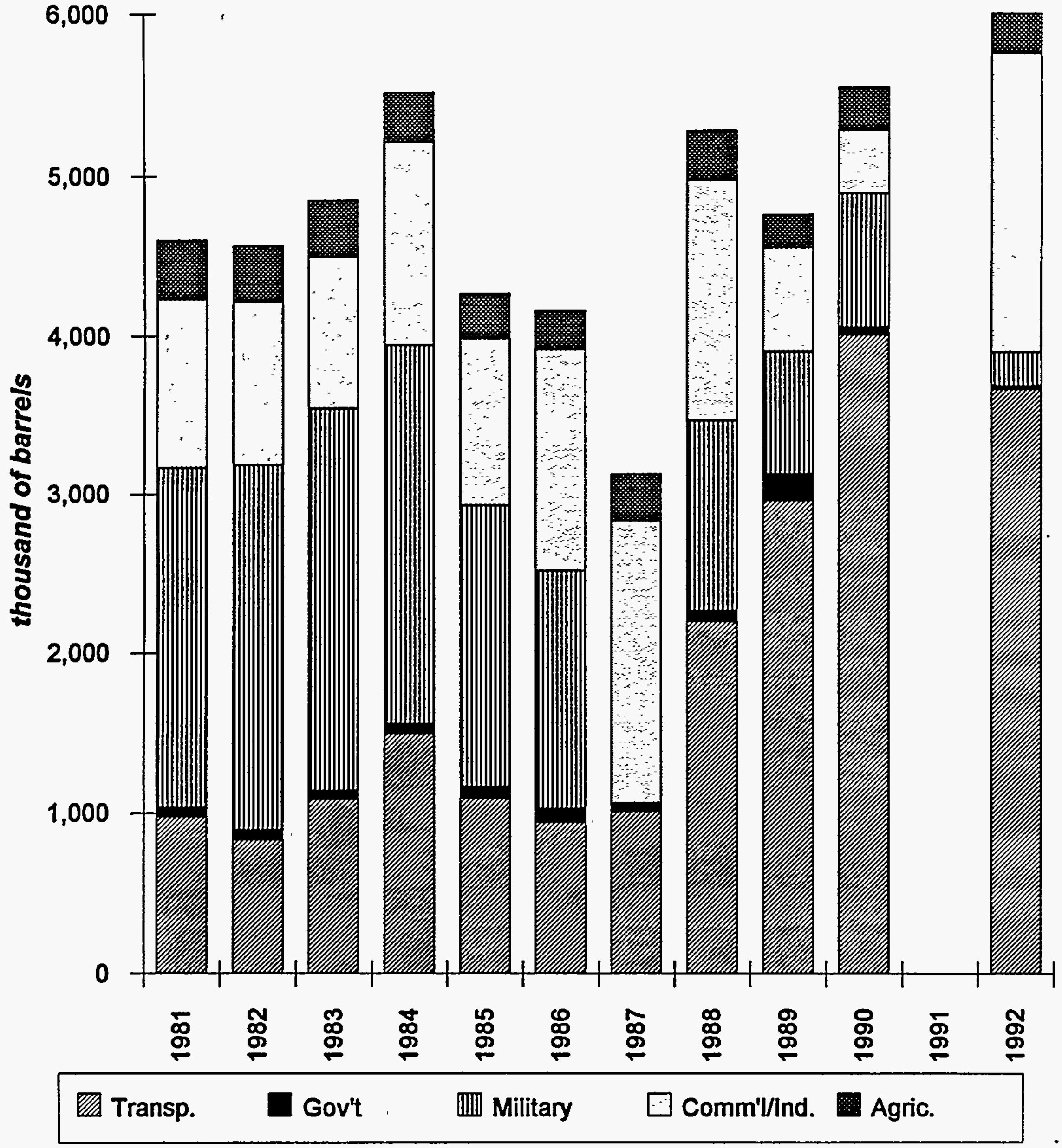
In volume terms, diesel is the least significant of the four main fuels, but it has the most diverse end-use pattern. Figure 14 illustrates that diesel is widely used in commercial/industrial ventures, military activities, transportation, and agriculture. The breakdown has shifted somewhat, with transport uses accounting for a greater share in the 1988-92 period than previously. There is also a noticeable anomaly in 1987, where military use of diesel essentially disappeared, more likely through a mistake in reporting than through any magic. But it does serve to reemphasize that military fuel uses are best considered independent of the civilian market. Diesel is already used fairly widely in the power sector, and this use may expand on the outer islands as a way of reducing interisland shipments of heavy fuel oil, which represents a more severe spill hazard than does diesel. Shippers of heavy fuel oil are concerned about their potential liability under the Oil Pollution Act of 1990. (See the discussion of this issue in section D.3. "The Electric Power Sector" below.)

Figure 15 presents the disposition of residual fuel oil. By far the largest end-use sector is the commercial/industrial sector, which is heavily dominated by electric power generation. In the section below on electricity, we separate oil use in the power sector from other commercial and industrial uses. Transport uses of fuel oil are for ships' bunker fuel, chiefly international bunkers. Fuel oil is also used on sugar plantations, where some subsequently returns to the general energy market via sales of electricity to local utilities.

2. Sectoral Oil Use by County

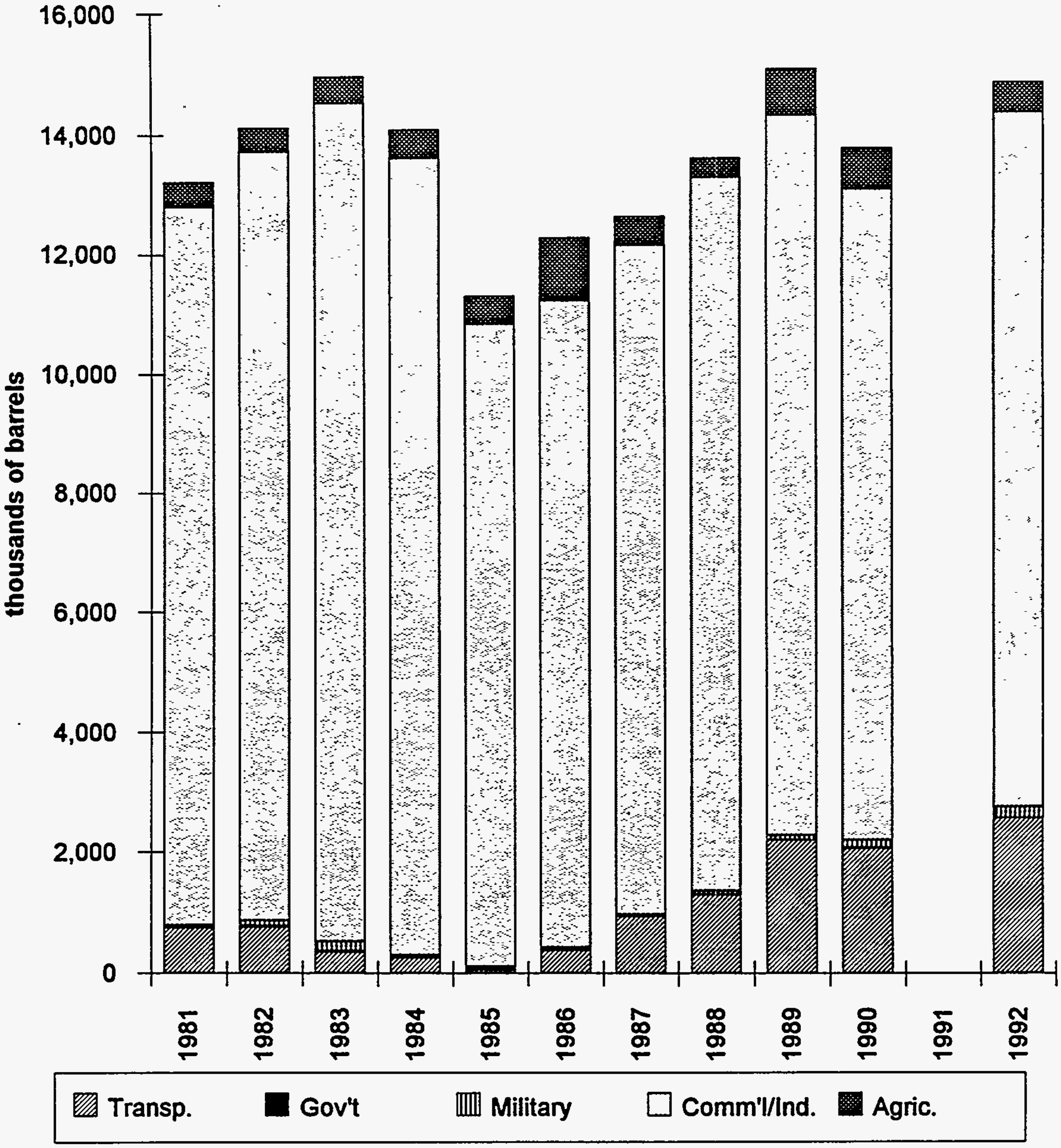
Adopting 1992 as a base year and excluding military fuel use, Figure 16 displays the allocation of petroleum products to Hawaii County end-use sectors. Road transport and the commercial/industrial sector are the main energy users, with smaller amounts of oil flowing to agriculture and air transport. Figure 17 presents the breakdown by product. Gasoline is devoted mainly to road transport, though a small amount is also used by other sectors, including agriculture and water transport (boats with outboard motors). Jet fuels go to air

Figure 14. Diesel Consumption by End Use Sector, 1981-92



Note: 1991 data not available in consistent form

Figure 15. Fuel Oil Consumption by End Use Sector, 1981-92



Note: 1991 data not available in consistent format

Figure 16. Hawaii County Sectoral Fuel Use, 1992

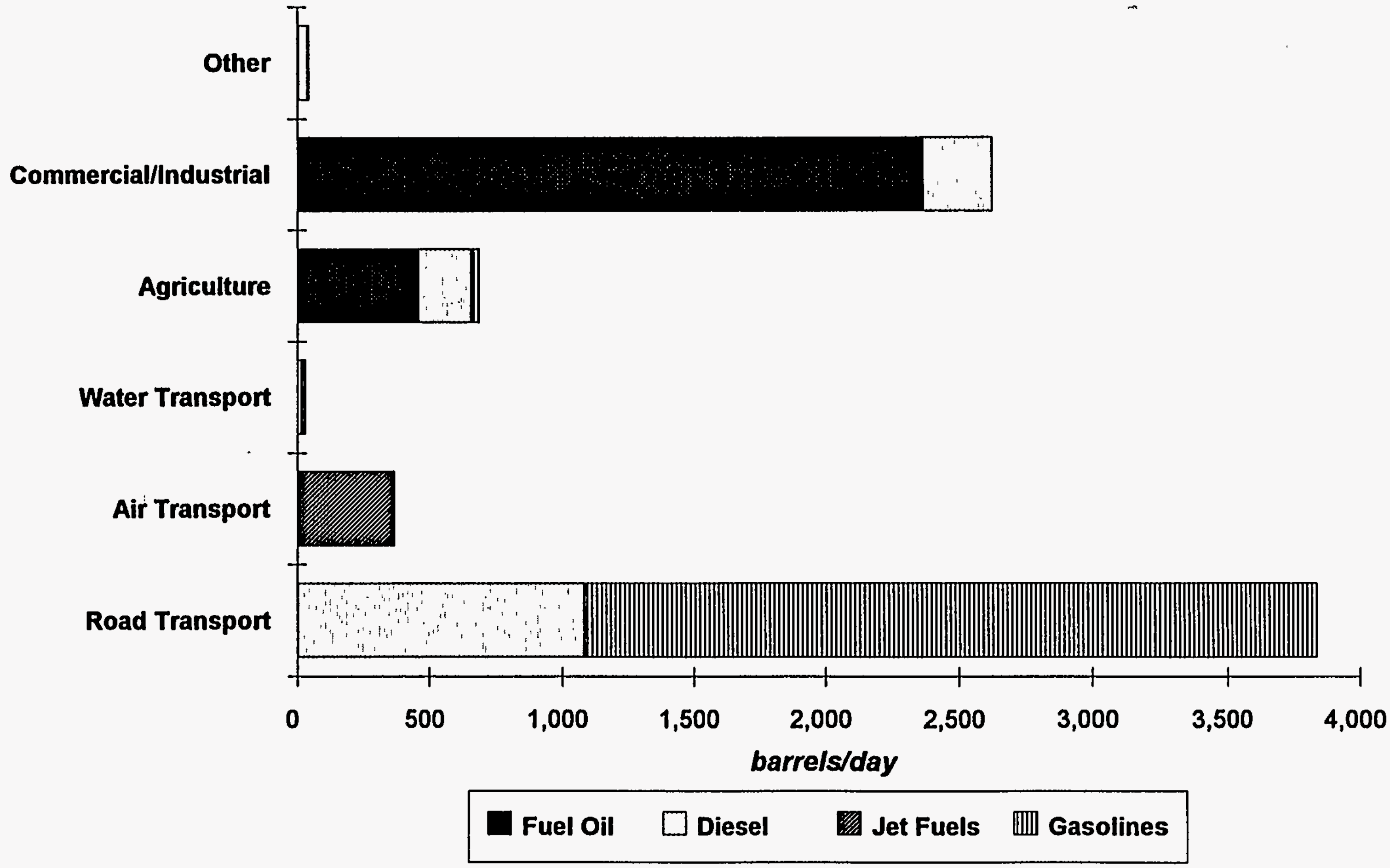
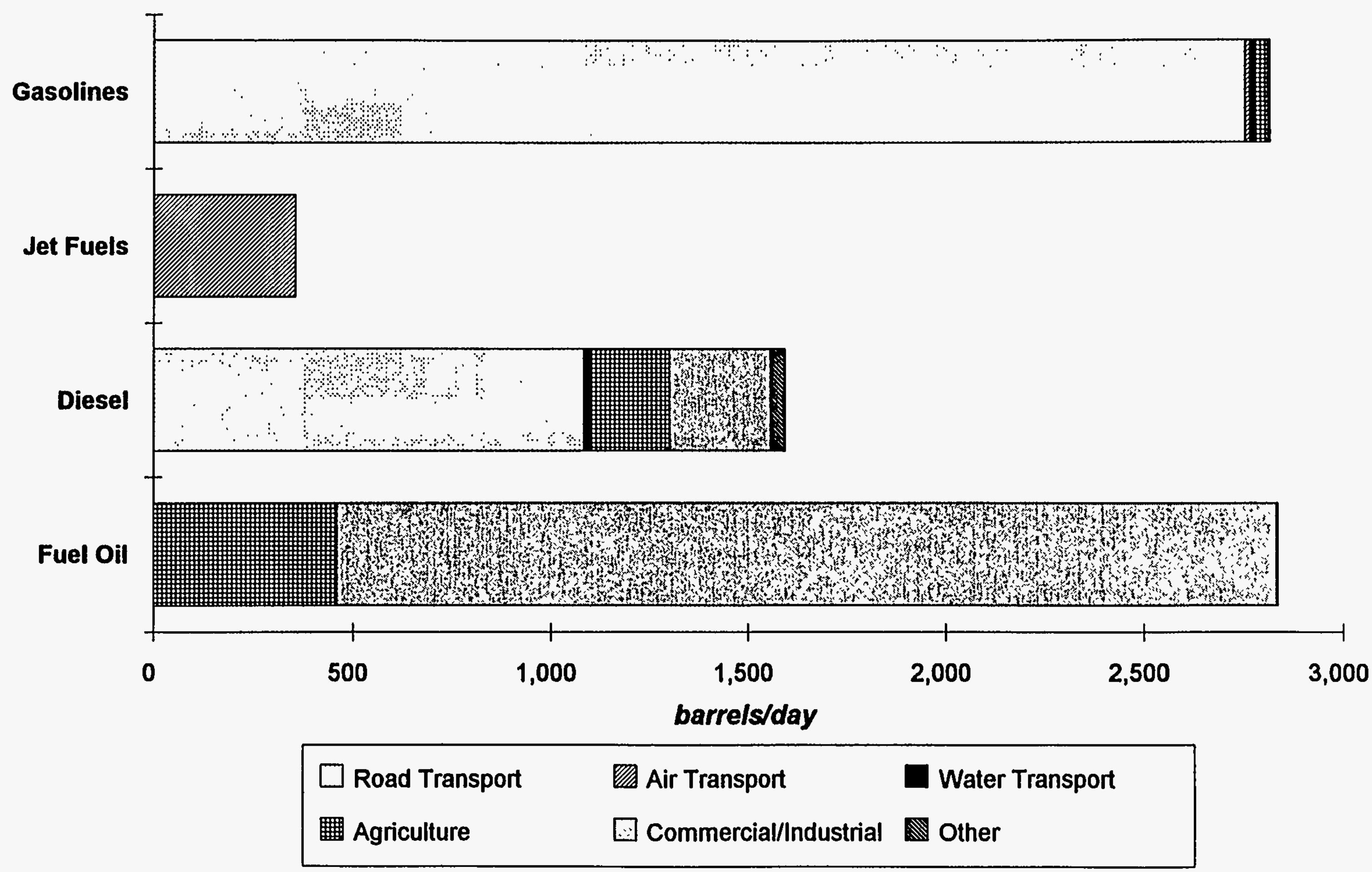


Figure 17. Hawaii County Fuel Use by Sector, 1992



transport. Diesel use is more diverse, reaching all sectors but focusing mainly on road transport and the commercial/industrial sector. Fuel oil use centers on power generation by utilities and by sugar plantations, chiefly Hilo Coast Processing. The sugar plantations use fuel oil, diesel, and coal to supplement bagasse and are net wholesale producers of electricity.

Kauai County's sectoral fuel use is depicted in Figure 18. More than any other county, Kauai's oil use is dominated by road transport. Relatively little oil goes to other sectors: some fuel oil goes to the commercial/industrial sector, some diesel is used by the agricultural sector, and jet fuel is needed for air transport. The breakdown by fuel type appears in Figure 19. Kauai's demand pattern appears lopsidedly weighted toward gasoline and diesel, but one of the chief reasons for this is the widespread use of bagasse plus hydropower in the electric sector. Fuel oil shipments ceased to Kauai in early 1992, because of concerns over liability provisions in the Oil Pollution Act of 1990. Previously, very little fuel oil was used in Kauai's power sector. Also, the main sugar plantation, Lihue, uses mainly diesel oil.

Sectoral fuel use in Maui County, which includes Molokai and Lanai, is displayed in Figures 20 and 21. Road transport is the principal oil user in Maui County, followed by commercial and industrial users, air transport, and agriculture. A large portion of the fuel oil and diesel used in Maui County is devoted to power generation. Both fuels are used on Maui, while Molokai and Lanai use diesel generators only. Fuel oil is also used by the two sugar plantations (Hawaiian Commercial & Sugar Company and Pioneer Mill), some of which is fed back into the electricity grid as utility purchased power.

The island of Oahu (City and County of Honolulu) is the state's major oil market. As Figure 22 illustrates, the presence of Honolulu International Airport has a huge impact on fuel use; air transport is the leading end-use sector on Oahu. The large population and higher levels of economic activity, however, also translate into high levels of fuel demand in the commercial and industrial sector. Road and water transport are the two other major end-use sectors; the agricultural industry on Oahu has contracted and accounts for only a small

Figure 18. Kauai County Sectoral Fuel Use, 1992

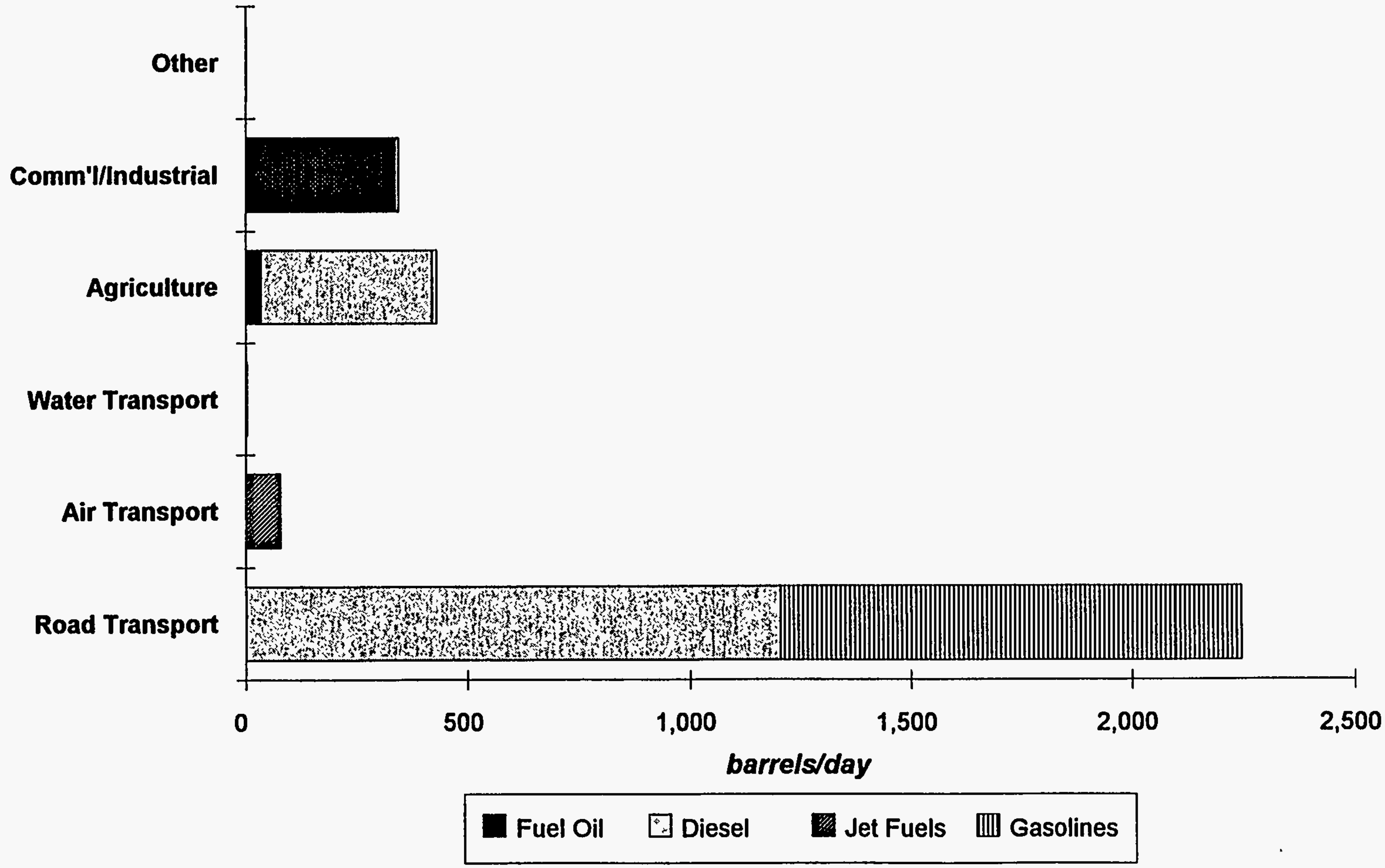


Figure 19. Kauai County Fuel Use by Sector, 1992

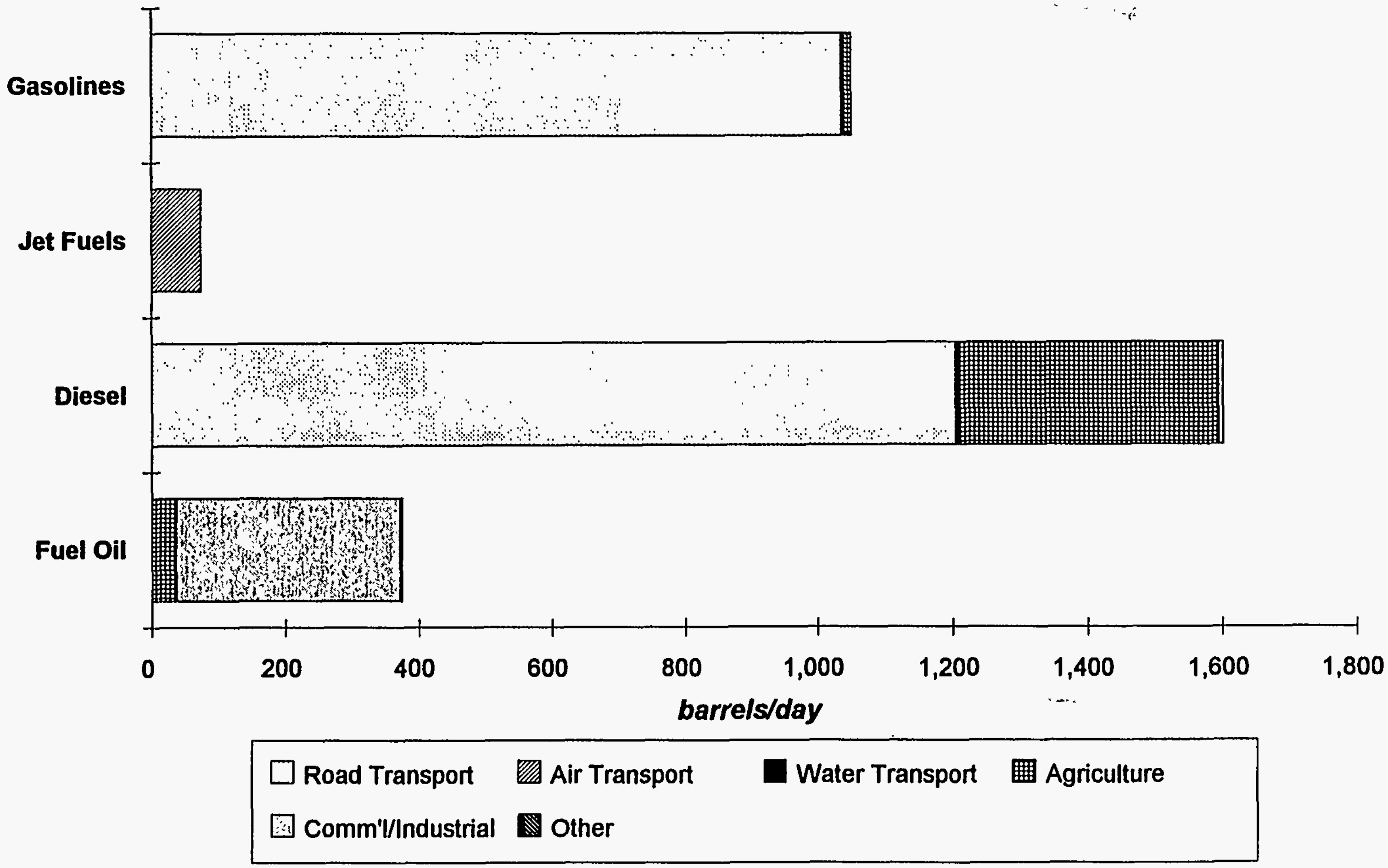


Figure 20. Maui County Sectoral Fuel Use, 1992

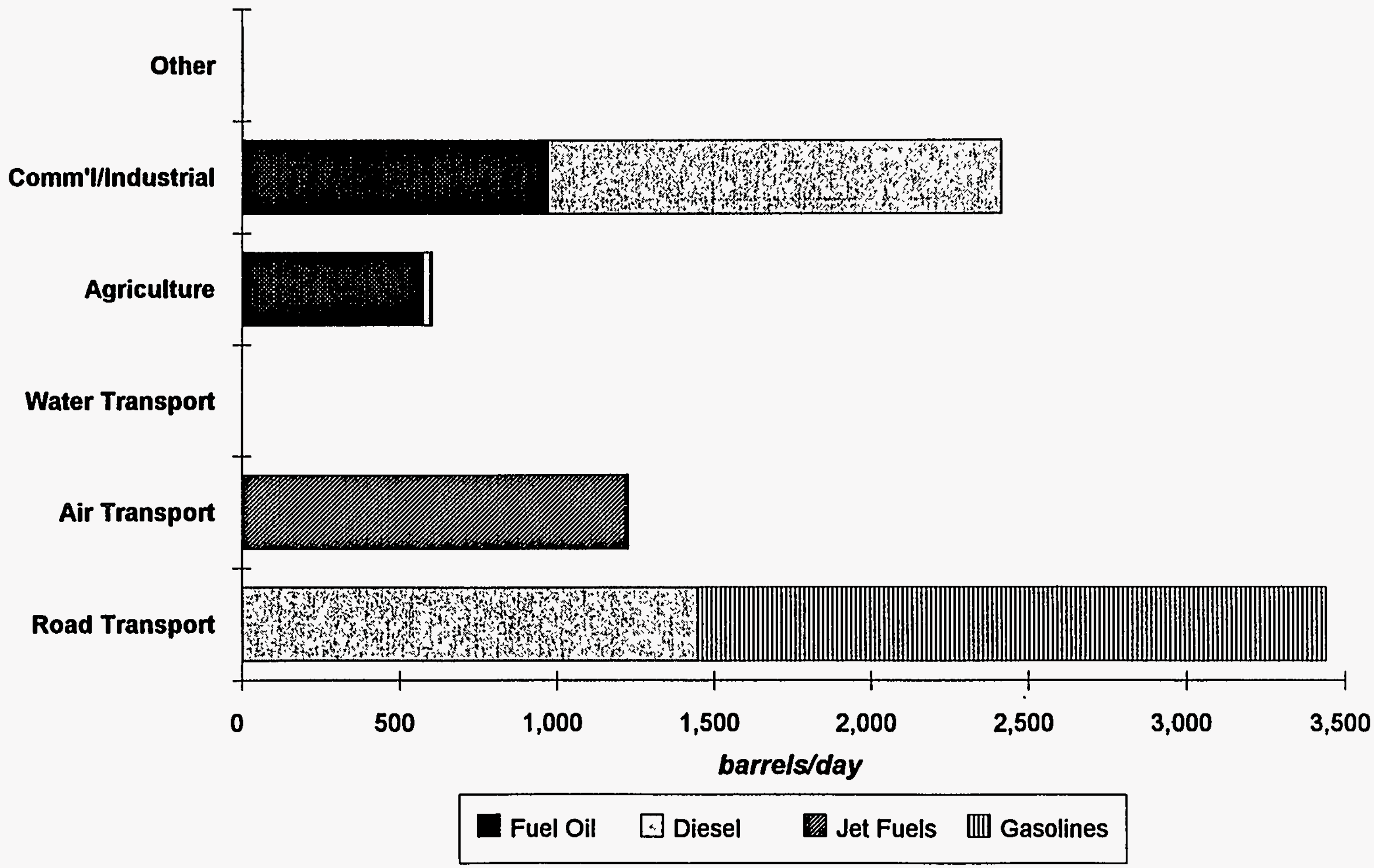


Figure 21. Maui County Fuel Use by Sector, 1992

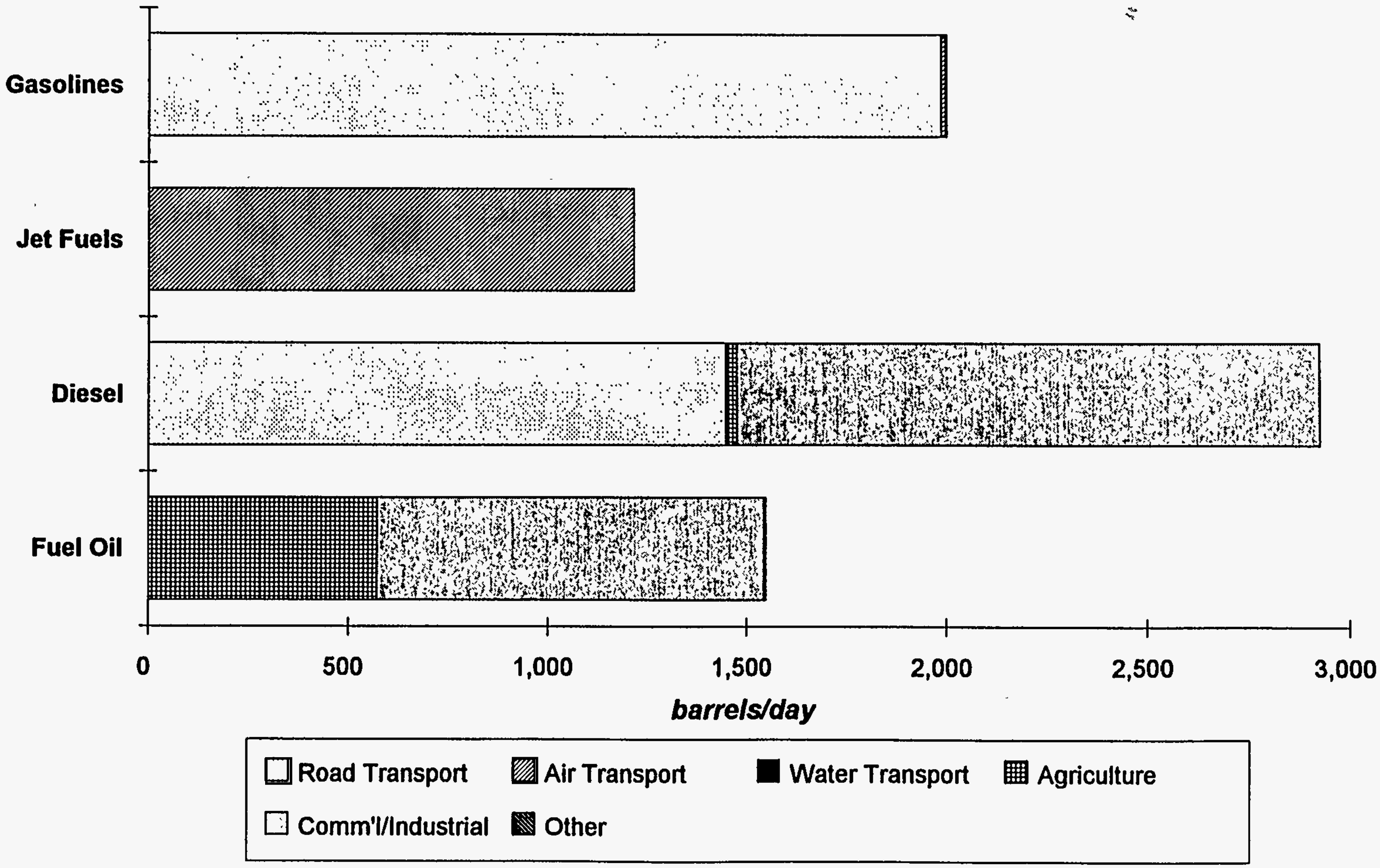
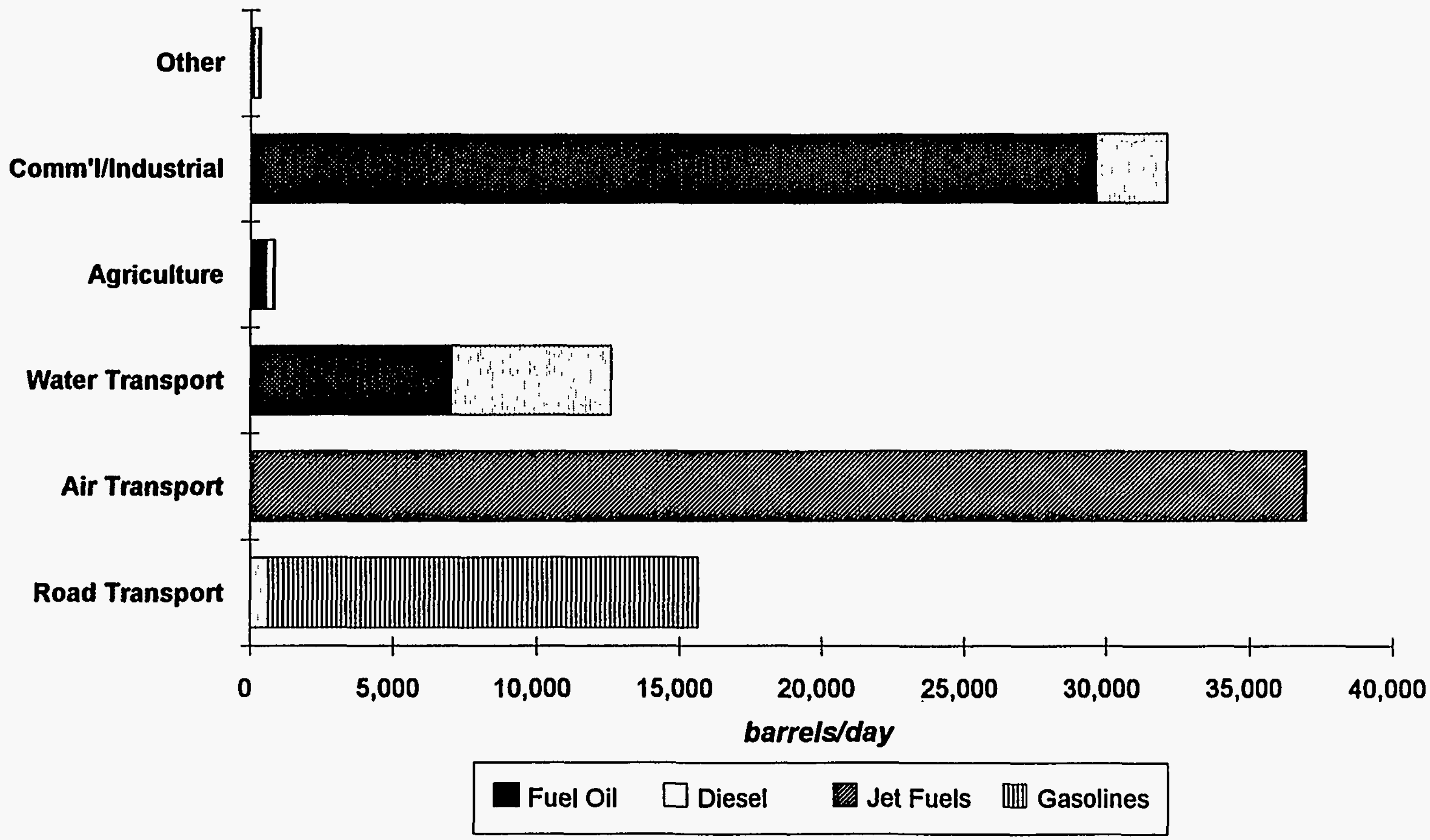


Figure. 22. City and County (C & C) of Honolulu Sectoral Fuel Use, 1992



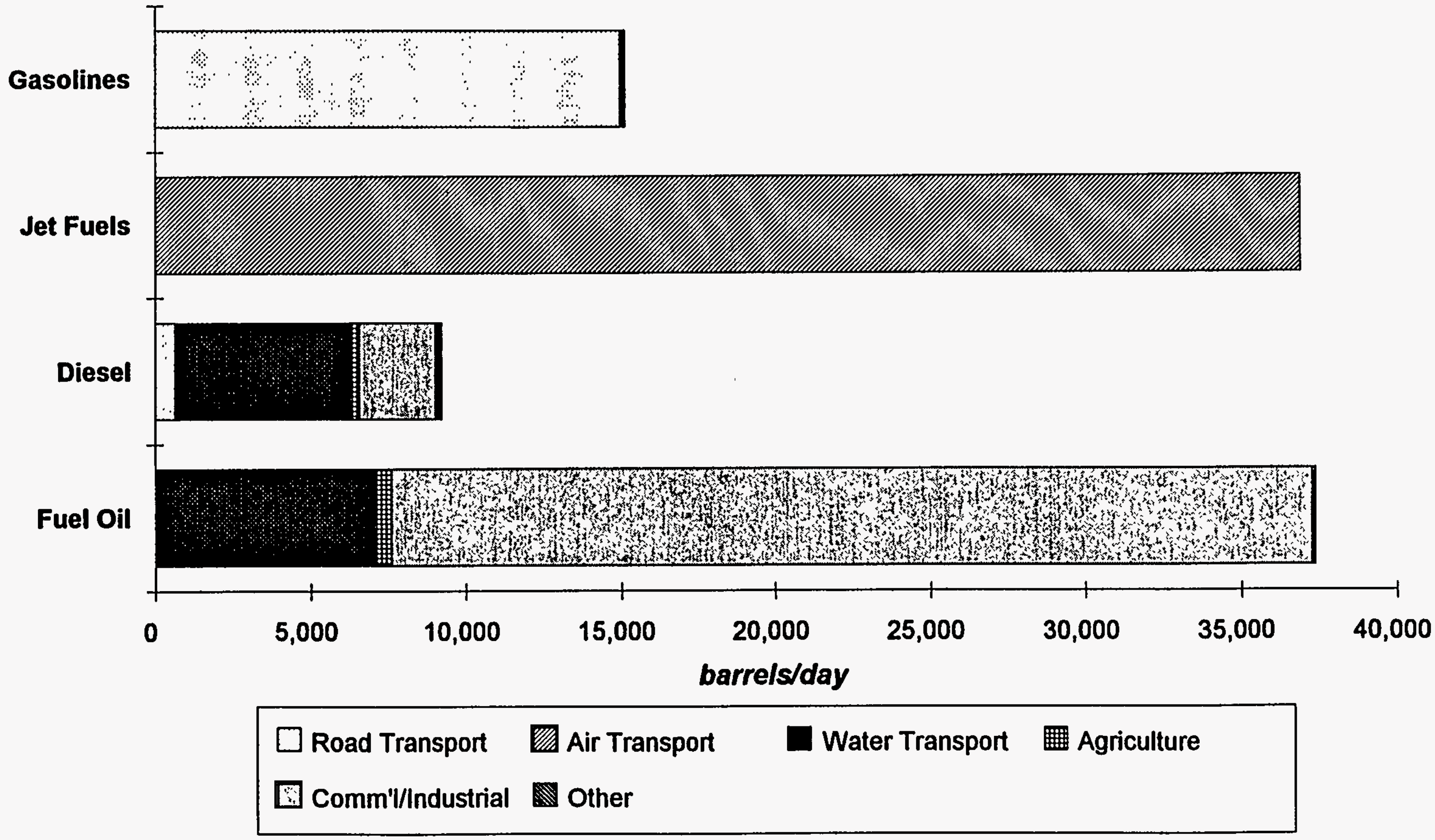
amount of fuel use. Figure 23 provides the breakdown by fuel type. Gasolines and jet fuels predictably are devoted to road and air transport, respectively. A large portion of the diesel and fuel oil are used for waterborne transport, including both interisland and overseas shipping. The largest use of fuel oil, however, is in power generation. On Oahu, close to 8 million barrels per year of low-sulfur fuel oil are used to produce electricity, with approximately 6 million barrels coming from the local refiners and 2 million barrels supplied via imports.

D. Direct and Indirect Dependence on Fossil Fuels

When we use the term "direct dependence" on fossil energy, we are speaking of those end-uses that use fossil energy directly, in its (largely) untransformed condition. A consumer does not use crude oil directly, but is directly dependent on oil when she/he fills an automobile's gasoline tank. The dominant "indirect" use of fossil energy is of course the electric power sector. The role of fossil energy in the power sector varies considerably from island to island. For autoproducers (consumers who generate their own power) and cogenerators, it is a simple matter to identify the exact mix of fuels used to produce captive power; for other users, however, the fuel mix behind the supply must be assumed to be proportional for all users unless specific contributions to the load shape are obvious. For example, on the Big Island, the geothermal facility generates around 25 MW of electricity, which is sold to Hawaii Electric Light Company (HELCO); if we wanted to set up a business on the Big Island, could we ask to purchase only the electricity that was generated by geothermal energy? Then our business could say that it had very little indirect dependence on fossil energy: "We Only Use Geothermal Energy" would be our slogan. In reality, of course, once energy is transformed into electricity and enters the grid, it cannot be distinguished by its source.

In Hawaii, most energy flows to the consumer in the form of transportation and electric power. But these are by their nature rather diffuse; is there any individual or any economic activity in the state that does *not* rely on electricity and transport? In this sense, it

Figure 23. City and County (C & C) of Honolulu, Fuel Use by Sector, 1992



can be concluded that virtually everyone in the state is equally dependent and equally vulnerable. Energy flows through these diffuse sectors, filtering through the economy and affecting all facets of our lives. There do not appear to be any analogous "heroin junkies" in Hawaii's energy market that absorb vastly more than their healthy share and would suffer immediate withdrawal if supplies were cut back.

1. Petroleum Product Consumption Trends

Petroleum is Hawaii's dominant fuel. Consumers are not directly dependent on crude oil but rather on finished petroleum products. Table 5 presents Hawaii's petroleum product demand from 1960 to 1992. At around 50 million barrels per year (mmb/y)—135 thousand barrels per day (mb/d)—Hawaii's oil market is not particularly large (California's demand, for example, is around 2 mmb/d), but oil plays the main role in Hawaii's energy market. Oil demand grew at rates averaging around 6.7 percent per year during the 1960s, bringing the size of the market from around 17.4 mmb in 1960 to 33.5 mmb in 1969. Despite the oil price shocks of the 1970s, the decade was still one of growth in the oil market; oil demand grew at average annual rates of over 2.5 percent, bringing demand levels to 44.1 mmb in 1979. During the 1980s, oil demand grew more slowly, at rates of under 1.8 percent per year. In 1989, oil demand reached a peak of around 51.3 mmb. Estimates of 1992 demand at around 49.2 mmb suggest that total oil demand may have stabilized. This may be explained in part by the continued economic recession and reduction in tourism.

Figure 24 displays the course of oil product demand over the 1960-92 period. It is easy to see the importance of jet fuel and fuel oil in the demand pattern, with lesser roles played by gasoline and diesel. The steady upward movement in the 1960s is derailed by the first oil price shock, recovers in the latter half of the 1970s, then is sent into another slump after the second price shock. The collapse of oil prices in 1986 unleashed demand growth once again—during the 1986-89 period, oil demand grew at 6 percent per year, the fastest growth seen since the 1960s. A more complete picture can be gained by looking at the trends in individual products, as plotted in Figure 25. Here, the interplay between jet fuel

Figure 24. Demand for Key Petroleum Fuels in Hawaii, 1960-92

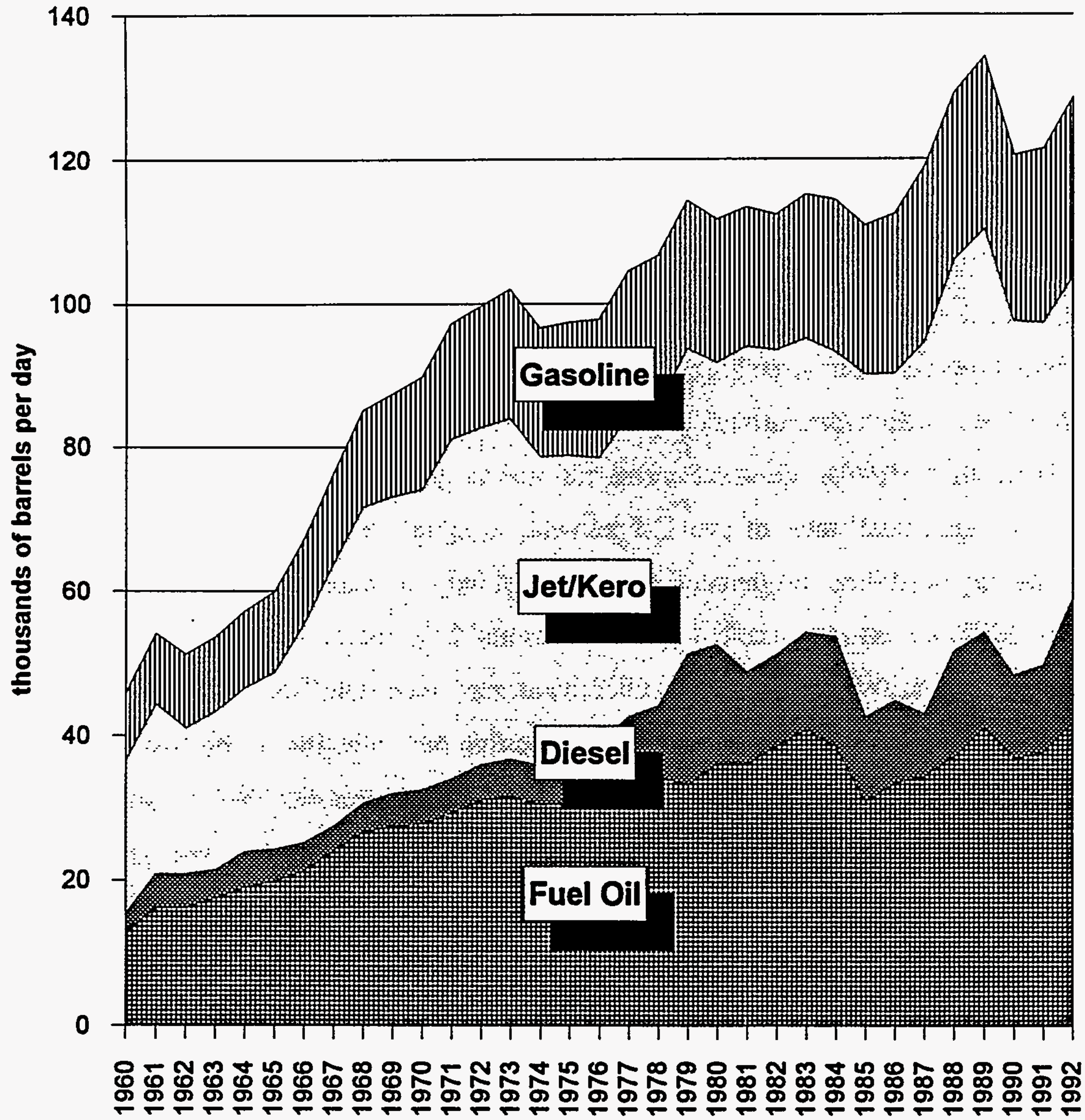


Figure 25. Trends in Demand for Major Petroleum Fuels in Hawaii, 1960-92

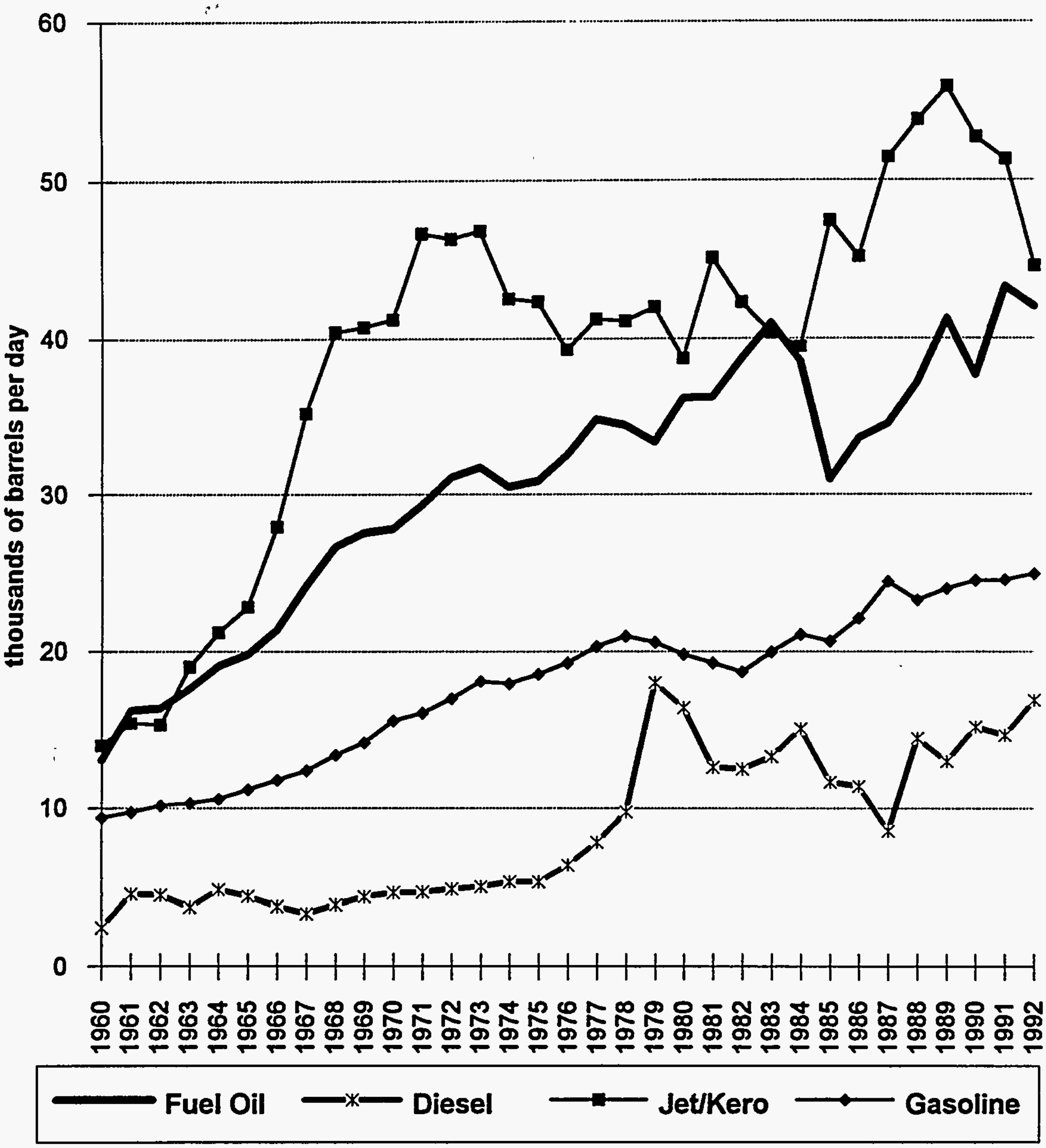


Table 5. Petroleum Product Consumption in Hawaii, 1960-92.
(thousands of barrels)

	LPG	Gasoline	Av. Gas	Jet Fuel	Kerosene	Diesel	Fuel Oil	Other	Total
1960	112	3,429	2,582	5,011	91	886	4,766	553	17,430
1961	140	3,546	2,994	5,558	69	1,663	5,926	578	20,474
1962	172	3,708	1,790	5,532	55	1,637	5,974	591	19,459
1963	232	3,756	1,084	6,892	49	1,362	6,431	638	20,444
1964	257	3,861	561	7,682	50	1,761	6,965	664	21,801
1965	219	4,082	626	8,275	49	1,612	7,230	684	22,777
1966	242	4,294	870	10,158	37	1,378	7,801	668	25,448
1967	285	4,526	477	12,802	33	1,208	8,818	636	28,785
1968	298	4,882	268	14,723	27	1,420	9,738	653	32,009
1969	912	5,176	195	14,834	29	1,601	10,056	666	33,469
1970	938	5,691	162	14,884	153	1,695	10,154	643	34,320
1971	963	5,872	165	16,939	80	1,709	10,701	618	37,047
1972	945	6,202	165	16,839	52	1,776	11,338	645	37,962
1973	942	6,608	153	17,043	41	1,837	11,575	723	38,922
1974	966	6,543	145	15,432	75	1,951	11,122	693	36,927
1975	872	6,766	133	15,363	76	1,948	11,255	693	37,106
1976	1,036	7,029	130	14,202	129	2,337	11,871	739	37,473
1977	877	7,406	147	14,875	169	2,865	12,695	789	39,823
1978	702	7,639	141	14,861	146	3,567	12,556	846	40,458
1979	1,583	7,506	152	15,276	40	6,567	12,167	824	44,115
1980	1,573	7,231	199	14,116	9	5,987	13,196	815	43,126
1981	1,285	7,033	55	16,451	0	4,604	13,223	821	43,472
1982	1,335	6,823	45	15,427	0	4,569	14,121	827	43,147
1983	1,360	7,274	215	14,724	0	4,853	14,958	832	44,216
1984	1,273	7,682	74	14,398	0	5,513	14,077	838	43,855
1985	1,292	7,528	65	17,297	0	4,262	11,293	844	42,581
1986	1,281	8,063	45	16,486	0	4,157	12,253	850	43,135
1987	1,333	8,911	29	18,775	0	3,124	12,606	856	45,634
1988	1,350	8,491	175	19,648	0	5,289	13,574	862	49,389
1989	1,470	8,755	51	20,399	0	4,749	15,054	868	51,346
1990	1,490	8,940	45	19,239	0	5,541	13,735	875	49,865
1991	1,490	8,958	45	18,720	0	5,355	15,796	881	51,245
1992	1,541	9,100	48	17,921	0	5,998	15,336	887	50,832
AAG 60-69	23.33%	4.20%	-22.77%	11.46%	-10.81%	6.10%	7.75%	1.88%	6.74%
AAG 70-79	5.37%	2.81%	-0.64%	0.26%	-12.55%	14.50%	1.83%	2.51%	2.54%
AAG 80-89	-0.67%	1.93%	-12.73%	3.75%	-100.00%	-2.29%	1.33%	0.64%	1.76%
AAG 74-79	8.58%	2.31%	0.79%	-0.17%	-9.95%	22.42%	1.51%	2.93%	3.01%
AAG 80-85	-3.86%	0.81%	-20.05%	4.15%	-100.00%	-6.57%	-3.07%	0.71%	-0.25%
AAG 86-89	4.69%	2.78%	4.26%	7.36%	na	4.54%	7.10%	0.71%	5.98%
AAG 90-92	1.70%	0.89%	3.49%	-3.49%	na	4.05%	5.67%	0.71%	0.97%

Source: State Energy Resources Coordinator's Annual Report, 1991, for data 1960-91.

Notes: Data for 1990 are revised; data for 1991 are preliminary; data for 1992 are East-West Center estimate based on oil company communications.

"Other" products data series had discontinuity 1981-91; and a straight-line interpolation has been adopted for this period.

AAG = average annual growth (%).

and fuel oil is easier to see. Jet fuel demand took off in the 1960s, reached 40 thousand barrels per day (mb/d) by 1968, hovered in the 40-45 mb/d range during the 1970s and early 1980s, then peaked at 56 mb/d in 1989 before dropping to 45 mb/d in 1992.

The figures seem to suggest that the reduction in jet fuel use is responsible for essentially all of the apparent drop in oil demand during the 1989-92 period; however, it must be acknowledged that oil statistics in Hawaii are inconsistent. At first glance, it seems that it should be relatively easy to track all commodity flows within the state and from island to island, since the boundaries are discrete. The truth, for any analyst, planner, or observer of Hawaii's energy market, is painfully different. There are several main reasons: First, the presence of the Hawaiian Foreign Trade Zone makes it possible for oil to appear and disappear almost mystically. Second, many sources—probably unintentionally—misreport, or miss entirely, the use of bonded fuels for international transport. This can affect statistics for jet fuel, diesel, and fuel oil—in other words, almost everything. Third, it is almost impossible to cross-check and verify data from different sources, even those that claim to be reporting the same thing. Finally, the oil company submissions, required monthly under Act 65, have been found to be riddled with inconsistencies, partly because of poor survey instrument design, implementation, and enforcement, partly because of wide variations in the reporting procedures and interpretations used by the oil companies. A change in company personnel responsible for filling out the monthly Act 65 forms apparently can foment a major change in the oil market. The data problems became so severe in the early stages of this research project that we submitted a special white paper on energy data issues to the state, since a full discussion of the topic would be a diversion too lengthy to include here. We will not go into the same level of detail here; suffice it to say that the data figures used in the state are not carved in stone; a "trend" cannot safely be said to be a trend unless it clearly becomes a consistent feature of the market.

To achieve a certain measure of consistency, we have adopted the petroleum product demand time series presented in Table 5 as our base assumption. The primary energy use and oil use figures presented earlier were derived from this series converted into barrels of crude oil equivalent (boe). This conversion appears in Table 6. Since fuel oil has a higher heat content than the lighter products, it is a more dominant part of the demand barrel in oil-equivalent terms. In boe terms, more than twice as much fuel oil is used as gasoline.

2. Coal Consumption Trends

Hawaii's coal use has been extremely modest in recent years; the only users were the cement industry and two of the sugar plantations. Coal was used to raise steam and to produce electricity. Coal use has risen sharply, however, and is likely to increase further in the future. In 1991, Hawaii's coal use on sugar plantations was around 9.4 thousand tons (mt). In late 1992, the AES Barbers Point coal-fired power plant came online, adding around 190 mt to the state coal consumption figure for 1992. Coal use on sugar plantations also expanded markedly, jumping sixfold to 56.5 mt. Increasing the use of coal on two sugar plantations (Hilo Coast Processing and Hawaiian Commercial and Sugar Company) enabled them to cut fuel oil use by more than one-third off the previous year's consumption figure. Nineteen ninety-three marks the first full year of operation for the AES Barbers Point plant, and coal use is expected to be in the range of 600-700 mt for that year. This will translate into greater indirect dependence on coal as a fossil fuel for power generation, but at the same time it will serve to reduce indirect dependence on oil in the power sector.

There are at present no direct uses of coal by Hawaii consumers, nor are there likely to be any in the future. For example, consumers do not purchase coal and use it in homes; despite the fact that this is done in many other regions, we tend to view such a thing as archaic—seeing cellars filled with piles of coal for home heating furnaces seems like something from an old movie, and since Hawaii does not require much by way of home heating, it is unlikely that such a use would ever emerge here. Future increases in dependence on coal will almost certainly be indirect dependence, such as will result from increased use of coal in the power sector. Additional discussion of coal and a discussion of natural gas use follow in Chapter II below ("Fossil Fuel Imports").

Table 6. Petroleum Product Consumption in Hawaii in Oil-Equivalent Terms, 1960-92

(thousands of barrels of oil equivalent, based on contents)

	3.8605	*5.253*	*5.048*	*5.67*	*5.67*	*5.825*	*6.287*	*6.3*	
	LPG	Gasoline	Av. Gas	Jet Fuel	Kerosene	Diesel	Fuel Oil	Other	Total
1960	75	3,106	2,247	4,899	89	890	5,166	601	17,072
1961	93	3,212	2,606	5,433	67	1,670	6,424	628	20,133
1962	114	3,358	1,558	5,408	54	1,644	6,476	642	19,254
1963	154	3,402	943	6,738	48	1,368	6,971	693	20,317
1964	171	3,497	488	7,510	49	1,769	7,550	721	21,755
1965	146	3,697	545	8,090	48	1,619	7,837	743	22,724
1966	161	3,889	757	9,930	36	1,384	8,456	726	25,339
1967	190	4,099	415	12,515	32	1,213	9,558	691	28,714
1968	198	4,422	233	14,393	26	1,426	10,556	709	31,964
1969	607	4,688	170	14,502	28	1,608	10,900	723	33,226
1970	624	5,154	141	14,550	150	1,702	11,007	698	34,027
1971	641	5,318	144	16,559	78	1,716	11,600	671	36,727
1972	629	5,617	144	16,462	51	1,784	12,290	701	37,676
1973	627	5,985	133	16,661	40	1,845	12,547	785	38,623
1974	643	5,926	126	15,086	73	1,959	12,056	753	36,623
1975	580	6,128	116	15,019	74	1,956	12,200	753	36,826
1976	690	6,366	113	13,884	126	2,347	12,868	803	37,196
1977	584	6,708	128	14,542	165	2,877	13,761	857	39,621
1978	467	6,919	123	14,528	143	3,582	13,610	919	40,291
1979	1,054	6,798	132	14,934	39	6,595	13,189	895	43,636
1980	1,047	6,549	173	13,800	9	6,013	14,304	885	42,780
1981	855	6,370	48	16,082	0	4,624	14,333	892	43,204
1982	889	6,180	39	15,081	0	4,589	15,307	898	42,982
1983	905	6,588	187	14,394	0	4,874	16,214	904	44,066
1984	847	6,958	64	14,075	0	5,537	15,259	911	43,651
1985	860	6,818	57	16,909	0	4,280	12,241	917	42,082
1986	853	7,303	39	16,116	0	4,175	13,282	924	42,691
1987	887	8,071	25	18,354	0	3,137	13,664	930	45,069
1988	899	7,690	152	19,208	0	5,312	14,714	937	48,911
1989	978	7,929	44	19,942	0	4,769	16,318	943	50,925
1990r	992	8,097	39	18,808	0	5,565	14,888	950	49,339
1991p	992	8,113	39	18,300	0	5,378	17,122	957	50,902
1992*	1,026	8,242	42	17,520	0	6,024	16,624	963	50,441

Notes: Data for 1990 are revised; data for 1991 are preliminary; data for 1992 are East-West Center estimate b LPG is to be 95% propane and 5% butane.

3. The Electric Power Sector

The Hawaii Energy Strategy Project 4, dealing with demand side management, will be going into more detail about the power sector and end users. But because the power sector is such an important consumer of fossil energy and offers the first target for many fuel substitution strategies, some discussion is also warranted here. Electricity can be produced from a wide variety of sources. Most modern electric power plants use steam-driven turbines to generate electricity, so there are as many possible electric energy sources as there are ways to produce the heat required for steam. Oil, natural gas, and coal are the fossil fuel resources commonly burned to produce electricity. Other resources used to generate electricity include biomass, geothermal, hydropower, nuclear, ocean thermal energy conversion (OTEC), solar radiation, and wind. The second group of resources mentioned are commonly referred to as alternatives or renewable, because they are alternatives to fossil fuels and, with the exception of nuclear, are all renewable resources. In many documents referring to the Hawaii energy situation, however, the term "alternative" is taken to mean anything other than oil. Coal and natural gas are then considered alternatives as well in many of these discussions.

In spite of all of the ways that electricity can be generated, in Hawaii petroleum products alone account for 89 percent of all of the electricity generated in Hawaii. Figure 26 displays the historical trend in electricity generation by energy source, 1970-92. Two features stand out: first, total electricity demand has grown strongly over the period, and second, much of the increase in demand has been satisfied by non-oil sources (though diesel use has grown). Entering the picture in significant amounts are coal, solid waste, geothermal, and wind, with continuing contributions from bagasse and hydro. The percentage dependence on oil varies substantially by island, from 62 percent on Kauai, where significant contributions are made by biomass and hydroelectric generation, to 100 percent on Lanai, where no alternative sources are used to generate electricity. Figure 27 compares electricity sources by island between 1991 and 1993 in order to display the significance of

Figure 26. Electricity Generation by Type, 1970-92

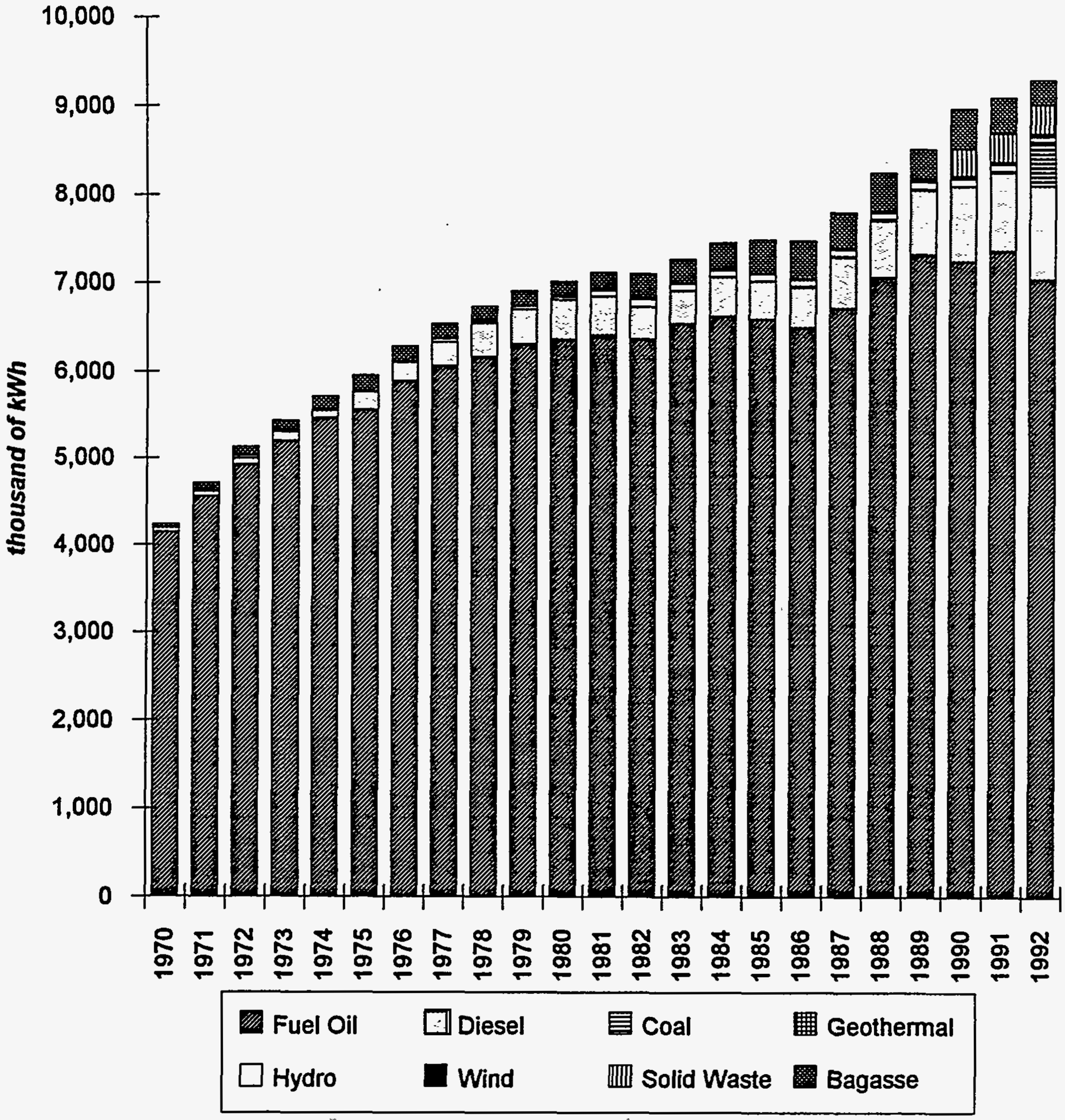
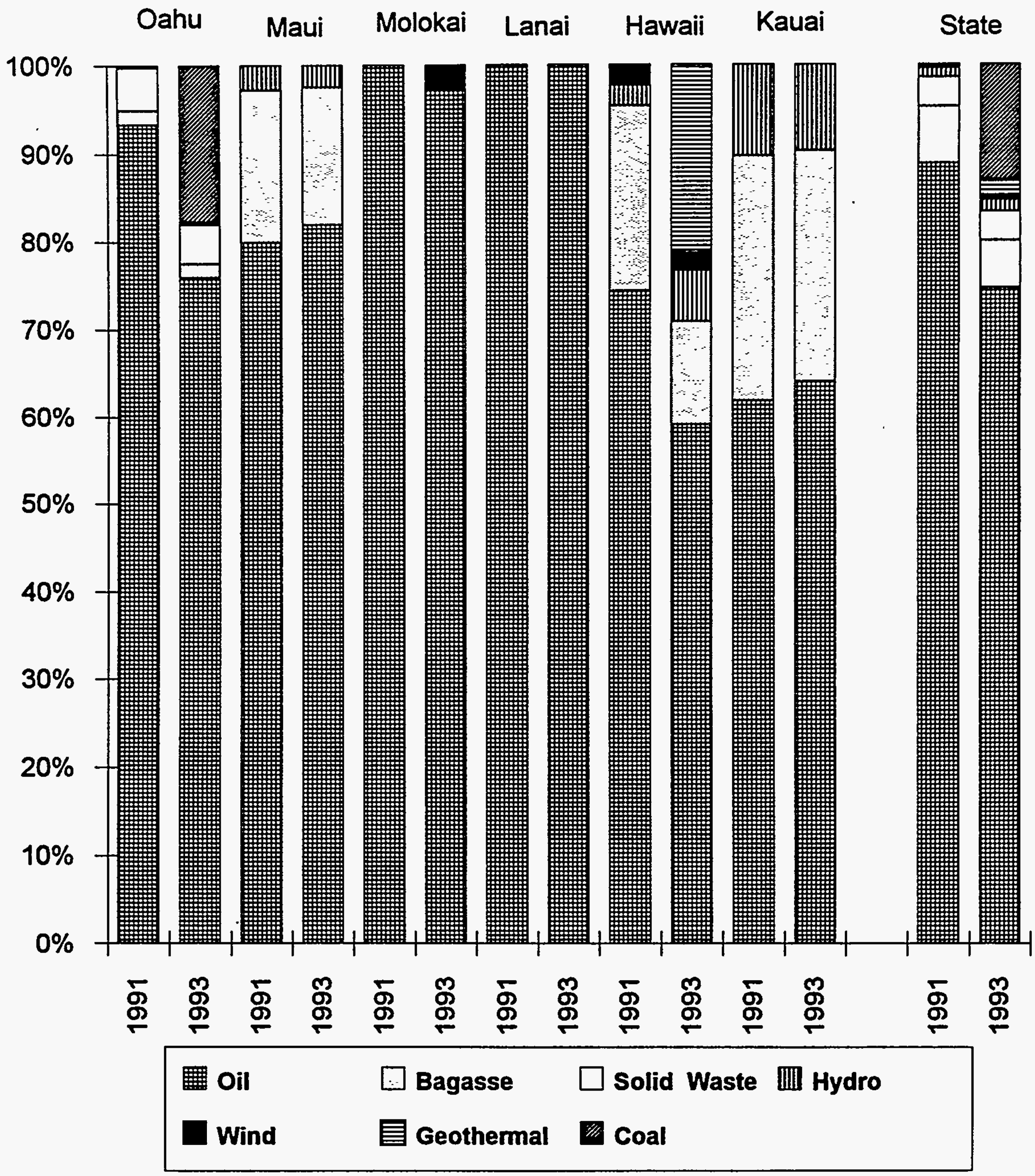


Figure 27. Fuel Sources For Electric Power Generation by Island, 1991-93



the changes in fuel mix over just the past few years. The preliminary estimates of 1993 were provided by HECO.[1]

Alternatives may become more significant energy producers in the future as political and social pressures mount to diversify the resource base. Two of the five principal recommendations made in the *Hawaii Integrated Energy Policy* published in December of 1991 involve promoting alternative fuels and developing an implementation strategy.[2] Of the alternative methods used to produce electricity, any of the technologies mentioned above could theoretically be deployed in Hawaii, though economic, technical, and political considerations make some less likely than others. (Nuclear power, for example, is rarely mentioned as a likely option for Hawaii; the state constitution requires a two-thirds majority of both legislative bodies to approve construction of a nuclear fission power plant.) Biomass (5.3 percent), hydropower (1.3 percent), and solid waste (3.3 percent) already make contributions to electricity generation in the state. Geothermal recently resumed operations on the Big Island and is expected to produce 21 percent of the electricity generated on the Big Island and 2 percent of the state total in 1993. Solar and wind are small-scale contributors at less than 1 percent, and OTEC is being studied for future use in the islands.

The major petroleum product used to generate electricity in Hawaii is residual fuel oil, with diesel playing a greater role on the neighbor islands. Table 7 and Figures 28 and 29 show the amount of fuel oil and diesel used in electricity generation throughout the state from 1970-92. The picture is striking; by far the majority (ranging from around 65 percent to 90 percent over the period) of Hawaii's fuel oil has gone to the power sector. Diesel use is not so overwhelmingly devoted to the electric sector, yet its use for power generation is on the upswing. In the early 1970s, only around 4 percent of Hawaii's diesel was used to

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[1]Alan S. Lloyd, Hawaiian Electric Company. "Fuel Sources for Electric Power Generation in Hawaii," March 8, 1993.

[2]Department of Business, Economic Development & Tourism, Energy Division (December, 1991). *Hawaii Integrated Energy Policy*. Honolulu, Hawaii.

Figure 28. Fuel Oil Use in Hawaii: Power Sector Use vs. State Total, 1970-92

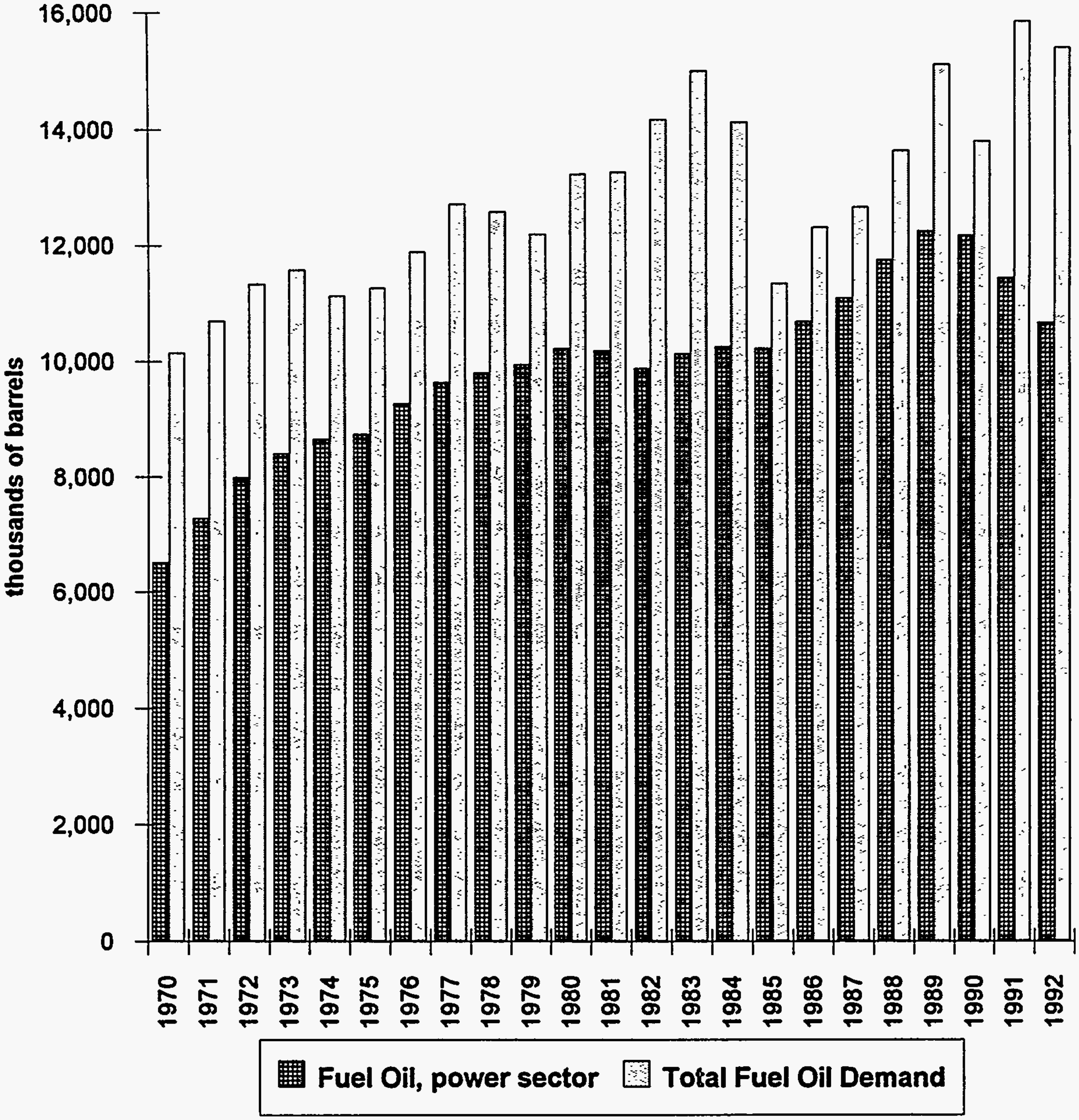


Figure 29. Diesel Use in Hawaii: Power Sector Use vs. State Total, 1970-92

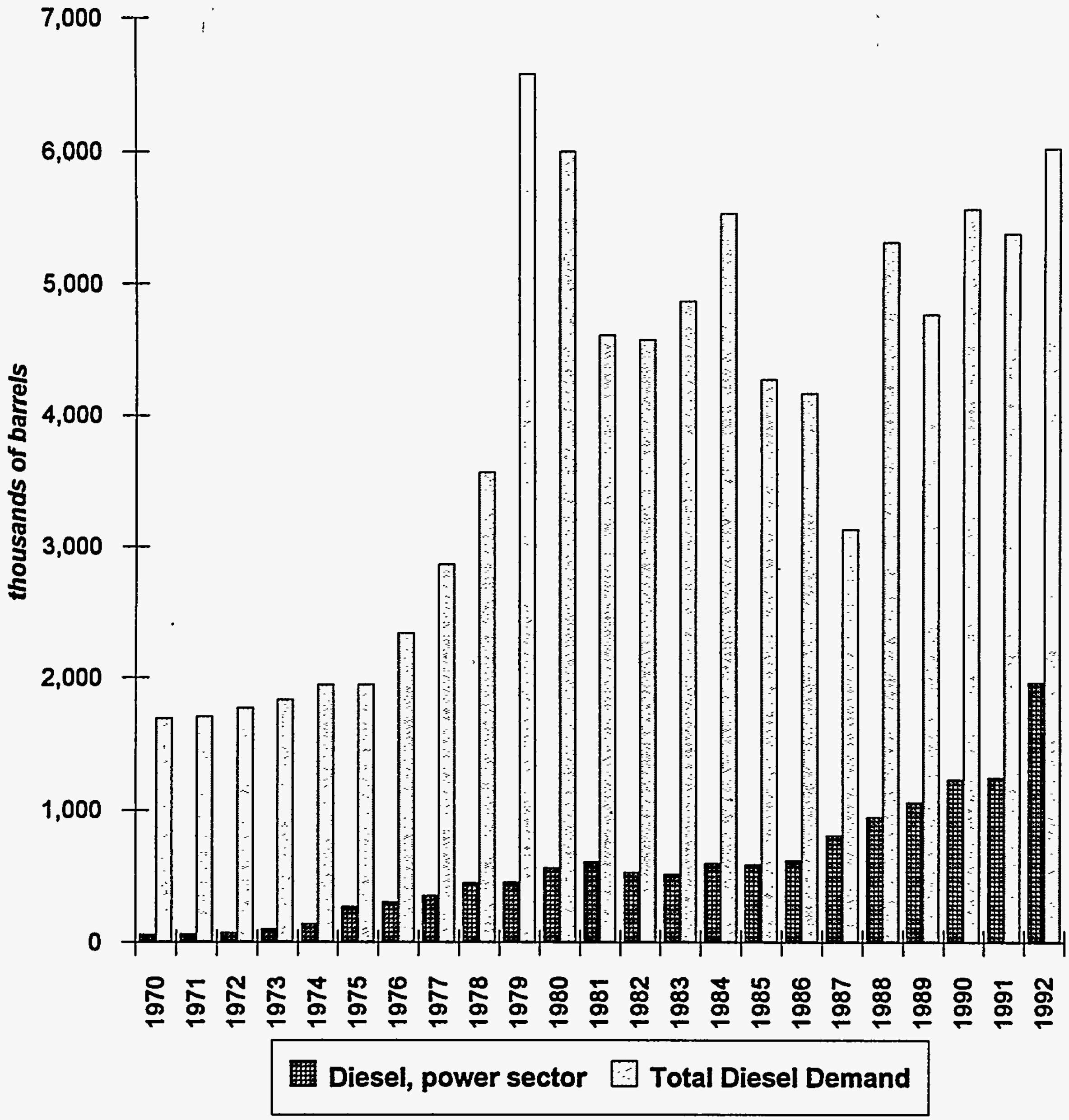


Table 7. Oil Use in Hawaii's Power Sector, 1970-92

(thousands of barrels per day)

	Fuel Oil, Power Sector	Diesel, Power Sector	Fuel Oil, Total Demand	Diesel, Total Demand	Fuel Oil, % for Power	Diesel, % for Power
1970	6,518	60	10,154	1,695	64.2%	3.6%
1971	7,284	65	10,701	1,709	68.1%	3.8%
1972	7,990	72	11,338	1,776	70.5%	4.0%
1973	8,409	105	11,575	1,837	72.6%	5.7%
1974	8,650	142	11,122	1,951	77.8%	7.3%
1975	8,734	275	11,255	1,948	77.6%	14.1%
1976	9,267	308	11,871	2,337	78.1%	13.2%
1977	9,626	355	12,695	2,865	75.8%	12.4%
1978	9,788	450	12,556	3,567	78.0%	12.6%
1979	9,927	452	12,167	6,567	81.6%	6.9%
1980	10,188	563	13,196	5,987	77.2%	9.4%
1981	10,154	612	13,223	4,604	76.8%	13.3%
1982	9,847	527	14,121	4,569	69.7%	11.5%
1983	10,095	515	14,958	4,853	67.5%	10.6%
1984	10,210	597	14,077	5,513	72.5%	10.8%
1985	10,182	588	11,293	4,262	90.2%	13.8%
1986	10,647	618	12,253	4,157	86.9%	14.9%
1987	11,040	807	12,606	3,124	87.6%	25.8%
1988	11,693	949	13,574	5,289	86.1%	17.9%
1989	12,182	1,062	15,054	4,749	80.9%	22.4%
1990	12,101	1,235	13,735	5,541	88.1%	22.3%
1991	11,370	1,250	15,796	5,355	72.0%	23.3%
1992	10,610	1,961	15,344	5,998	69.1%	32.7%

Sources: Oil use in power sector per HECO and KED data, supplemented with unpublished HSPA data and DBET data. Oil demand per DBET and EWC data.

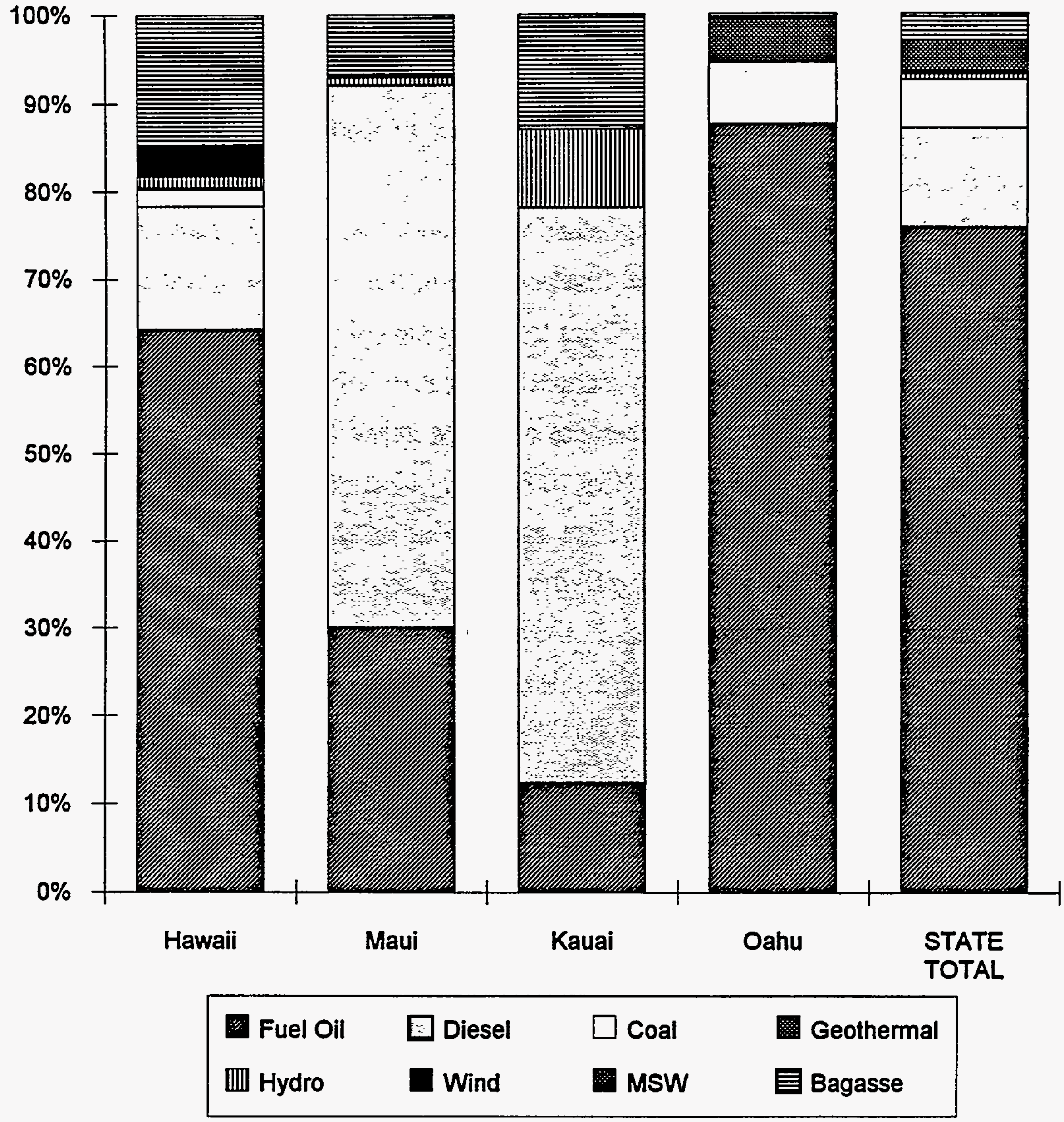
generate electricity. By 1975, the figure had grown to around 14 percent, and as of 1992, nearly 25 percent of the state's diesel supplies went to the power sector.

Actual generation figures for 1992 at the county level are presented in Figure 30. The percentage of diesel fuel use varies widely from county to county, being particularly high in Kauai and Maui Counties. Diesel fuel is a more highly refined petroleum product and therefore commands a higher market price than fuel oil. Even though diesel costs more, it is used on islands that have isolated, low-volume electrical demands because, for fuel oil powered facilities to become economical, economies of scale would require much larger demand than is found on these islands.

On Maui, Kauai, and the Big Island where both fuel oil and diesel are used, problems have arisen regarding the interisland transportation of fuel oil. The neighbor islands rely on the BHP and Chevron refineries on Oahu to supply the bulk of their petroleum products. In 1992 Chevron and BHP (then PRI) announced that they would no longer be willing to ship #6 fuel oil to the neighbor islands because of the unlimited liability clause in the federal government's Oil Pollution Act of 1990 (OPA 90). Most of the shippers were subsidiaries of larger companies and accordingly did not want to risk liability for a spill.

Fuel oil was targeted as a higher risk product because of its heavy consistency and slow evaporation and dispersal rate. In the event of a spill when transporting product interisland, lighter petroleum products would quickly evaporate, whereas fuel oil would create a persistent oil slick causing many undesirable environmental and economical consequences. Fuel oil is therefore a riskier commodity to ship. As a result of the decisions by BHP and Chevron, less fuel oil was used on the neighbor islands in 1992, and that amount is expected to decline further in 1993. Kauai has already made the decision to retrofit its fuel oil generating facility to burn diesel oil, severing all reliance on fuel oil. With only one facility using fuel oil, and with fuel oil representing only about 10 percent of

Figure 30. Electricity Generation by County by Type, 1992



its electrical generation capacity, the switch on Kauai was much easier than it would be on the other islands. Maui and the Big Island use fuel oil when available, and use diesel or coal as a supplement, depending on the fuel switching abilities of the generating unit. Both islands have decided to retrofit existing equipment to burn diesel.

Two immediate solutions have been proposed to provide fuel oil to Maui and the Big Island. The first involves transport of fuel oil by an independent shipper who is willing to assume the risk. The second option is switching to diesel for electric power generation. Advocates for switching to diesel fuel point out that the fuel would evaporate in case of a spill. While this solution may address concerns regarding potential spills, there are additional consequences of this decision that should be considered. As mentioned above, diesel fuel costs more than fuel oil, and that differential has increased over time as product specifications become more stringent and refiners' costs increase. Table 8 shows the prices of diesel and fuel oil in Hawaii from 1970-92 on all islands using both fuels. The gap between fuel oil and diesel prices has grown wider in recent years, and this trend is projected to continue in response to increased demand in the Asia-Pacific market. At the same time, high sulfur fuel oil prices are expected to decline relative to crude prices because of reduced demand resulting from increasingly stringent environmental regulations. The other cost involved in switching to diesel includes converting all generating facilities currently using fuel oil over to diesel, a process that would require significant capital investments.

Another aspect of the diesel fuel oil debate that should be discussed is the comparative efficiency ratios of the two fuels. Generating electricity by burning fuel is a very inefficient process. This should be expected given the second law of thermodynamics; energy always moves from a higher to a lower form after conversion. As much as two-thirds of the energy content of the fuel is lost in electric generation and distribution. As such, electricity has a relatively higher cost per energy unit than the fuel from which it is generated. Steam turbine generators using fuel oil typically operate at efficiency ratios in the 27-30 percent range. Diesel generators by comparison operate in the 38-45 percent range.[3] Clearly there are risks

[3]Alan Lloyd, Hawaiian Electric Company, personal communication, May 21, 1993.

Table 8. Prices of Fuel Oil and Diesel in Hawaii, 1970-1992

($/barrel)

HECO	Fuel Oil	Diesel	Diesel - Fuel Oil	Fuel Oil as % of Diesel	Kauai Electric Fuel Oil	Diesel	Diesel - Fuel Oil	Fuel Oil as % of Diesel
1970	$2.45	n/a			$2.95	$5.88	$2.93	0.50
1971	$3.12	n/a			$4.11	$6.20	$2.09	0.66
1972	$3.17	n/a			$4.34	$6.21	$1.87	0.70
1973	$3.95	n/a			$4.84	$6.92	$2.08	0.70
1974	$4.55	$5.41	$0.86	0.84	$12.21	$12.57	$0.36	0.97
1975	$9.54	$6.61	($2.93)	1.44	$11.50	$14.10	$2.60	0.82
1976	$9.80	$11.02	$1.22	0.89	$11.96	$13.96	$2.00	0.86
1977	$11.62	$12.52	$0.90	0.93	$12.57	$16.28	$3.71	0.77
1978	$14.03	$15.76	$1.73	0.89	$12.69	$16.58	$3.89	0.77
1979	$15.78	$16.43	$0.65	0.96	$16.23	$23.96	$7.73	0.68
1980	$23.14	$29.84	$6.70	0.78	$24.12	$35.53	$11.41	0.68
1981	$42.48	$37.44	($5.04)	1.13	$28.90	$41.57	$12.67	0.70
1982	$43.08	$41.20	($1.88)	1.05	$29.07	$43.81	$14.74	0.66
1983	$34.55	$41.76	$7.21	0.83	$28.45	$41.56	$13.11	0.68
1984	$34.61	$40.47	$5.86	0.86	$29.60	$37.69	$8.09	0.79
1985	$30.87	$37.41	$6.54	0.83	$25.89	$45.47	$19.58	0.57
1986	$19.38	$34.34	$14.96	0.56	$14.49	$24.69	$10.20	0.59
1987	$21.75	$25.49	$3.74	0.85	$17.97	$25.04	$7.07	0.72
1988	$18.58	$21.76	$3.18	0.85	$14.00	$22.84	$8.84	0.61
1989	$20.47	$24.05	$3.58	0.85	$15.37	$26.83	$11.46	0.57
1990	$25.24	$26.89	$1.65	0.94	$19.50	$33.13	$13.63	0.59
1991	$22.78	$28.68	$5.90	0.79	$15.30	$31.32	$16.02	0.49
1992	$18.69	$26.33	$7.64	0.71	$14.05	$26.95	$12.90	0.52

MECO	Fuel Oil	Diesel	Diesel - Fuel Oil	Fuel Oil as % of Diesel	HELCO Fuel Oil	Diesel	Diesel - Fuel Oil	Fuel Oil as % of Diesel
1970	$2.90	n/a			$2.87	$6.99	$4.12	0.41
1971	$4.11	n/a			$4.05	$7.22	$3.17	0.56
1972	$4.64	n/a			$4.21	$6.18	$1.97	0.68
1973	$6.53	n/a			$4.67	$6.23	$1.56	0.75
1974	$10.12	n/a			$10.03	$9.06	($0.97)	1.11
1975	$11.31	$13.40	$2.09	0.84	$11.12	$13.15	$2.03	0.85
1976	$11.11	$15.10	$3.99	0.74	$10.95	$14.68	$3.73	0.75
1977	$12.56	$16.68	$4.12	0.75	$11.98	$16.31	$4.33	0.73
1978	$12.61	$18.17	$5.56	0.69	$12.22	$17.15	$4.94	0.71
1979	$17.49	$23.29	$5.80	0.75	$17.18	$20.72	$3.54	0.83
1980	$23.38	$35.28	$11.90	0.66	$23.63	$29.84	$6.21	0.79
1981	$28.41	$42.35	$13.94	0.67	$28.84	$41.66	$12.82	0.69
1982	$28.99	$43.68	$14.69	0.66	$28.65	$44.17	$15.52	0.65
1983	$28.19	$42.18	$13.99	0.67	$28.14	$42.87	$14.73	0.66
1984	$29.06	$37.76	$8.70	0.77	$29.26	$40.42	$11.16	0.72
1985	$26.48	$36.97	$10.49	0.72	$26.66	$39.02	$12.36	0.68
1986	$15.47	$24.59	$9.12	0.63	$16.07	$26.75	$10.68	0.60
1987	$16.53	$24.43	$7.90	0.68	$17.27	$26.08	$8.81	0.66
1988	$12.62	$21.30	$8.69	0.59	$12.89	$22.36	$9.47	0.58
1989	$12.76	$25.50	$12.74	0.50	$14.70	$26.39	$11.69	0.56
1990	$16.97	$29.82	$12.85	0.57	$18.10	$31.97	$13.87	0.57
1991	$15.69	$30.77	$15.08	0.51	$16.65	$32.55	$15.90	0.51
1992	$15.41	$28.05	$12.63	0.55	$16.67	$30.29	$13.62	0.55

Source: Department of Business, Economic Development and Tourism, Energy Division.
Note: HECO fuel oil has maximum sulfur content of 0.5% by weight. Neighbor Islands fuel oil may have sulfur levels up to 2.0% by weight.

generators using fuel oil typically operate at efficiency ratios in the 27-30 percent range. Diesel generators by comparison operate in the 38-45 percent range.[3] Clearly there are risks associated with either decision. In order to compare the costs and benefits, further analysis is required that would consider the present and projected costs of fuel oil and diesel, generating efficiencies, cost of construction or retro-fitting, and the estimated costs of a spill when transporting fuel oil.

The reason that petroleum accounts for most electricity generation in Hawaii is simple economics. Because Hawaii lacks significant indigenous fuel sources, any fuel for electricity generation must arrive by ship. The cost of transporting liquid fuels like crude or fuel oil is lower than transporting solid fuels such as coal. In addition, the presence of the two oil refineries, which exist mainly to supply jet fuel, makes it easy to produce residual fuel oil as a "by-product" that can be piped directly to the electric power plants. As demand for electricity has increased in recent years, low-sulfur fuel oil has been imported to meet demand above what the refineries already produce and excess high-sulfur material is exported.

In late 1992, Applied Energy Services (AES) began operation of a 180-MW coal-fired power plant at Barbers Point on Oahu. The AES Barbers Point plant is the first large-scale power producer to use coal in Hawaii since 1905. Coal use and sources are the topic of a subsection in Chapter II below. Also, Task III (*Greenfield Options*) will delve into the issue of clean coal technologies for Hawaii. It is important, however, to note here that coal now produces 18 percent of Oahu's electricity and that additional coal-fired plants are being considered to fulfill future electricity requirements in Hawaii. While increasing the percentage of coal used in the power sector reduces reliance on oil, it does not affect the level of fossil fuel dependence in the state. Coal is an imported fossil fuel, just as oil is. AES imports coal for the Barbers Point facility from Indonesia—coincidentally, the source of much of the crude used in the local refineries.

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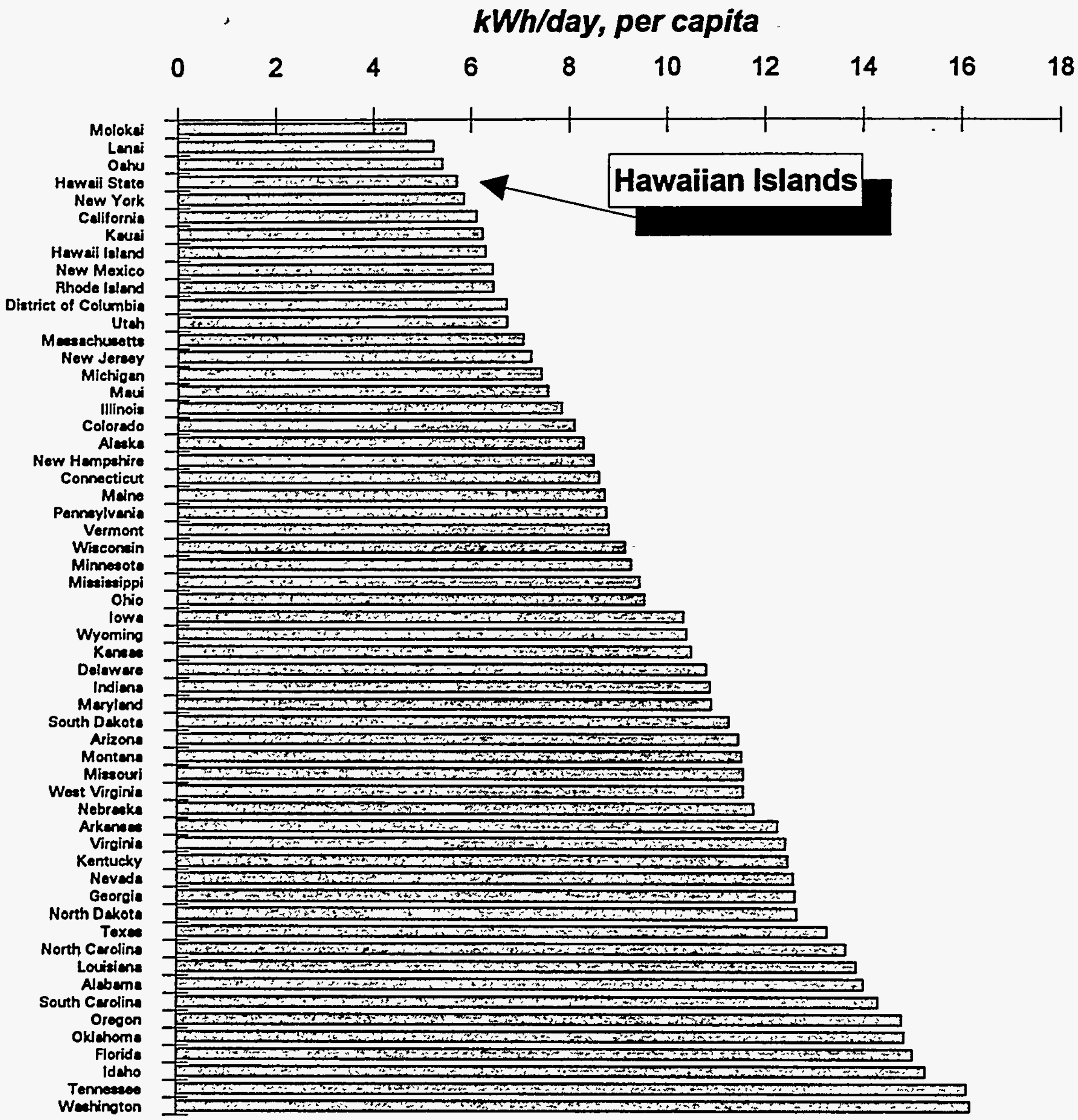
[3]Alan Lloyd, Hawaiian Electric Company, personal communication, May 21, 1993.

Hydropower is an alternative source of electricity generation that is currently cost competitive with fossil fuels, and as a result most of the hydroelectric possibilities in the state have already been exploited. Large-scale wind generation has not been cost competitive with fuel-oil-fired power plants, especially in Hawaii given the high cost of land. Still, interest in wind generation continues, and it is hoped that wind power will continue to make a contribution to Hawaii's energy demand. Even though generating electricity from fossil fuels is very costly, for Hawaii it is still the cheapest source of electricity and is therefore expected to remain dominant.

Data for electricity consumption by sector in Hawaii is spotty. The electric utilities keep sales data by rate classification, which (except for residential sales) generally does not coincide with economic classification of use. For example, over half of the electricity sold on Oahu is on rate schedule "P" for large power use. The purchasers of such power are very diverse and include the U.S. military, hotels, the University of Hawaii, and master-metered apartment buildings. Clearly such users cannot be lumped together under any reasonable economic classification scheme. For the purposes of this report, electricity sales will be divided into two categories: residential and other.

At 5.7 kilowatt-hours (kWh) per person per day, Hawaii residents use less electricity per capita than any other state in the United States (see Figure 31). Two key factors explain this phenomenon. First, Hawaii's weather reduces the need for heating and air conditioning. Second, consumption is so low because electricity prices are high. There are few energy resources able to provide inexpensive power to meet demand. While it is less expensive to import fossil energy from which electricity can be generated than to use indigenous resources, it still ends up costing more than most other consumers pay in the United States. The effect of price on consumption should not be overlooked. The two states with the highest residential consumption of electricity are Tennessee and Washington. Both the Tennessee Valley Authority and the Bonneville Power Administration provide access to large amounts of cheap hydroelectric power. As a result, Tennessee and Washington consume almost three times as much electricity per capita as Hawaii.

Figure 31. Comparison of United States Per-Capita Residential Electricity Consumption, 1990



Source: Statistical Abstract of the United States, 1992

Molokai, at 4.7 kWh per person per day, uses the least residential electricity per capita of all of the Hawaiian Islands and also has the highest electricity prices (see Figure 32). In contrast, Maui has lower rates and the highest per-capita residential electricity use at 7.6 kWh per person per day. Oahu is the only island with lower electricity rates than Maui. The differential in electricity rates between Oahu and the neighbor islands is in part a function of the additional transport costs that are incurred when fuel oil, diesel, or coal are shipped from Oahu. Rates may also be lower on Oahu as a result of higher population densities and more efficient generating and transmission systems. statewide electricity sales are illustrated in Figure 33, showing a steady increase since 1970.

Figures 34 through 39 show residential and other electricity sales by island from 1970-91. In general, the Hawaiian Islands have levels of residential electricity consumption that increase in relation to population growth, although not proportionately because of increases in efficiency over time. On Molokai and Lanai where demand is much smaller, the line graphs show greater variation, indicating less predictable growth patterns in the "other" category. Lanai's "other" category shoots up in 1987 and continues the pattern through 1991. This can be explained by changes in the island's two major industries. First, the Manele Bay Hotel opened, creating a significant increase in demand. Second Maui Electric Company (MECO) bought the electricity generating facilities from Dole as the pineapple industry began its withdrawal from the island. The transfer of ownership from private industry to public utility registered as a huge increase in sales.

On Molokai, the jump in sales in 1977 corresponds to the opening of the Kaluakoi Resort. Large resorts are electricity intensive. For example, when the Westin Kauai Resort complex opened on Kauai in 1987, it consumed 6 percent of the island's total electricity generation.[4] Molokai's increase in sales is followed by a dip in 1979, which was the result of the loss of a 500-horsepower diesel engine burning up, forcing conservation until it was brought on line again a few years later.

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[4]Susan Hooper, "Charging Ahead," *Hawaii Business* (July, 1992), p. 66.

Figure 32. Residential Electricity Prices by Island, 1981-90

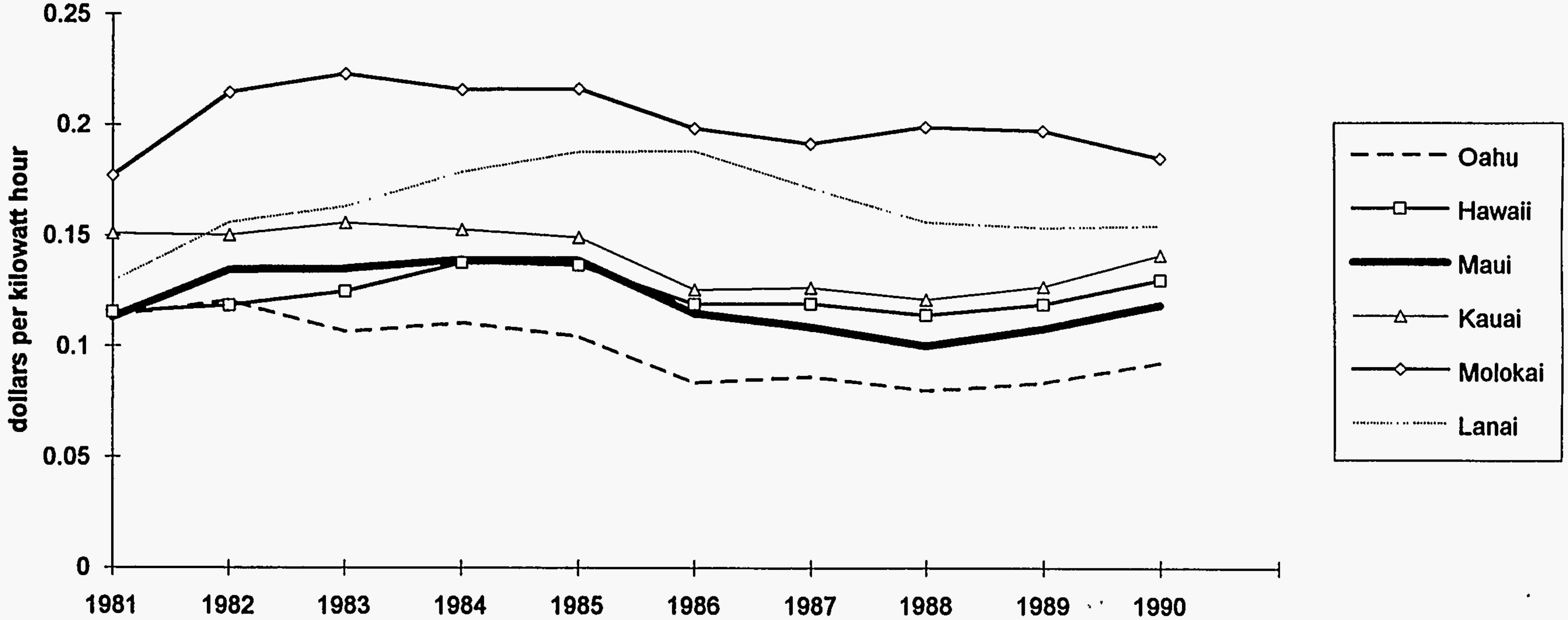


Figure 33. Electricity Sales in the State of Hawaii, 1970-91

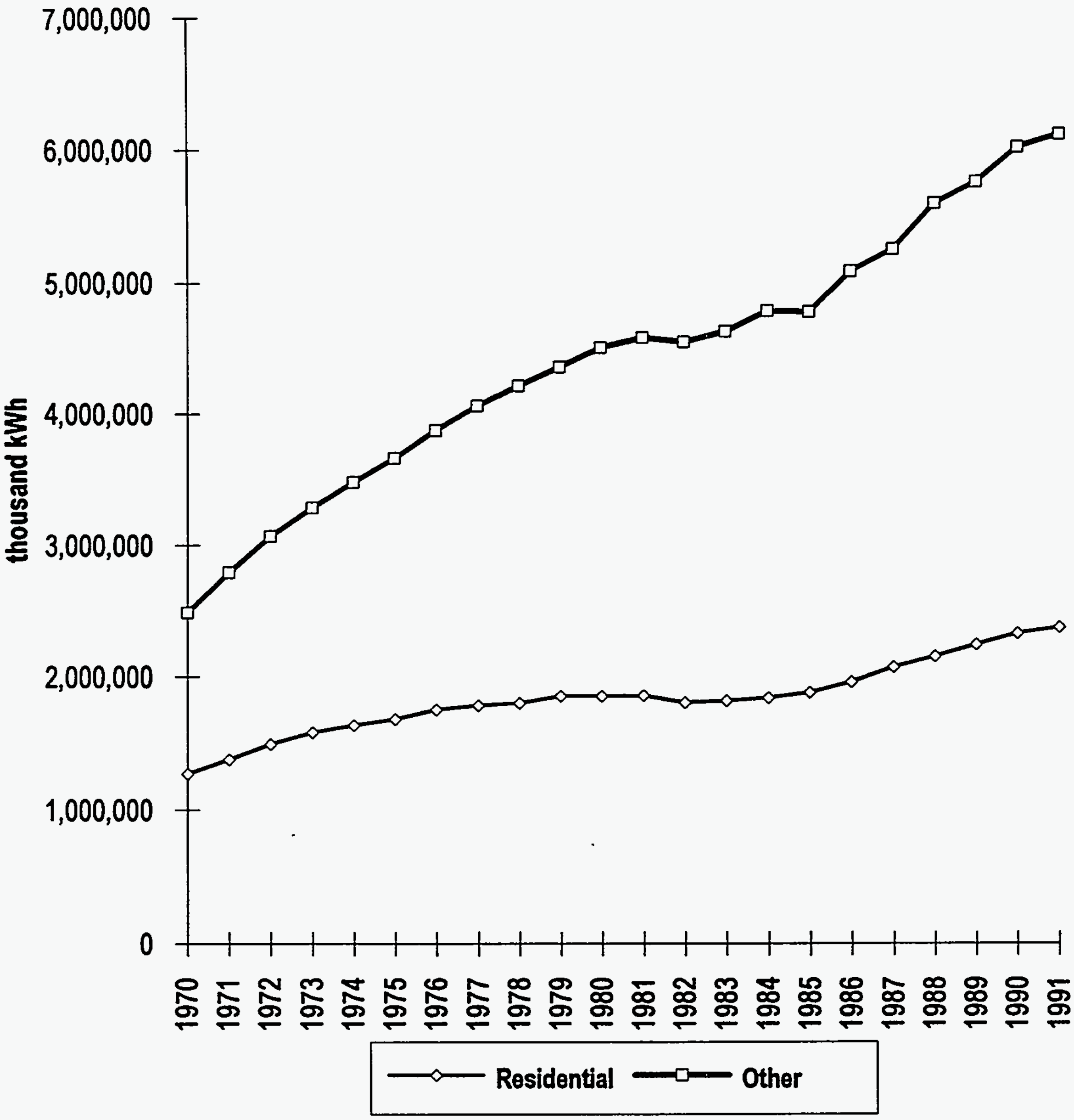


Figure 34. Electricity Sales on Oahu, 1970-91

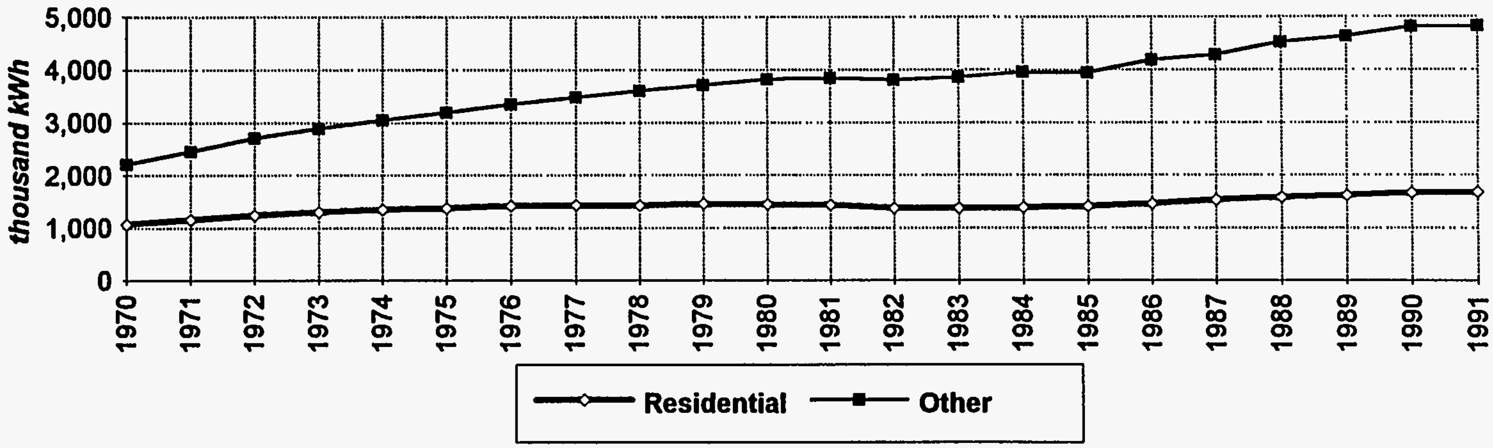


Figure 35. Electricity Sales on Maui, 1970-91

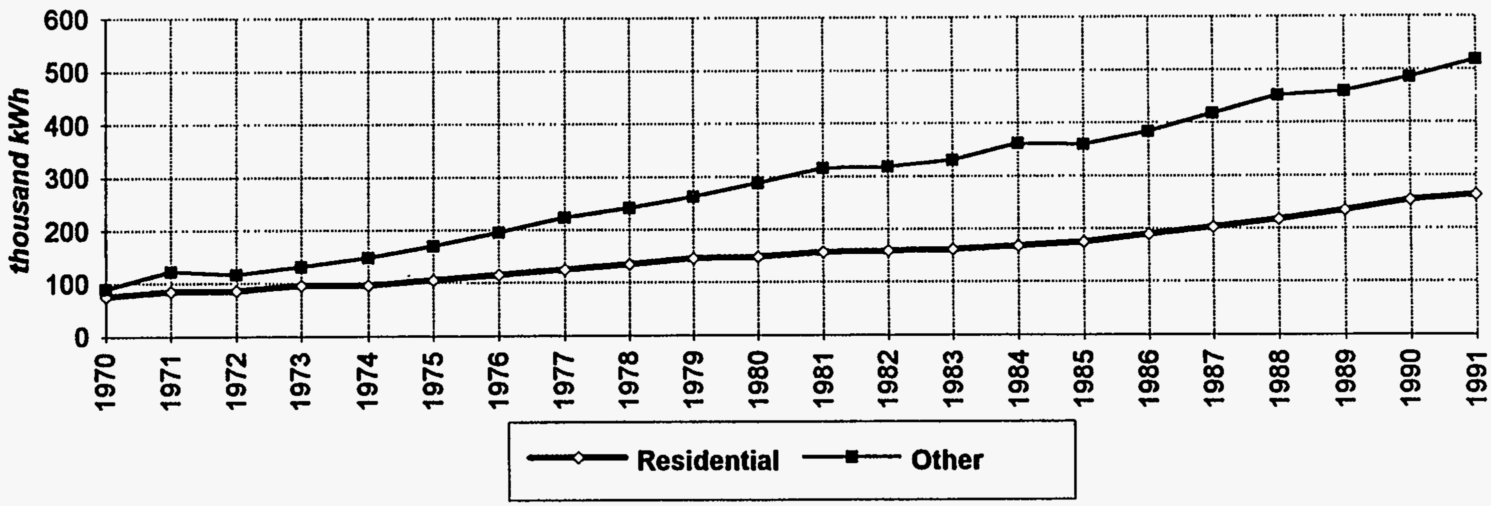


Figure 36. Electricity Sales on the Big Island, 1970-91

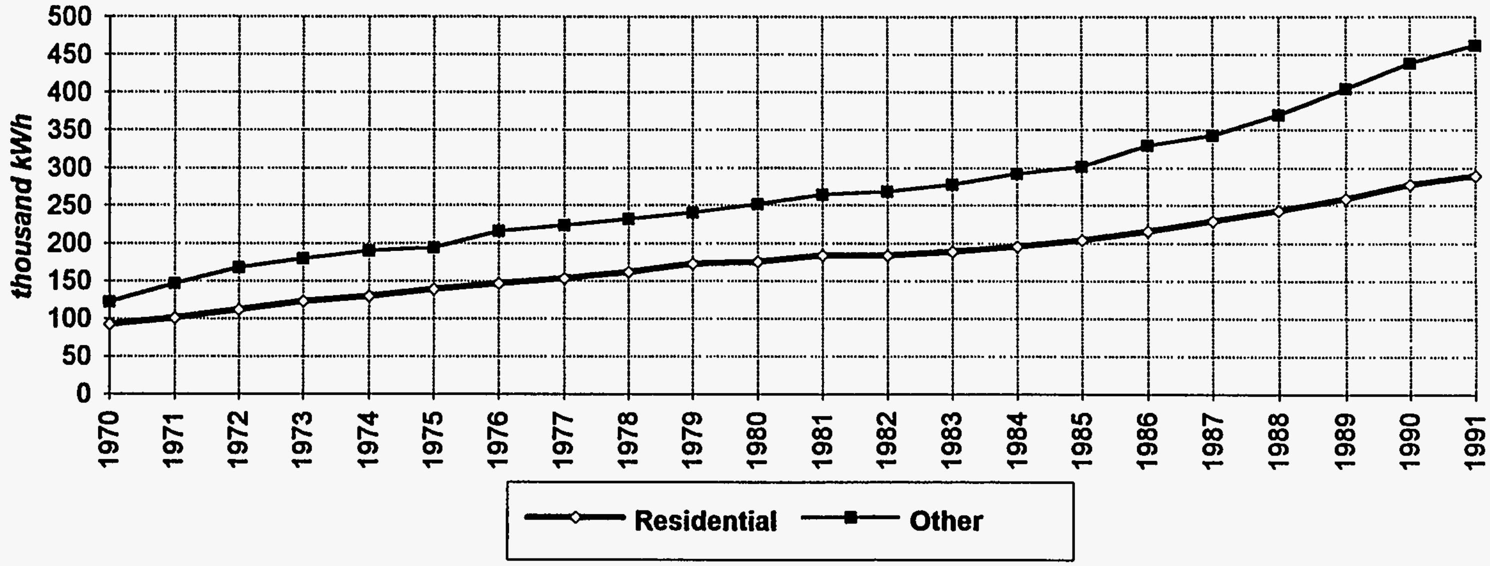


Figure 37. Electricity Sales on Kauai, 1970-91

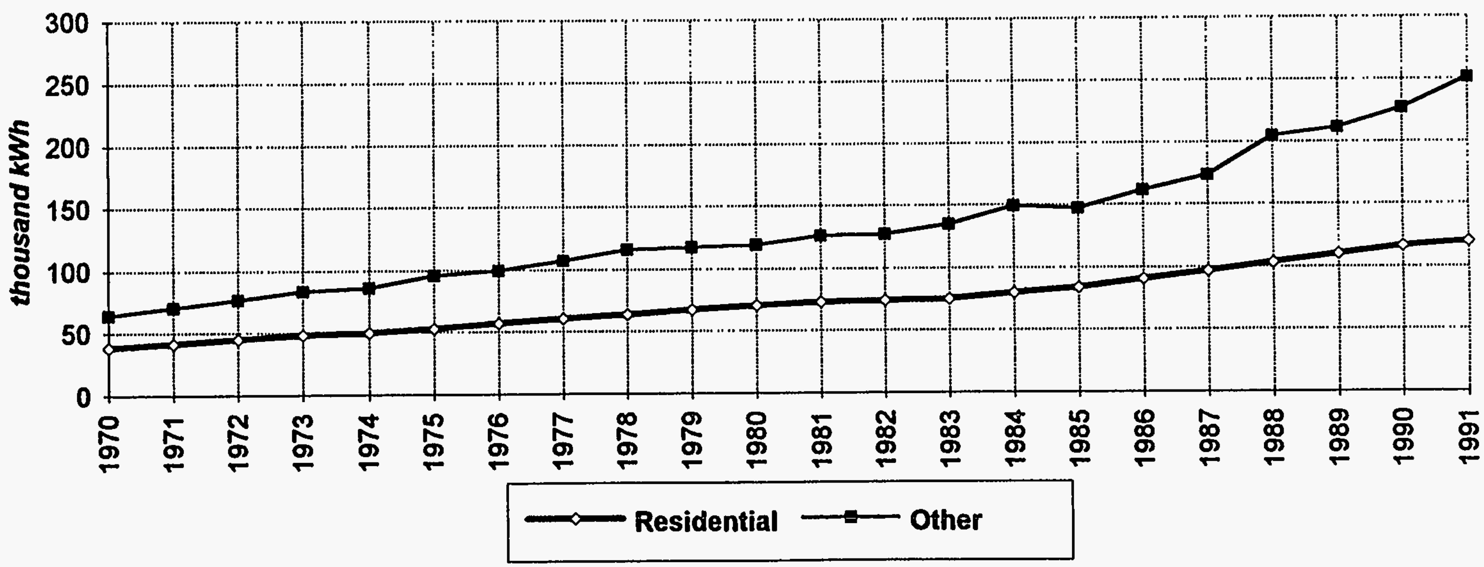


Figure 38. Electricity Sales on Molokai, 1972-91

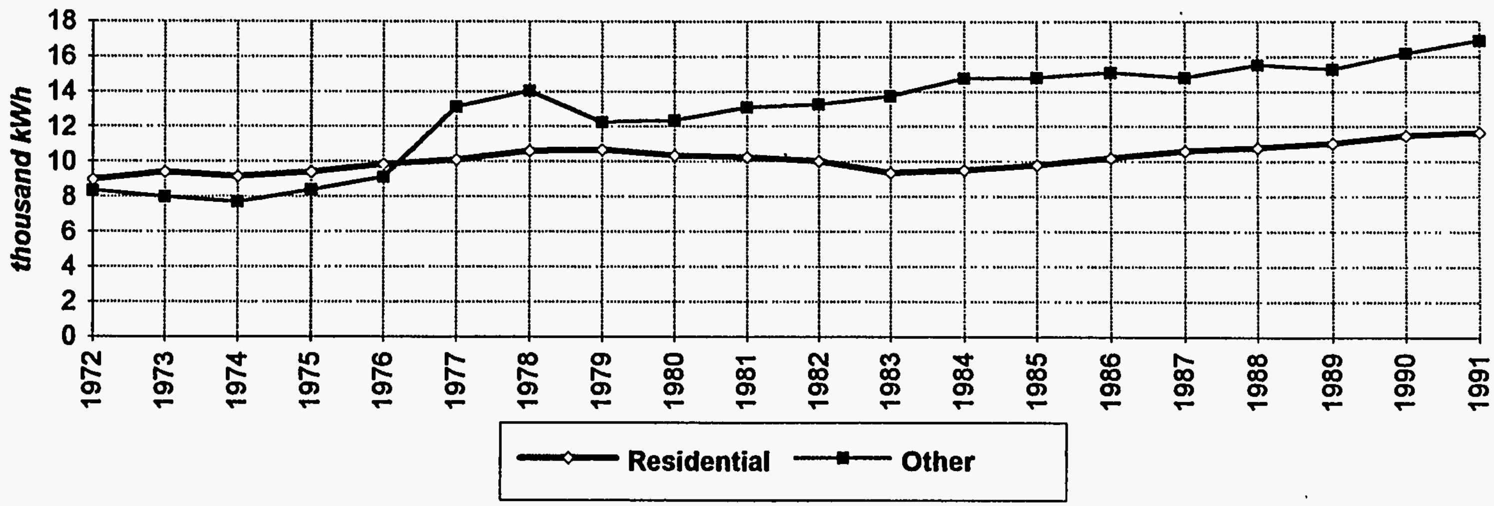
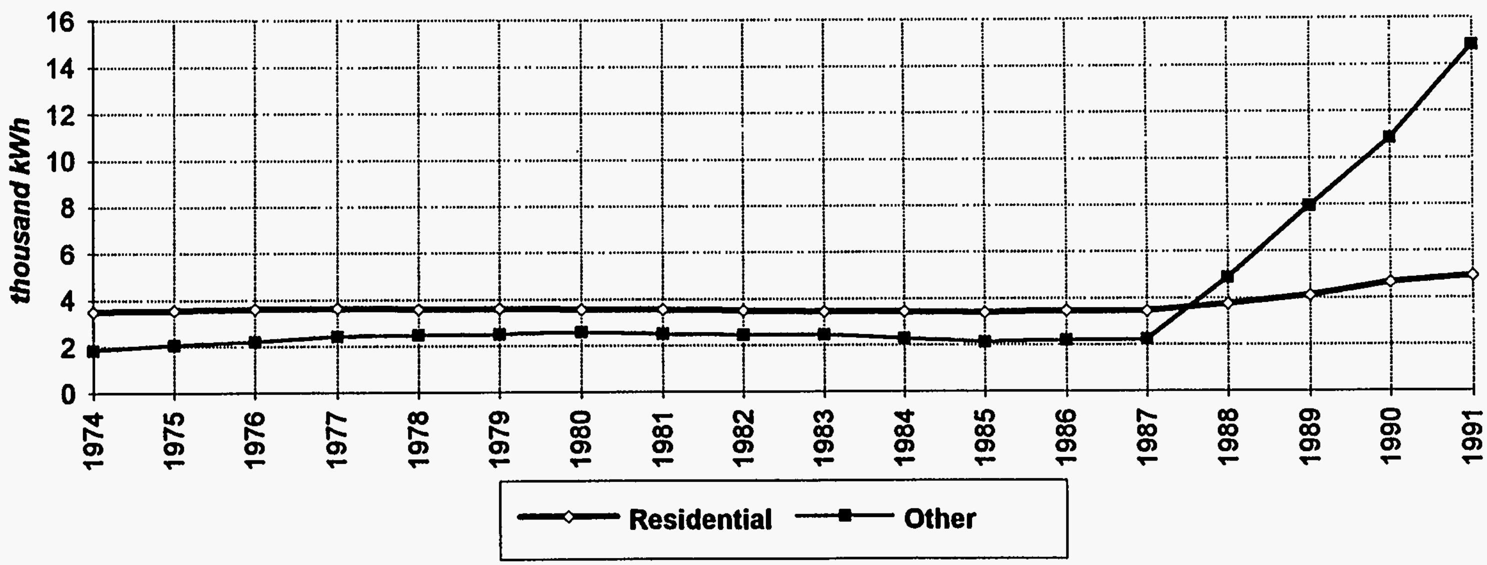


Figure 39. Electricity Sales on Lanai, 1974-91



4. Energy Balances, State and Counties, 1992

We have now summarized Hawaii's energy structure and noted the prominent role of petroleum in the energy mix. We have noted that coal is capturing a larger share of the market. Coal sources are discussed further in Chapter II below. Natural gas sources, in the form of liquefied petroleum gases (LPG) and natural gas liquids (NGL) will also be examined in greater detail in Chapter II. We have covered the various end-uses of petroleum fuels statewide and at the county level. We have described the dominance of fossil energy use in the power sector on all islands, but note the wide variation of power sector fuels on the outer islands.

In order to integrate this overload of information into a somewhat more cohesive picture, we have designed energy balance sheets for each county and for the state as a whole and prepared a simple flow chart (Figure 40). In Figure 40, energy comes either through imports of crude oil, oil products, coal, and LPG, or through local production of biomass (bagasse and solid waste), wind, geothermal, solar, and hydropower. Crude oil is transformed into oil products, which are either transformed further into electricity, are exported or used as bunkers, or are consumed locally. Oil products are also transformed into synthetic natural gas (SNG). Coal is transformed into electricity, as are most locally produced energy forms (biomass, geothermal, and so forth). Electricity is consumed locally. This provides a simple overview; more details can be gleaned from the county and state balance sheets, which appear as Tables 9 through 13.

The tables are overly busy in appearance, but the concept is simple: At the top of each balance is the list of energy forms used in Hawaii, including coal, crude oil, synthetic natural gas, petroleum products, biomass, and electricity. Each county procures supply through either production or import. Imports may arrive from other islands, other U.S. regions, international sources, or may be unknown in origin. Commodities may be exported or used for bunker fuel for local and international marine and fuel for air transport. The local consumption row is equal to production + imports - exports - bunkers - stock change. the transformation sector. For example, crude oil is transformed at the refineries to produce

Figure 40
Energy Flows in Hawaii

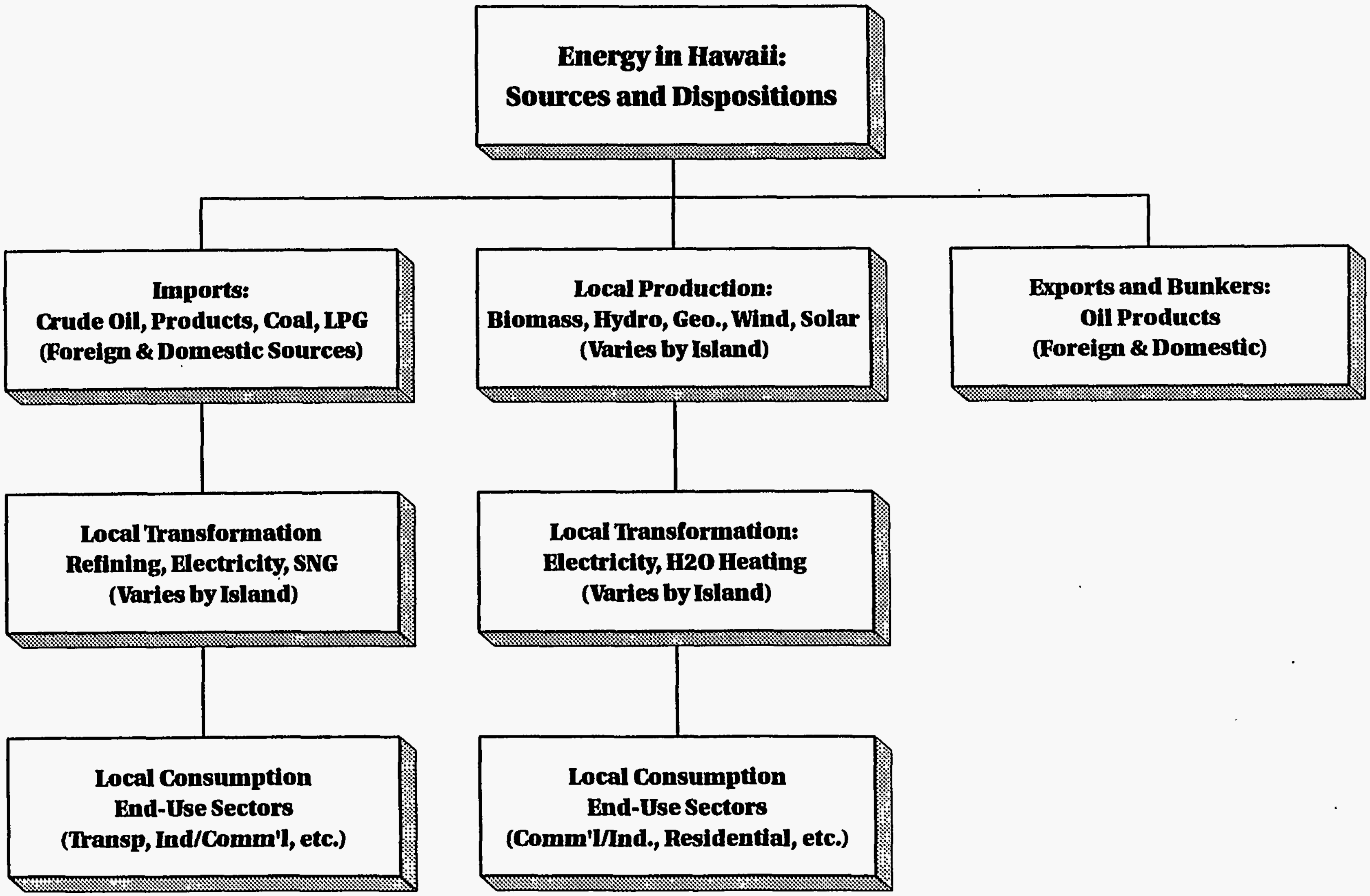


Table 9. Energy Balance Sheet, Island of Hawaii, 1992

	Coal	Crude Oil	SNG	Refinery Gases	LPG	Naphtha	Aviation Gasoline	Motor Gasoline	Naphtha Jet	Kero Jet	Diesel	Fuel Oil	Waste Oil	Other Oil Prod	Bagasse/ Biomass	Other Fuels	Electricity
	(1000 t)	*(1000 b)*			*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 bfoe)*	*(1000 boe)*	*(m kwh)*
Production													0.4		624.4		905.9
Imports:	18.7		0.0	0.0	0.0	0.0	6.2	1,024.2	0.0	146.0	995.5	2,109.3	0.0	0.0	0.0	0.0	0.0
Other Islands	18.7				?		6.2	1,024.2		146.0	995.5	2,109.3					
Other US																	
International																	
Unknown																	
Exports:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Islands																	
Other US																	
International																	
Bunkers:	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	130.1	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Aviation-Overseas										1.6							
Aviation-Local							4.3			128.5							
Marine-Local											5.3						
Marine-Other											0.6						
Stock Change																	
Local Consumption	18.7	0.0	0.0	0.0	0.0	0.0	1.9	1,024.2	0.0	15.8	989.7	2,109.3	0.4	0.0	624.4	0.0	905.9
Total Consumption	18.7	0.0	0.0	0.0	0.0	0.0	6.2	1,024.2	0.0	146.0	995.5	2,109.3	0.4	0.0	624.4	0.0	905.9
TRANSFORMATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	447.8	1,072.3	0.4	0.0	624.4	0.0	905.9
Coal Electric																	14.8
Fuel Oil Electric												1,072.3					484.2
Diesel Boiler Electric											268.7						106.6
Diesel Gen. Electric											179.1						112.1
Waste Oil Electric													0.4				0.0
Bagasse Electric															624.4		158.0
Hydroelectric																	11.8
Geothermal Electric																	1.3
MSW																	
Wind Electric																	17.2
Petroleum Refining																	
Synthetic Gas																	
Losses/Adjustment																	
Final Consumption	18.7	0.0	0.0	0.0	0.0	0.0	6.2	1,024.2	0.0	146.0	547.7	1,037.0	0.0	0.0	0.0	0.0	0.0
ROAD TRANSPORT								888.7			389.8	1.4					
AGRICULTURE	18.7						1.9	9.1			41.7	167.9					
MILITARY								0.8			5.3						
STATE GOVT								0.3			0.4	0.8					
OTHER GOVT								0.6			5.1						
CONSTRUCTION								2.2			11.5	0.1					
COMM'L/INDUSTR.					?			117.0			94.7	866.8					
RESIDENTIAL					?												

Table 10. Energy Balance Sheet, Island of Kauai, 1992	Coal	Crude Oil	SNG	Refinery Gases	LPG	Naphtha	Aviation Gasoline	Motor Gasoline	Naphtha Jet	Kero Jet	Diesel	Fuel Oil	Waste Oil	Other Oil Prod	Bagasse/ Biomass	Other Fuels	Electricity
	(1000 t)	*(1000 b)*			*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 bfoe)*	*(1000 boe)*	*(m kwh)*
Production													2.3		330.3		366.6
Imports:	0.0		0.0	0.0	0.0	0.0	1.4	383.6	2.2	39.6	1,028.4	179.1	0.0	0.0	0.0	0.0	0.0
Other Islands							1.4	383.6	2.2	39.6	1,028.4	179.1					
Other US																	
International																	
Unknown																	
Exports:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Islands																	
Other US																	
International																	
Bunkers:	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	2.2	25.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Aviation-Overseas										0.0							
Aviation-Local							1.4		2.2	25.1							
Marine-Local											1.5						
Marine-Other																	
Stock Change																	
Local Consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	383.6	0.0	14.5	1,026.9	179.1	2.3	0.0	330.3	0.0	366.6
Total Consumption	0.0	0.0	0.0	0.0	0.0	0.0	1.4	383.6	2.2	39.6	1,028.4	179.1	2.3	0.0	330.3	0.0	366.6
TRANSFORMATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	446.1	42.1	2.3	0.0	330.3	0.0	366.6
Coal Electric																	
Fuel Oil Electric												42.1					45.4
Diesel Boiler Electric											446.1						240.7
Diesel Gen. Electric																	
Waste Oil Electric													2.3				
Bagasse Electric															330.3		47.6
Hydroelectric																	33.0
Geothermal Electric																	0.0
MSW																	0.0
Wind Electric																	0.0
Petroleum Refining																	
Synthetic Gas																	
Losses/Adjustment																	
Final Consumption	0.0	0.0	0.0	0.0	0.0	0.0	1.4	383.6	2.2	39.6	582.3	137.0	0.0	0.0	0.0	0.0	0.0
ROAD TRANSPORT								366.8			439.4						
AGRICULTURE								3.8			140.5	13.0					
MILITARY										14.5	0.1						
STATE GOVT																	
OTHER GOVT								1.7			0.9						
CONSTRUCTION												1.1					
COMM'L/INDUSTR.								11.4		0.0		122.9					
RESIDENTIAL																	

Table 11.Energy Balance Sheet, Maui County-1992

	Coal (1000 t)	Crude Oil (1000 b)	SNG	Refinery Gases	LPG (1000 b)	Naphtha (1000 b)	Aviation Gasoline (1000 b)	Motor Gasoline (1000 b)	Naphtha Jet (1000 b)	Kero Jet (1000 b)	Diesel (1000 b)	Fuel Oil (1000 b)	Waste Oil (1000 b)	Other Oil Prod (1000 b)	Bagasse/ Biomass (1000 bfoe)	Other Fuels (1000 boe)	Electricity (m kwh)
Production															474.9		1,023.3
Imports:	37.8		0.0	0.0	0.0	0.0	4.1	728.0	0.0	445.8	2,114.4	1,136.8	0.0	0.0	0.0	0.0	0.0
Other Islands	37.8						4.1	728.0		445.8	2,114.4	1,136.8					
Other US																	
International																	
Unknown																	
Exports:	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Islands																	
Other US																	
International																	
Bunkers:	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	444.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation-Overseas										312.0							
Aviation-Local							3.9			133.0							
Marine-Local																	
Marine-Other																	
Stock Change																	
Local Consumption	37.8	0.0	0.0	0.0	0.0	0.0	0.2	728.0	0.0	0.9	2,114.4	1,136.8	0.0	0.0	474.9	0.0	1,023.3
Total Consumption	37.8	0.0	0.0	0.0	0.0	0.0	4.1	728.0	0.0	445.8	2,114.4	1,136.8	0.0	0.0	474.9	0.0	1,023.3
TRANSFORMATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,046.3	570.8	0.0	0.0	474.9	0.0	1,023.3
Coal Electric																	
Fuel Oil Electric												570.8					260.5
Diesel Boiler Electric											1,046.3						579.8
Diesel Gen. Electric																	
Waste Oil Electric													0.0				
Bagasse Electric															474.9		163.0
Hydroelectric																	20.0
Geothermal Electric																	
MSW																	
Wind Electric																	
Petroleum Refining																	
Synthetic Gas																	
Losses/Adjustment																	
Final Consumption	37.8	0.0	0.0	0.0	0.0	0.0	4.1	728.0	0.0	445.8	1,068.2	566.0	0.0	0.0	0.0	0.0	0.0
ROAD TRANSPORT								693.2			529.2						
AGRICULTURE	37.8						0.2	1.4		0.1	9.7	209.2					
MILITARY										0.8							
STATE GOVT																	
OTHER GOVT																	
CONSTRUCTION												1.7					
COMM'L/INDUSTR.								33.5		0.0	529.5	355.0					
RESIDENTIAL																	

Table 12. Energy Balance Sheet, City and County of Honolulu, 1992

	Coal	Crude Oil	SNG	Refinery Gases	LPG	Naphtha	Aviation Gasoline	Motor Gasoline	Naphtha Jet	Kero Jet	Diesel	Fuel Oil	Waste Oil	Other Oil Prod	Bagasse/ Biomass	Other Fuels	Electricity
	(1000 t)	*(1000 b)*	*(TBTU)*		*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 b)*	*(1000 bfoe)*	*(1000 boe)*	*(m kwh)*
Production			2.9		1,431.3	1,827.2	48.2	10,870.7	120.5	12,533.0	6,680.0	16,496.1	20.9	1,566.0	263.2		7,061.2
Imports:	277.0	48,199.3	0.0	0.0	110.0	0.2	0.0	33.1	0.0	3,968.4	357.8	1,994.7	0.0	0.2	0.0	0.0	0.0
Other US		21,697.8				0.2		33.1		2,983.9	242.1	635.8		0.2			
International	277.0	26,501.5			110.0					984.5	115.8	1,358.9					
Unknown																	
Exports:	56.5	0.0	0.0	0.0	0.0	993.0	20.4	3,939.9	0.0	830.5	3,133.3	4,645.8	0.0	574.6	0.0	0.0	0.0
Other Islands	*56.5*						*20.4*	*2135.8*		*631.4*	*2,162.2*	*2,711.0*					
Other US						320.3		1,164.3		199.1	970.3	484.9		555.1			
International						672.7		639.8			0.9	1,449.9		19.5			
Bunkers:	0.0	0.0	0.0	0.0	0.0	0.0	26.5	0.0	0.0	13,476.0	2,040.9	2,566.1	0.0	0.0	0.0	0.0	0.0
Aviation-Overseas										11,237.9							
Aviation-Local							26.5			2,238.1							
Marine-Local											261.2						
Marine-Other											1,779.7	2,566.1					
Stock Change																	
Local Consumption	220.5	48,199.3	2.9	0.0	1,541.3	834.4	1.3	6,963.9	120.5	2,194.9	1,863.6	11,278.9	20.9	991.5	263.2	0.0	7,061.2
Total Consumption	220.5	48,199.3	2.9	0.0	1,541.3	834.4	27.8	6,963.9	120.5	15,670.9	3,904.5	13,845.0	20.9	991.5	263.2	0.0	7,061.2
TRANSFORMATION	190.5	48,199.3	0.0	0.0	0.0	834.4	0.0	0.0	0.0	0.0	20.4	8,966.7	20.9	0.0	263.2	0.0	7,061.1
Coal Electric	190.5																492.5
Fuel Oil Electric												8,966.7					6,157.2
Diesel Boiler Electric																	
Diesel Gen. Electric											20.4						4.0
Waste Oil Electric													20.9				
Bagasse Electric															263.2		54.1
Hydroelectric																	
Geothermal Electric																	
MSW																	327.4
Wind Electric																	5.0
Petroleum Refining		48,199.3															20.9
Synthetic Gas						834.4											
Losses/Adjustment																	
Final Consumption	30.0	0.0	2.9	0.0	1,541.3	0.0	1.3	6,963.9	120.5	2,194.9	1,843.3	2,312.3	0.0	991.5	0.0	0.0	0.0
												6.3					
ROAD TRANSPORT					12.7			5,173.1			222.7						
AGRICULTURE								13.2			403.3	201.7					
MILITARY								31.6	118.3	1,192.8	210.6	191.1					
STATE GOVT								0.5			7.0	1.1					
OTHER GOVT							1.3	56.9		0.2	8.5						
CONSTRUCTION								17.2			74.9	36.6		361.0			
COMM'L/INDUST.	30.0		2.4		571.5			247.5		18.6	912.0	1,882.1					
RESIDENTIAL			0.5		144.8												

t = tons, b = barrels, TBTU = trillion Btu. bfoe = barrels of fuel oil equivalent boe = barrels of oil equivalent.

Table 13. Energy Balance Sheet, State of Hawaii-1992												45.35913	38.3287				
	Coal (1000 t)	Crude Oil (1000 b)	SNG (TBTU)	Refinery Gases	LPG (1000 b)	Naphtha (1000 b)	Aviation Gasoline (1000 b)	Motor Gasoline (1000 b)	Naphtha Jet (1000 b)	Kero Jet (1000 b)	Diesel (1000 b)	Fuel Oil (1000 b)	Waste Oil (1000 b)	Other Oil Prod (1000 b)	Bagasse/ Biomass (1000 bfoe)	Other Fuels (1000 boe)	Electricity (m kwh)
Production			2.9		1,431.3	1,827.2	48.2	10,870.7	120.5	12,533.0	6,680.0	16,496.1	23.7	1,566.0	1,692.9		9,245.5
Imports:	277.0	48,199.3	0.0	0.0	110.0	0.2	0.0	33.1	0.0	3,968.4	357.8	1,994.7	0.0	0.2	0.0	0.0	0.0
Other US		21,697.8				0.2		33.1		2,983.9	242.1	635.8		0.2			
International	277.0	26,501.5			110.0					984.5	115.8	1,358.9					
Unknown																	
Exports:	0.0	0.0	0.0	0.0	0.0	993.0	0.0	1,804.1	0.0	199.1	971.2	1,934.8	0.0	574.6	0.0	0.0	0.0
Other US						320.3		1,164.3		199.1	970.3	484.9		555.1			
International						672.7		639.8			0.9	1,449.9		19.5			
Bunkers:	0.0	0.0	0.0	0.0	0.0	0.0	36.1	5.6	2.2	14,084.1	2,048.2	2,566.1	0.0	0.0	0.0	0.0	0.0
Aviation-Overseas										11,551.5							
Aviation-Local							36.1		2.2	2,532.6							
Marine-Local								5.6			268.0						
Marine-Other											1,780.3	2,566.1					
Stock Change																	
Local Consumption	277.0	48,199.3	2.9	0.0	1,541.3	834.4	12.1	9,094.2	118.3	2,218.2	4,018.5	13,990.0	23.7	991.5	1,692.9	0.0	9,245.5
Total Consumption	277.0	48,199.3	2.9	0.0	1,541.3	834.4	48.2	9,099.7	120.5	16,302.3	6,066.7	16,556.1	23.7	991.5	1,692.9	0.0	9,245.5
TRANSFORMATION	190.5	48,199.3	0.0	0.0	0.0	834.4	0.0	0.0	0.0	0.0	2,160.1	10,609.8	23.7	0.0	1,692.9	0.0	9,245.4
Coal Electric	190.5																507.3
Fuel Oil Electric												10,609.8					7,015.4
Diesel Boiler Electric											1,960.6						927.1
Diesel Gen. Electric											199.5						127.1
Waste Oil Electric													23.7				
Bagasse Electric															1,692.9		281.5
Hydroelectric																	51.1
Geothermal Electric																	1.3
MSW																	327.4
Wind Electric																	31.1
Petroleum Refining		48,199.3															
Synthetic Gas						834.4											
Losses/Adjustment																	-23.8
Final Consumption	86.5	0.0	2.9	0.0	1,541.3	0.0	12.1	9,094.2	118.3	2,218.2	1,858.4	3,380.2	0.0	991.5	0.0	0.0	0.1
ROAD TRANSPORT					12.7			7,121.8			1,581.3	1.4					
AGRICULTURE	56.5						2.2	27.5		0.1	248.7	492.8					
MILITARY								32.3	118.3	1,223.3	215.9	191.1					
STATE GOVT								0.8			7.8	1.9					
OTHER GOVT							1.3	59.2		0.2	14.5						
CONSTRUCTION								19.4			88.5	39.6		361.0			
COMM'L/INDUST.	30.0		2.4		571.5			409.3		19.2	1,536.2	3,851.5					
RESIDENTIAL			0.5		144.8												

Total consumption includes bunker fuel, which in Hawaii's case makes a major difference in the overall picture.

The middle section deals with transformation. Some local consumption takes place in petroleum products, which then reappear in the top row as production figures (on Oahu only; the other islands receive product supply via imports from Oahu). Coal, diesel, fuel oil, waste oil, and bagasse are transformed into electricity in the transformation section. Naphtha-range material is transformed into synthetic natural gas (SNG). Total consumption minus transformation equals final consumption, where we have allocated the fuels to their end-uses as well as the existing data would permit—which is to say, not very well. These energy balances are not presented here as a definitive guide, but we believe that a model such as this one is a useful one for the state.

It is, of course, up to state planners (DBEDT, PUC, DCCA, for example) to decide the level of sectoral breakdown fits within the bounds of the desirable and the possible. Numerous data gaps remain. For example, the entire LPG/SNG/naphtha situation has been impossible to sort out (even, apparently, by those working in the industry). Naphtha-range material is used as a feed to the SNG plant, and gasified propane may also be used, but data are not available as to how much of which feeds were used. Additionally, there is no published data on LPG trade, international or interisland. LPG imports simply materialize, and their importers apparently do not file supply forms that parallel the forms required from the refiners and oil companies. During the course of our research, we had to contact LPG shippers based in New York to tell us the details of LPG shipments into Hawaii. This is like buying the *New York Times* in order to see what the weather report is for Honolulu, but it was the only way to verify which LPG ships had called at Hawaii ports.

Another factor that makes it impossible to complete the balances as they are now structured is that, as noted above, electricity sales are not recorded by the same end-use sectors. The only end-use category that appears consistent is the residential sector.

The disposition of autoproducers and cogenerators should also be indicated in the balance. For example, if the refineries use fuelgas, LPG, or fuel oil to produce electricity, their generation, net sales, and fuel use should be accounted for to complete that balance. A final point is that utility records of fuel oil and diesel consumption volumes significantly exceed the figures that are inferred from oil supplier records. It may be that utility oil requirements are at times excluded from total consumption, or it may be that utility purchasers have procured fuel from outside the system.

We present these balances with caveats as works in progress; ideally, as the HES project continues, more of the gaps can be filled in. In the interim, they at least provide a rough guide to the types of energy used by island, the transformation processes, and the final consumption. In the longer term, the balances may actually balance.

II. Fossil Fuel Imports

A. Crude Oil: Current and Future Sources

Hawaii's position in the middle of the Pacific Ocean affords conveniences and inconveniences in terms of importing crude oil. On the one hand, Hawaii is in Petroleum Administration for Defense District V (PADD-V). PADD-V is currently a crude-surplus region, by virtue of Alaskan and Californian production levels of around 1.8 and 1.0 million barrels per day (mmb/d) respectively. Alaska and California are in fact the second- and fourth-largest oil producing states in the United States. Hawaii is also linked to the greater Asia-Pacific oil market, where the typical crudes produced are very low in sulfur and thus are desirable refinery feedstocks. Additionally, Hawaii is in a relatively good position to benefit from possible future production of unconventional heavy crudes in Western Canada and Latin America, though processing large quantities of heavy crudes would entail additional investment in refinery downstream capacity. So, it might be said that Hawaii is in the middle of an active oil market, and that the size of Hawaii's market is so small that its needs can easily be fulfilled.

On the other hand, it can be said that Hawaii is equally far away from all sources of oil, and that the state is dangerously dependent on non-indigenous energy resources, chief among which is oil. Alaskan and Californian crude production levels are entering a period of decline, and the oil demand boom in Asia will be absorbing ever-greater volumes of crude that otherwise would be entering the market. Hawaii is not dependent on "insecure" sources of oil from politically unstable regions. But if the state's appetite for oil continues to grow, and demand in the rest of the world continues to grow, the day will come when Middle Eastern oil producers once again wield great control over oil markets around the world. There is little doubt that Hawaii is a price-taker, with little or no market power, that the state's economy is vitally dependent on imported energy, and that the state's economy is also linked to the vagaries of the U.S., Asia-Pacific, and world economies.

1. Petroleum Supply Logistics and Infrastructure

The Island of Oahu is the center of Hawaii's petroleum industry. Located on Oahu are Hawaii's two refineries, the major marine terminals, and the bulk of the petroleum storage capacity. The four major locations for these facilities are Campbell Industrial Park (Barbers Point), Honolulu Harbor, Honolulu International Airport, and Red Hill. These sites are connected by a network of pipelines which move petroleum products from the refineries to storage and consumption sites. Figure 41 illustrates the infrastructure.[5]

Crude oil arrives at Oahu via LR (large range) oil tankers of around 80,000 to 100,000 deadweight tons (dwt).[6] They unload their cargo at one of two mooring facilities located between one and two miles offshore at Barbers Point. These mooring facilities are operated by the two refineries, Chevron and Hawaiian Independent Refinery, Inc. (HIRI, owned by BHP), and are linked by underwater pipeline directly to the respective refineries at Campbell Industrial Park. Each mooring facility can accommodate tankers of 100,000 dwt unloading at a rate of up to 30,000 barrels per hour. A traveler flying in to Honolulu will often see tankers at the offshore moorings. The two are quite distinctive: Chevron's mooring is closer to shore and is a fixed-point mooring, while BHP's mooring is further offshore and is a single-point mooring. From the air, it can be seen that a tanker calling at the Chevron mooring will be moored by lines to buoys surrounding the ship, and its position will be fixed. In contrast, a tanker calling at the HIRI refinery will be anchored to a single buoy that will swivel as currents and winds change.

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[5]Additional details and maps can be found in Edward K. Noda and Associates, Inc., "A Study of the Aviation Fuels Industry in Hawaii for the Purpose of Energy Emergency Preparedness," prepared for DBEDT, August 1992. Also see Williams Brothers Engineering Co., "A Relocation Program and Development Plan for Petroleum-Oil-Lubricants (POL) Facilities in the Honolulu Waterfront," prepared for DBEDT, August 1992.

[6]Deadweight tonnage (dwt) is the weight of the ship's cargo, fuel, and stores. In a large tanker, most of the deadweight tonnage is cargo. A good rule of thumb is to assume that 95 percent of a large tanker's dwt is cargo.

Figure 41. Oahu's Petroleum Infrastructure

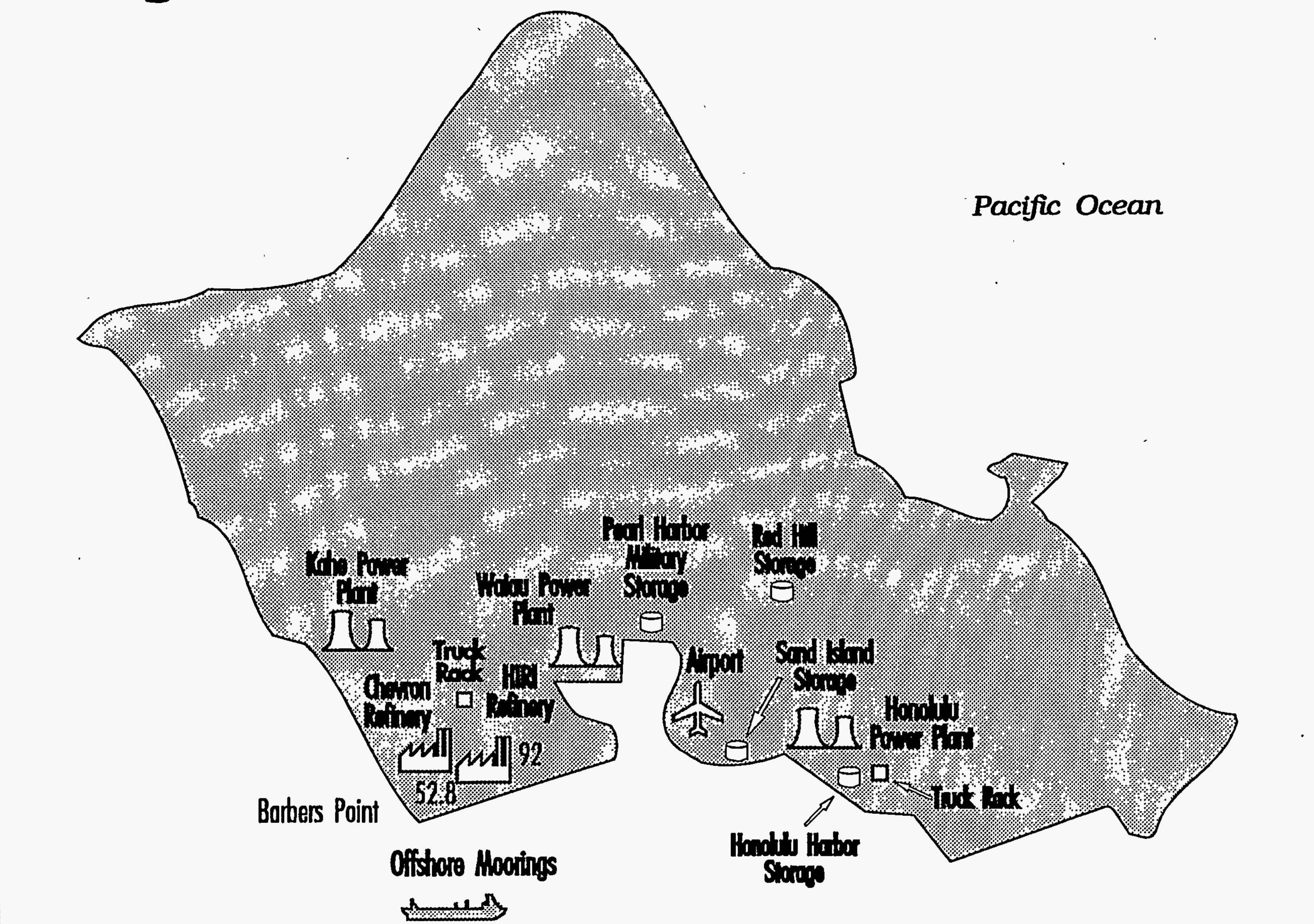


Table 14 provides a summary of marine distances to Hawaii from key oil sources and markets in the Americas, the Asia-Pacific region, the Middle East, and Africa.

To provide a more detailed look at the logistics of oil transport in Hawaii, Table 15 presents a few typical voyages and descriptions of ships recently calling at Oahu ports.[7] Presented in the table are two large range crude tankers, the *Apache Spirit* used in 1992 to bring crude and low-sulfur waxy resid (LSWR) from Australia, Indonesia, and Singapore; and the *Palmstar Cherry*, used to bring crude, LSWR, and low-sulfur fuel oil (LSFO) from Australia. Also noted are two product tankers, the *Philadelphia Sun*, employed to bring diesel and light cycle oil (LCO) in from California and to take naphtha and reformate back on the return trip; and the *Umm Said*, which has been used to import LSWR and export high-sulfur fuel oil (HSFO). Shipping costs are greatly reduced when round trip routing is possible. Accordingly, clean product tankers calling at Hawaii ports will most likely bring in a product such as diesel or LCO and take aboard naphtha, while a dirty product or crude tanker will deliver crude and/or LSWR/LSFO and will take aboard surplus HSFO.

Once unloaded, crude oil is stored at the refineries while awaiting refining. Because of the large quantity of crude oil that is contained in an oil tanker (around 700,000 barrels for the size tanker commonly used in Hawaii), and because of the long delivery time involved, the refineries have significant storage capacity. The combined storage capacity of crude oil, intermediate product and refined product at the two refineries is 9,100,000 barrels—roughly two months' supply if fully utilized.

Most product moves from the refineries via pipeline. The location and capacity of this network of pipelines is summarized in Table 16. Each refinery is connected by pipeline to the Barbers Point Harbor, where product can be loaded as well as unloaded. HIRI also has the capability to load and unload product via its Barbers Point offshore mooring facility.

[7] *Journal of Commerce Import Bulletin* and BHP provide voyage details, while ship characteristics are taken from *The Tanker Register*, published by Clarkson Research Studies, Ltd., London.

Table 14. Marine Distances: Key Oil Sources/Markets to Honolulu
(Nautical Miles and Days Steaming)

	Nautical Miles To Honolulu:	*# of Days Voyage, 14 knots speed:*
Africa		
Nigeria, Port Harcourt	10,008	29.8
Asia/Pacific		
Australia, Brisbane	4,120	12.3
Australia, Cairns	4,718	14.0
Australia, Melbourne	4,940	14.7
Australia, Sydney	4,425	13.2
China, Shanghai	4,336	12.9
Guam	3,333	9.9
Indonesia, Balik Papan	5,182	15.4
Indonesia, Jakarta	5,934	17.7
Indonesia, Straits of Lombok	5,446	16.2
Indonesia, Surabaya	5,598	16.7
Hong Kong	4,857	14.5
New Zealand, Auckland	3,850	11.5
Philippines, Manila	4,767	14.2
Singapore	5,877	17.5
South Korea, Inchon	4,312	12.8
Thailand, Bangkok	6,319	18.8
Taiwan, Keelung	4,350	12.9
Tahiti, Papeete	2,381	7.1
Japan, Tokyo	3,455	10.3
Vietnam, Saigon	5,542	16.5
Middle East		
Qatar, Umm Said	9,532	28.4
North America		
Longview, Washington	2,287	6.8
Los Angeles, California	2,231	6.6
Portland, Oregon	2,329	6.9
San Francisco, California	2,095	6.2
Seattle, Washington	2,403	7.2
Vancouver, British Colombia	2,419	7.2
Latin America		
Ecuador, Guayaquil	4,853	14.4
Panama Canal	4,732	14.1
Trinidad and Tobago, Port of Spain	5,887	17.5
Venezuela, Maracaibo	5,328	15.9

Source: BP World-Wide Marine Distance Tables and Reed's Marine Distance Tables.

Table 15. Characteristics of Oil Tankers Calling at Hawaiian Oil Terminals

	Crude Oil/Dirty Tankers:			Product Tanker:
	Apache Spirit	*Palmstar Cherry*	*Umm Said*	*Philadelphia Sun*
Deadweight Tonnage	104,999	98,444	90,055	34,090
Draft (ft)	50.91	47.04	41.99	35.49
Length Overall (ft)	810	803	809.84	612
Breadth (ft)	139.4	135.2	138.97	90.19
Flag	Liberia	Bahamas	Qatar	American
Year Built	1991	1990	1990	1981
Site Built	Rijeka	Onomichi	Imabari	Chester
Speed (knots)	15	14.5	14	16
Features:				
Double Hull				
Double Bottom	yes			
Crude Oil Washing (COW)	yes	yes	yes	
Inert Gas System (IGS)		yes		yes
Gas Freeing System (GF)			yes	yes
Segregated Ballast Tanks (SBT)	yes	yes	yes	yes
Clean Ballast Tanks (CBT)	yes		yes	yes
Heating Coils (HC)			yes	yes
Tank Cleaning				yes
Typical Cargo	Crude/FO	Crude/FO	FO/Crude	Clean Products

Source: Clarkson's Tanker Register 1992 and Lloyd's Green Tanker Guide

Table 16. Major Petroleum and SNG Pipelines on Oahu

Diameter	Source	Destination	Product
8"	Chevron Refinery	Honolulu Harbor	black oil
8"	Chevron Refinery	Honolulu Harbor	clean product
8"	Harbor	onolulu Power Plant	black oil
10"	Chevron Refinery	Kahe Power Plant	black oil
10"	HIRI refinery	earl Harbor Middle, Pearl Harbor East, Sand Island, Honolulu Harbor	clean product
16"	Enerco	Honolulu Harbor	SNG
16"	Red Hill	Pearl Harbor Middle	(clean)
8"	earl Harbor Middle	Barbers Point NAS	(clean)
8"	earl Harbor Middle	Barbers Point NAS	(clean)
16"	Red Hill	Pearl Harbor East	(clean)
8"	Pearl Harbor East	ickam AFB, Kipapa	(clean)
8"	Pearl Harbor East	ickam AFB, Kipapa	(clean)

Gasoline destined for use on Oahu is loaded onto tank trucks either at the Texaco truck rack facility at Campbell Industrial Park or truck rack facilities owned by Chevron, Aloha Petroleum, Shell, HIRI, and Unocal located in the Honolulu Harbor area. Gasoline is piped to these locations directly from the refineries. The Honolulu Harbor area can also receive gasoline shipments from out of state. Gasoline destined for the neighbor islands is loaded onto barges at Honolulu Harbor. HIRI has also from time to time shipped gasoline out of state from its Barbers Point offshore mooring facility.

Diesel distribution for on-highway uses is similar to gasoline distribution, but diesel is also used by all four electric utilities: Hawaii Electric Company, Maui Electric Company, Hawaiian Electric Light Company, and Kauai Electric Division (HECO, MECO, HELCO, and KED).

Jet fuel is transported by pipeline to civilian storage locations at Honolulu International Airport, Sand Island Bulk Fuel Storage (not actually on Sand Island), and Honolulu Harbor. The storage facilities at Honolulu International Airport and Sand Island are owned by the Hawaii Fueling Facilities Corporation (a consortium of 25 air carriers) and are operated by the Pipeline and Tank Farm Department of Lockheed Air Terminal. The total jet fuel storage capacity at these two locations is 1,062,000 barrels (948,000 barrels at Sand Island and 114,000 barrels at the airport). Most airplanes refuel on Oahu; however, a small amount of jet fuel is barged to Hilo, Kahului, and Nawiliwili from Honolulu Harbor and Barbers Point Harbor. Jet fuel imported by various airlines is received at Honolulu Harbor and transferred to Sand Island.

Jet fuel is also delivered by pipeline to military storage facilities located at Pearl Harbor, where it can be transported by pipeline to and from the military's main storage facility in Red Hill.

On Oahu, the major consumers of residual fuel oil are the Hawaiian Electric Company power plants at Kahe, Waiau, and Honolulu. The Kahe power plant is served by a direct pipeline connection from Campbell Industrial Park. This pipeline provides low-sulfur (less than 0.5 percent sulfur) residual fuel oil produced by both refineries. Fuel oil imported directly by HECO is unloaded via the Chevron offshore mooring facility and is delivered to storage tanks owned by HECO located at a site adjacent to the Chevron refinery. The Honolulu power plant is served by a pipeline originating from the Honolulu Harbor storage facilities which receives residual from the Chevron refinery. Fuel oil (mostly high-sulfur) is also exported from Oahu to the neighbor islands and to foreign destinations. The larger neighbor islands—Hawaii, Maui and Kauai—have all used fuel oil as well as diesel for power generation, but there is now more interest in using diesel in order to avoid the risks of accidental spills of fuel oil. Diesel is a lighter petroleum product than fuel oil; it evaporates more readily and therefore creates less of an oil slick.

As well as receiving product directly from the HIRI refinery via pipeline, the military complex in the Pearl Harbor area also receives direct product shipment through Pearl Harbor. The total storage capacity of the military complex is 8,500,000 barrels with the majority of this storage located underground in the Red Hill storage facility. A listing of oil storage capacity is provided in Table 17.

The petroleum infrastructure on the neighbor islands consists of harbor storage facilities which receive product shipped mainly from Oahu. A small amount of product is also shipped directly to the neighbor islands from out of state. The harbors which receive product are located at Hilo and Kawaihae on the Big Island, Port Allen and Nawiliwili on Kauai, Kahului on Maui, Manele Bay on Lanai, and Kaunakakai on Molokai. Figure 42 provides a map of the locations of Hawaii's oil terminals and ports.

2. Hawaii's Refineries

In Task I (*World and Regional Fossil Energy Dynamics*), Hawaii's refineries are described in terms of their complexities relative to other refinery industries worldwide. We also presented explanations of refinery technologies and processes, and the chemical properties of hydrocarbons. Here, we will describe the refineries briefly in the context of the Hawaiian oil market. Both refineries have a long-established presence in the market and play a vital role in providing consumer energy.

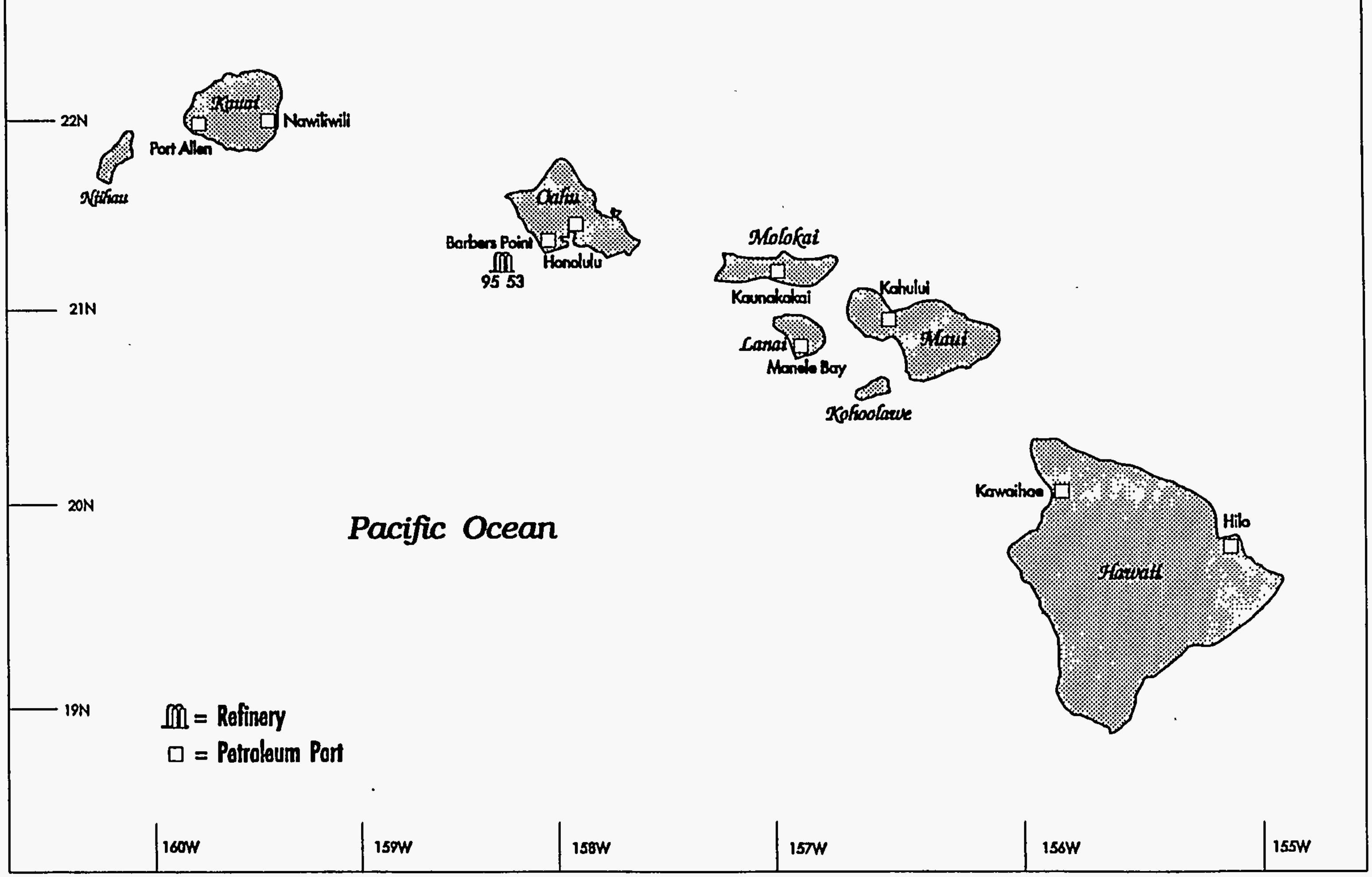
Table 17. Petroleum Storage Capacity in Hawaii

(barrels)

Oahu	crude	gasoline	jet fuel	diesel	marine	residual	not classified	Total
Refineries	*4,000,000*					1,100,000	4,100,000	9,200,000
Honolulu Harbor							*1,900,000*	1,900,000
Honolulu Airport/Sand Island			1,062,000					
Hawaiian Electric Plant Sites						300,000		300,000
Pearl Harbor/Red Hill (Military)		89,732	4,010,052	6,208	4,104,606	312,320		8,522,918
Gasoline/Service Stations		not available						0
Subtotal Oahu	4,000,000	89,732	5,072,052	6,208	4,104,606	1,712,320	6,000,000	19,922,918
Maui			67,825			112,950		180,775
Hawaii			32,520			134,360		166,880
Kauai			6,125			42,545		48,670
Lanai			0					0
Molokai			0					0
Unclassified Neighbor Islands						289,855	794,530	1,084,385
Total	4,000,000	89,732	5,178,522	6,208	4,104,606	2,292,030	6,794,530	21,403,628

Source: DBET "The State of Hawaii Emergency Preparedness Plan and Reference Book," June 1991.

Figure 42
Petroleum Ports in the Hawaiian Islands



Ground breaking for the Chevron refinery occurred in October 1958. The startup of this facility in 1960 ended what had been total reliance on imported oil products. By the following year, the refinery's fluid catalytic cracker (FCC) had been completed, increasing production of high-octane gasoline blending components. In 1987, Chevron installed a dimersol plant to further increase high-octane blendstock production. This plant uses a fairly simple polymerization process to convert refinery butene into an olefinic hydrocarbon, known as dimate, in the gasoline boiling range. Dimate, also known as polymer gasoline, has an octane rating of around 89.9 (R+M)/2. This compares quite favorably with unleaded mid-grade gasoline, which is typically 89 (R+M)/2. The Chevron refinery also uses sulfuric acid alkylation and butane isomerization to further convert refinery gases into gasoline blendstock. Isomerization reactions improve octane ratings by converting paraffins into isoparaffins or cyclopentanes into aromatics. Isomerate from C4 feeds typically has octane ratings of around 77 (R+M)/2. Isopentane (Iso-C5) has an octane rating of around 90-91 (R+M)/2. Alkylate from C4 feeds has an even higher octane rating of around 94 (R+M)/2.

The Chevron refinery has been expanded and revamped several times since its inception. In 1990 a cogeneration plant was added, making the refinery self-sufficient in electricity supply. Any surplus electricity is sold to HECO. The current capacity is rated at around 53 thousand barrels per day (mb/d).

The BHP refinery is rated at 95 mb/d, giving a total refining capacity in Hawaii of 147 mb/d. Table 18 shows the process capacities and technologies employed by the two refineries. When the Hawaiian Independent Refinery (HIRI) was built in 1972, it initially had a crude capacity of only 29.5 mb/d. The process of expansion has been almost continual: capacity was raised to 45 mb/d in 1974, 59.5 mb/d in 1975, 67.9 in 1979, 77 mb/d in 1990, and 90.25 mb/d in 1991. In 1974, the company also built a catalytic reformer to increase gasoline production. The reformate from this process has octane numbers ranging from around 78-94 (R+M)/2, depending on reformer severity. In 1981, the hydrocracker (HDC) was completed, greatly increasing the refinery's ability to convert heavy fuel oil into jet fuel and other light products. The HDC unit was expanded in 1985 to reach

Table 18. Refinery Capacity and Upgrading Technologies Employed in Hawaii, 1993

(thousands of barrels/day capacity)

Type of unit and abbreviation:	Chevron	HIRI	Total	*Generic type of technology*
Crude Distillation (CDU)	52.8	92.0	144.8	*(Basic)*
Vacuum Distillation (VDU)	30.0	39.0	69.0	*(Basic)*
Visbreaking (VBR)		12.4	12.4	*mild thermal cracking, conversion of heavy fuel oil*
Fluid Catalytic Cracking (FCC)	19.0		19.0	*Cracks heavy material into high-octane gasoline blendstocks*
Hydrocracking (HDC)		16.7	16.7	*Cracks heavy material into high-quality jet fuel or diesel blendstocks*
Catalytic Reforming (Catref)		12.4	12.4	*Converts low-octane heavy naphthas into high-octane gasoline blendstock*
Naphtha Hydrotreating (Nap HDT)	3.0	10.5	13.5	*Pretreats naphtha feeds to remove sulfur*
Alkylation (Alky.)	4.0		4.0	*Utilizes refinery gases to produce gasoline/aviation gasoline blendstock*
Polymerization (Poly.)	1.0		1.0	*Utilizes refinery gases to produce high-quality gasoline blendstock*
Butane Isomerization (C4 Isom)	1.2		1.2	*Utilizes refinery gases to produce high-quality gasoline blendstock*
Asphalt (ASP)	1.3	1.0	2.3	*Converts heavy vaccuum bottoms into asphalt*
Hydrogen Plant (H2, in mmcfd)	2	16.9	18.9	*Produces hydrogen for use in hydrotreating/hydrocracking*

Source: Unit capacities as reported by Oil and Gas Journal, "Annual Refining Survey."

a total capacity of 16 mb/d, and was revamped again in 1991 to reach 17 mb/d. A visbreaker was added in late 1987 to convert additional quantities of heavy material into lighter products. The BHP refinery is now a jet-fuel maximizer. The refinery is also a cogenerator, selling surplus electricity to HECO.

3. Foreign Sources of Crude Oil

Foreign sources supply the majority of Hawaii's crude oil. Currently, Alaskan crude represents around 45 percent of the state's crude slate, with foreign crudes—primarily from Indonesia, China, Malaysia, and Australia—making up the remainder. Table 19 provides a breakdown of foreign crude imports by source, 1985-92. Foreign crude imports typically amount to 60-80 thousand barrels per day, most of which originates in the Asia-Pacific region, but recent import data shows a small amount of diversification in the form of certain Latin American crudes. Figure 43 displays foreign imports in graphic form.

An interesting feature of Latin American crudes is that some of them are among the heaviest and sourest in the world. There is a fairly common misperception that Hawaii's refineries lack the ability to process heavy, sour crudes. Many seem to believe that we could not accept Middle Eastern crudes because of their poorer quality relative to Asian crudes. This is only partly true. It is true that the refineries would be unable to produce the same output of high-quality fuels (low-sulfur light and middle distillates) if they were given a steady diet of Latin American crudes rather than Asian crudes, but it is not true that the refineries simply are unable to process such crudes. Chevron's asphalt unit, for example, readily uses the superheavy (10-11° API), ultra-sour (5.5 percent sulfur) Boscan crude from Venezuela.

In terms of processing heavy, sour crudes in other units, the main constraint is the refineries' hydrogen balances and downstream processing capabilities. Hydrogen is used in refineries to desulfurize feedstocks and blendstocks; the hydrogen molecules bond with sulfur in oil, forming hydrogen sulfide gas (H_2S) which can then be processed to yield elemental sulfur. The sulfur can be sold for, among other things, chemical and pharmaceutical uses.

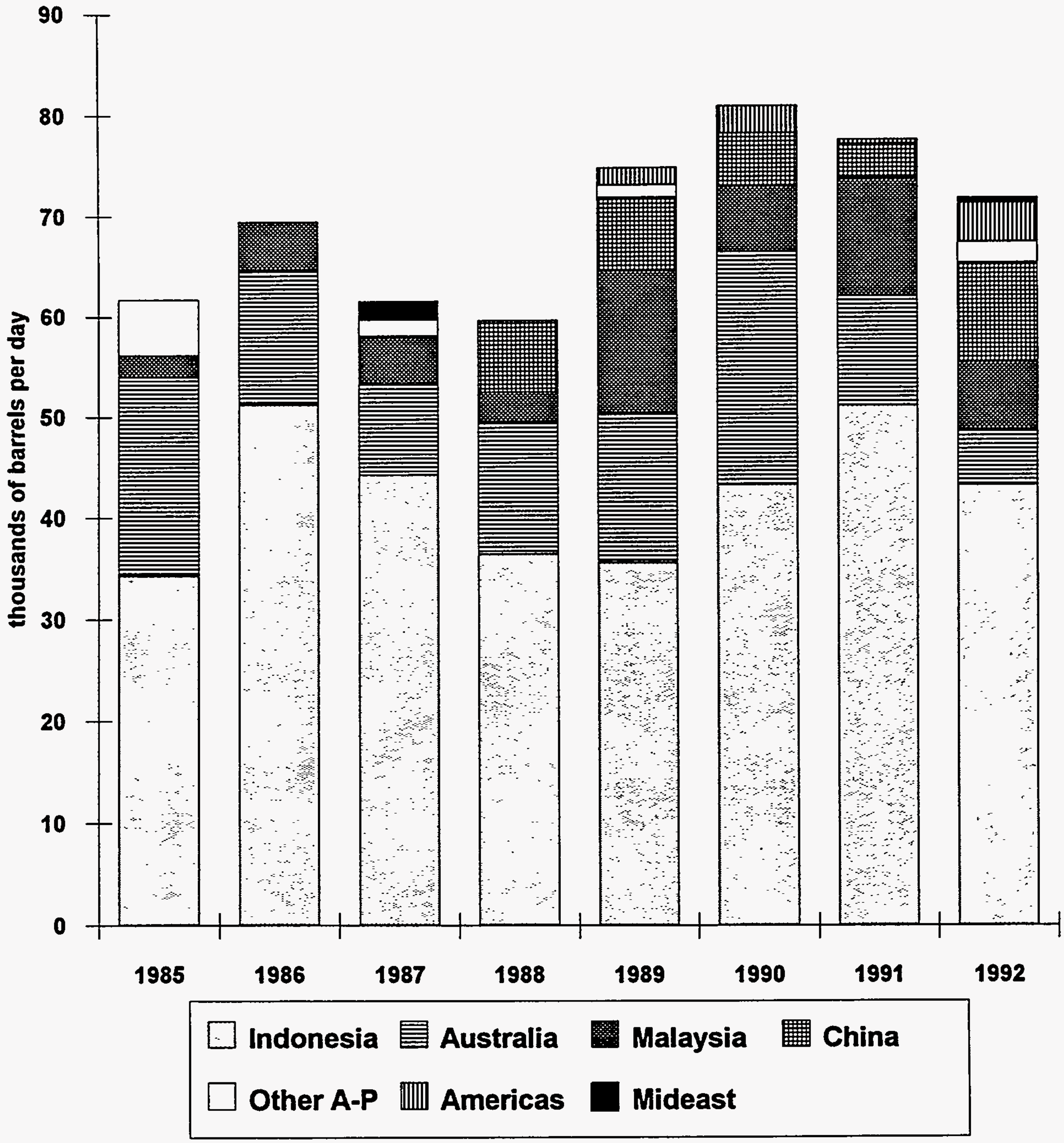
Table 19. Hawaii Crude Imports by Source, 1985-1992

(thousands of barrels/day)

	1985	1986	1987	1988	1989	1990	1991	1992
Asia:								
Austr/NZ	19.70	13.47	9.06	13.07	14.73	23.10	10.81	5.46
Brunei					1.27			
China				7.10	7.25	5.31	3.39	9.85
India	5.57							
Indonesia	34.28	51.24	44.19	36.45	35.55	43.16	51.06	43.10
Malaysia	2.18	4.74	4.80	2.95	14.11	6.39	11.57	6.72
PNG								2.03
Singapore			1.63					
America:								
Argentina								1.02
Canada								0.48
Ecuador					1.71	2.67		1.90
Venezuela							0.47	0.44
Mideast:								
Oman								0.54
Saudi Arabia			1.84					
Total	61.73	69.45	61.52	59.57	74.62	80.63	77.30	71.54

Source: Pacific West Oil Data

Figure 43. Foreign Crude Imports into Hawaii, 1985-1992



Refineries are in fact the largest suppliers of sulfur in the United States. The sourer the crude, the more hydrogen is required to desulfurize the refined products. Hydrogen is expensive to produce. Chevron's hydrogen is generated chiefly by the catalytic reformer, which takes mainly straight-chain hydrocarbons and "reforms" them into octane-rich, aromatics-rich reformate for gasoline blending. As the section on oil refining noted, aromatics are six-carbon ring structures with alternating double bonds; the carbon-to-hydrogen ratio is therefore much higher than that of straight-chain paraffins, and the reforming process yields hydrogen. The hydrogen can then be used in other refining processes, such as pre-treatment of heavy naphtha feeds used in the catalytic reformer or vacuum gasoils used as catalytic cracker feeds.

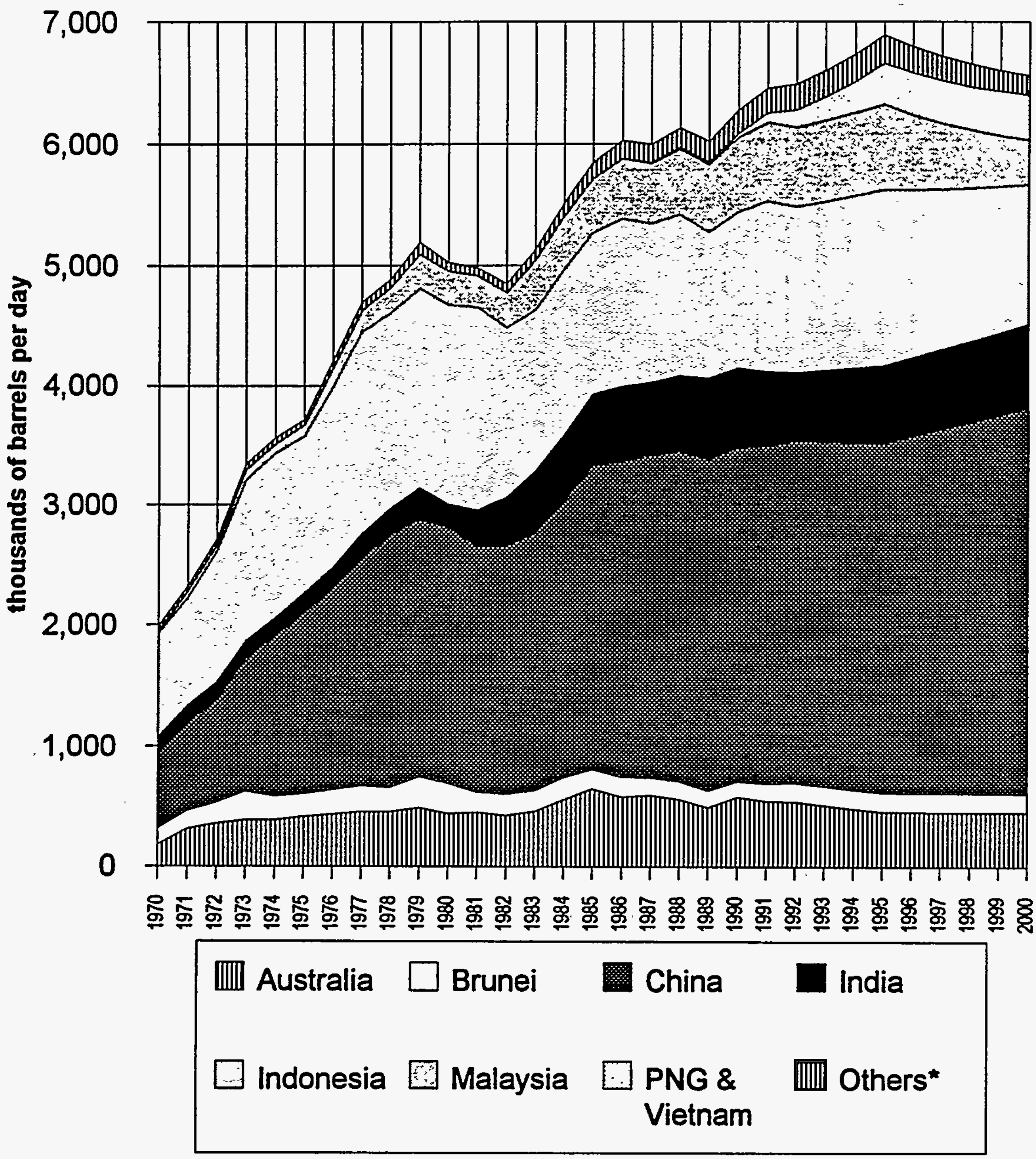
The BHP refinery, in contrast, does not have a catalytic reformer and must therefore produce hydrogen at a dedicated hydrogen plant. The hydrocracking technology used to maximize jet fuel output requires large amounts of hydrogen. This explains in part why hydrocracking units are among the most expensive downstream units to build and operate. It is technically possible to increase the size of the hydrogen plant and the hydrocracker, and it is technically possible to build or expand hydrodesulfurization units at the refineries. Therefore, it is technically possible to expand use of poorer-quality crudes. The economics, however, may not be attractive, even with lower-cost crude feedstocks. The prevailing poor rates of return on refinery investment make additional capital investments unlikely in the near future; the local refiner's choice is to rely on higher-quality crudes.

We have noted that oil demand in Asia is growing at the most rapid rate in the world; the area is a significant net importer of crude. Yet crude exports continue, and Asia-Pacific crudes still form the majority of Hawaii's input slate. For those who wonder how this pattern can persist, bear in mind that much of the Middle East imports go to Japan, South Korea, and Taiwan, where refineries are equipped to handle a predominantly Mideast slate. Crude oils move in and out of countries based on quality, price, and proximity. There is nothing to stop an oil exporter from being an oil importer as well, and often there are good technical and economic reasons for doing both. In the case of Indonesia, Middle Eastern crudes are imported by the Cilacap refinery in southern Java, while production from numerous Javanese oil fields is exported. The explanation is that Indonesian crudes are not well-suited for production of lubricating oils ("lubes"), and a certain quantity of Mideast crude is therefore required by the Cilacap refinery's lube plant. In the case of Australia, variable crude qualities and transport costs influence a trade pattern where Mideast crudes are imported into Western and Southern Australia while premium quality crudes and condensates from the Timor Sea area and the Bass Straits are exported. Even though the region is a net importer of crude, we do not expect Asia-Pacific crudes to simply disappear from the market.

Asia-Pacific crude oil production, 1970-2000 is displayed in Figure 44, with data presented in Table 20. Under our base-case forecast, oil production will continue to expand until 1995, after which there will be only a gentle decline. The largest producers are China and Indonesia, with other producers of note being Malaysia, Australia, India, and Brunei. Of the region's producers, only four are net-exporters of crude oil: Indonesia, Malaysia, China, and Brunei. Of these, only Brunei is expected to remain a net exporter over the long term. By the end of the decade, we expect that China will be a net importer; Indonesia and Malaysia may soon follow. As noted, however, this does not mean that exports will cease. Figure 45 and Table 21 display historical and projected crude oil exports by country. In the 1970s, Indonesia overwhelmingly dominated the export market, accounting for over 70 percent of the region's total exports. But Indonesian exports peaked in 1977, at nearly 1.5 million barrels per day (mmb/d), and in the following decade, Indonesia's share of regional exports fell to under 50 percent. Exports from China and Malaysia expanded rapidly in the 1980s. During the 1970s, their shares of regional exports had been around 7 percent each; in the 1980s, these shares grew to around 22 percent and 17 percent, respectively.

The 1990s are bringing further change to the pattern of exports. We forecast an all-time high in exports by 1995, with export volumes reaching around 2.26 mmb/d. The latter half of the decade, however, will be characterized by a sharp drop in export availability,

Figure 44. Near-Term Growth, Long-Term Decline in Asian Oil Production, 1970-2000



*Bangladesh, Pakistan, Japan, Taiwan, Philippines, Myanmar, Thailand, and New Zealand

Figure 45. Crude Exports from Asia-Pacific Countries, 1970-2000

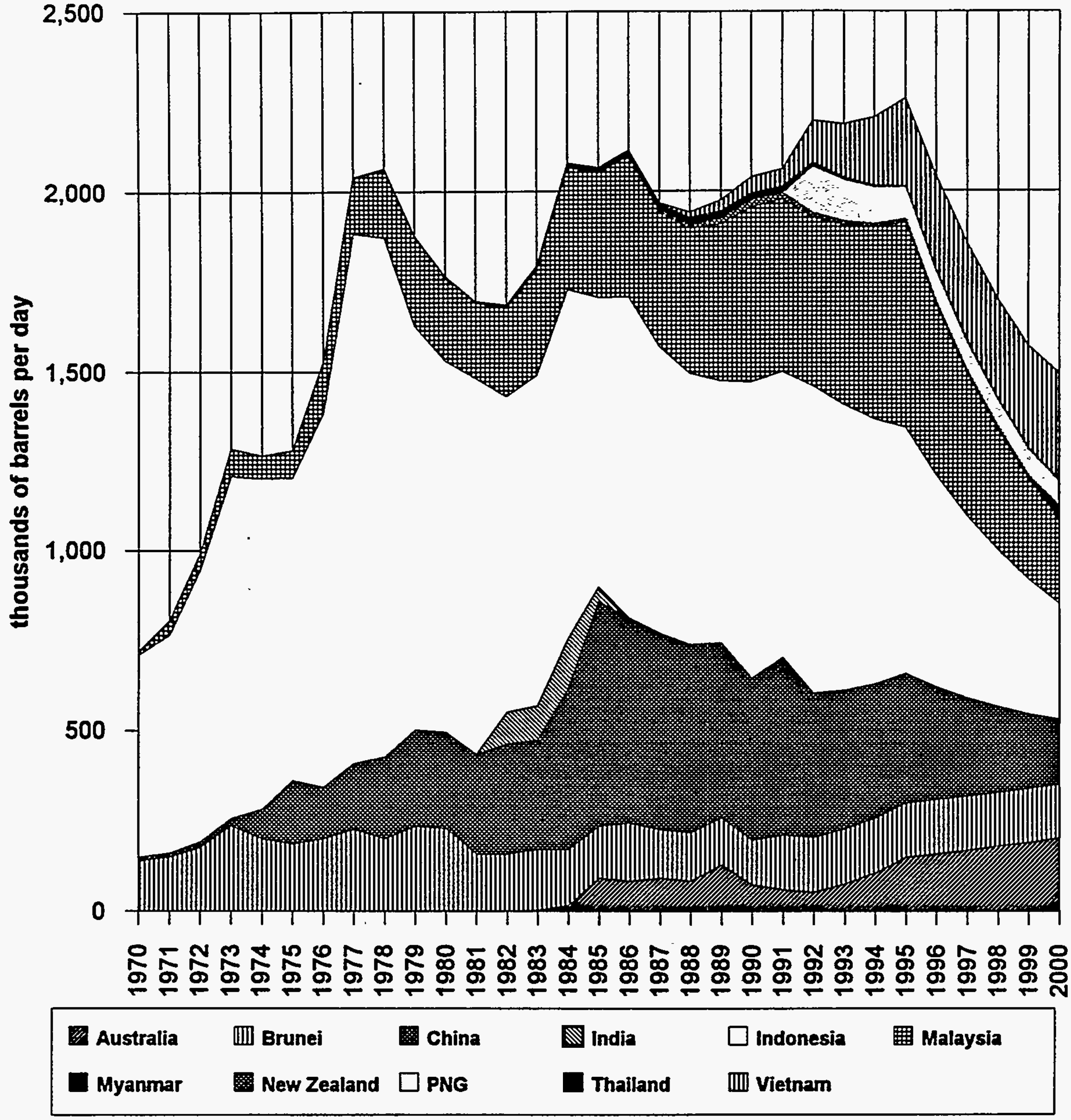


Table 20. Asia-Pacific Crude Production, 1970-1992, plus Year 2000 Forecast

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Australia	178	310	355	385	385	415	430	450	450	486	436	445	423	458	555	645	581
Bangladesh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brunei	139	150	175	235	200	190	205	220	205	260	254	170	178	173	185	164	162
China	616	735	845	1,100	1,320	1,490	1,675	1,880	2,090	2,132	2,122	2,033	2,051	2,130	2,289	2,517	2,620
India	142	140	155	150	151	170	170	205	225	267	195	311	411	524	560	604	630
Indonesia	854	890	1,080	1,335	1,375	1,305	1,505	1,690	1,635	1,665	1,663	1,694	1,416	1,340	1,375	1,338	1,384
Japan	15	15	14	14	14	12	12	12	11	11	9	8	8	8	8	7	13
Malaysia	18	52	55	90	80	100	165	185	215	284	278	261	295	420	440	446	502
Myanmar	18	18	20	21	21	18	22	26	27	31	30	28	29	29	30	22	24
New Zealand	1	2	3	4	4	4	10	15	12	15	14	11	8	10	19	22	28
Pakistan	9	8	9	8	8	6	7	10	11	10	10	10	12	12	18	34	41
PNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Philippines	0	0	0	0	0	0	0	0	0	21	10	4	9	14	11	8	8
Taiwan	2	2	2	3	4	4	4	4	4	5	4	3	3	2	3	3	3
Thailand	0	0	0	0	0	0	0	0	0	0	0	0	6	11	19	37	35
Vietnam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASIA-PACIFIC	1,992	2,323	2,714	3,344	3,561	3,714	4,206	4,697	4,886	5,187	5,025	4,978	4,849	5,131	5,512	5,847	6,031

Table 20 (continued)

							Base	Base	Base	Base	Base	Base	Base	Base	Low	Low	High	High
	1987	**1988**	**1989**	**1990**	**1991**	**1992**	1993	1994	1995	1996	1997	1998	1999	2000	1995	2000	1995	2000
Australia	591	560	489	576	544	539	510	482	455	454	453	452	451	450	350	250	550	500
Bangladesh	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	5	5
Brunei	148	150	143	134	145	159	159	160	160	160	160	160	160	160	130	130	200	200
China	2,680	2,734	2,751	2,768	2,799	2,834	2,856	2,878	2,900	2,958	3,016	3,076	3,138	3,200	2,800	2,500	3,500	4,000
India	609	637	677	665	625	574	598	624	650	660	670	680	690	700	450	500	700	1,000
Indonesia	1,312	1,331	1,209	1,289	1,411	1,370	1,396	1,423	1,450	1,384	1,322	1,262	1,205	1,150	1,200	900	1,600	1,400
Japan	12	12	11	10	15	17	16	16	15	15	15	15	15	15	10	10	20	20
Malaysia	498	542	557	623	652	661	677	694	711	626	551	485	427	376	450	300	850	600
Myanmar	15	14	15	13	12	15	19	24	30	29	28	27	26	25	15	10	40	30
New Zealand	41	50	54	56	55	46	46	45	45	41	38	35	33	30	30	25	50	40
Pakistan	42	45	49	62	67	75	75	75	75	69	64	59	54	50	60	40	75	60
PNG	0	0	0	0	0	40	53	69	90	86	81	77	74	70	70	50	110	130
Philippines	6	6	6	7	6	12	11	11	10	10	10	10	10	10	5	5	20	20
Taiwan	2	1	3	2	2	1	2	3	4	3	3	3	2	2	0	0	3	3
Thailand	32	34	36	42	45	49	49	50	50	45	41	37	33	30	30	20	60	40
Vietnam	5	15	20	30	80	103	138	186	250	259	269	279	289	300	160	200	300	350
ASIA-PACIFIC	**5,994**	**6,132**	**6,021**	**6,277**	**6,459**	**6,496**	**6,606**	**6,737**	**6,896**	**6,800**	**6,722**	**6,657**	**6,607**	**6,569**	**5,760**	**4,940**	**8,083**	**8,398**

Source: East-West Center Program on Resources

Table 21. Asia-Pacifi Crude Exports by Country, 1970-2000

(thousands of barrels per day)

	Australia	Brunei	China	India	Indonesia	Malaysia	Myanmar	NZ	PNG	Thailand	Vietnam	TOTAL
1970	0	139	9	0	562	10	0	0	0	0	0	720
1971	0	150	10	0	604	41	0	0	0	0	0	805
1972	0	175	15	0	756	45	0	0	0	0	0	991
1973	0	235	20	0	953	77	0	0	0	0	0	1,285
1974	0	200	80	0	921	63	0	0	0	0	0	1,265
1975	0	185	174	0	844	76	0	0	0	0	0	1,279
1976	0	200	142	0	1,042	144	0	0	0	0	0	1,528
1977	0	225	182	0	1,477	156	1	0	0	0	0	2,041
1978	0	200	226	0	1,448	189	2	0	0	0	0	2,065
1979	0	233	269	0	1,125	247	3	0	0	0	0	1,877
1980	0	228	266	0	1,038	231	2	0	0	0	0	1,765
1981	0	158	275	0	1,050	209	2	0	0	1	0	1,696
1982	0	158	304	90	879	247	2	0	0	6	0	1,686
1983	2	168	304	96	921	294	3	0	0	7	0	1,794
1984	18	153	446	139	972	341	3	0	0	8	0	2,079
1985	93	142	623	41	808	345	0	0	0	14	0	2,067
1986	85	157	570	0	897	391	0	0	0	14	1	2,116
1987	93	132	545	0	800	373	0	6	0	15	3	1,967
1988	85	132	521	0	758	400	0	10	0	20	15	1,941
1989	130	127	487	0	731	433	0	17	0	19	30	1,974
1990	75	121	450	0	825	485	0	20	0	19	45	2,040
1991	60	150	494	0	797	476	0	18	0	18	50	2,062
1992	55	150	400	0	855	467	0	10	133	10	117	2,197
1993	77	150	386	0	793	499	0	9	117	6	150	2,187
1994	107	150	373	0	735	533	0	9	103	3	194	2,207
1995	150	150	360	0	682	570	0	8	90	2	249	2,261
1996	159	150	313	0	587	476	0	8	86	2	258	2,040
1997	169	150	273	0	505	398	0	9	81	2	268	1,855
1998	179	150	238	0	435	332	0	9	77	2	278	1,700
1999	190	150	207	0	374	278	0	10	74	2	288	1,572
2000	202	150	180	0	322	232	28	10	70	2	299	1,495

Source: East-West Center Program on Resources

with year 2000 exports forecast at around 1.5 mmb/d. The role of traditional exporters such as Indonesia, China, and Malaysia will shrink further. New players will enter the market, chief among whom will be Vietnam and Papua New Guinea (PNG). Myanmar is also expected to reenter the export market with a revitalized oil industry. Together, Vietnam, PNG, and Myanmar may be exporting nearly 400 mb/d by the end of the decade—more than Indonesia's 320 mb/d, Malaysia's 220 mb/d, Australia's 200 mb/d, or China's 180 mb/d.

Since Hawaii's Asia-Pacific crude imports amount to around 60-70 mb/d, there will obviously be "enough" crude on the market. Price will be the variable. As discussed in the chapter dealing with Asia-Pacific product specifications in Task I (*World and Regional Fossil Energy Dynamics*), many Asia-Pacific countries are working to reduce sulfur contents in diesel, and a few are also tightening fuel oil sulfur specifications. The implication is that low-sulfur crudes may be in greater demand for environmental reasons, and prices may rise relative to sour crudes. It should be noted that there is some degree of variety among Middle Eastern and Latin American crudes, and that some of these crudes may play a larger role in Hawaii. While it is true that most crudes from these regions are sour and/or heavy, there are some important exceptions. For example, the Foster-Wheeler crude distillation unit at the BHP refinery was designed to run a mix of Omani (from Oman) and Seria (from Brunei) crudes. Omani crude is one of the Mideast's lower-sulfur crudes, with a sulfur content of around 1 percent—lower than Alaska North Slope (ANS) crude, which is a medium-gravity, medium-sulfur crude of about 28° API and 1.11 percent sulfur. Local refiners have processed small quantities of Omani crude and also some Saudi Arabian crude in recent years.

Hawaii refiners have also imported Ecuadorian crude. But this particular crude, Oriente, is not an ultra-heavy sour crude, but rather is remarkably like ANS crude. During the *Exxon Valdez* disaster, which temporarily limited supplies of ANS, Oriente crude served as a substitute for a number of refineries, including ARCO's Cherry Point refinery in Washington state, which was designed specifically for ANS. To a limited degree, Oriente can help supplement ANS supplies, but Oriente production levels are not sufficient to fully offset the impending decline in ANS production.

4. Domestic Sources of Crude Oil

The PADD-V oil market is a large and long-established one. As Table 22, PADD-V Field Production, indicates, production of crude oil and natural gas liquids (NGLs) and liquefied refinery gases (LRGs) expanded throughout the early and mid 1980s, declining only slightly after 1988, which marked the peak in ANS production. In 1992, crude oil production amounted to around 2,677 mb/d, with production of NGLs and LRGs at 99 mb/d. At its peak in 1988, PADD-V crude production reached 3,081 mb/d.

High levels of production in Alaska and California have afforded the area net-exporter status. Table 23 and Figure 46 display the PADD-V crude oil supply/demand balance from 1981 to 1992. The levels of production have been consistently above the levels of demand; exports have outpaced imports. But the gap between production and refinery input has narrowed visibly in just the past five years. The decline in production is obvious. We have not yet felt the impacts of the decline, because the region remains a net exporter. As long as supplies remain adequate for PADD-V demand, it is extremely unlikely that supplies would be diverted away from Hawaii. The long transport distances to other U.S. regions and the U.S. Virgin Islands makes the West Coast market the most attractive for West Coast crudes. Table 24 and Figure 47 illustrate this point by presenting a breakdown of ANS shipments by destination; the rise in PADD-V demand for ANS and the decline in ANS production has translated solely into a reduction in shipments to other U.S. regions. In 1983, shipments to other PADDs and the U.S. Virgin Islands amounted to 800 mb/d. By 1990, this figure had fallen below 300 mb/d. There is little doubt that the PADD-V market will make the transition to net oil importer within the coming years, but it also seems clear that "local crudes for local refiners" may continue to be the order of the day.

ANS has not always been a mainstay crude for Hawaii; full-fledged production began only in 1978. Table 25 displays PADD-V crude production by state, charted in Figure 48.

Table 22. PADD-V Field Production, 1981-92

(thousands of barrels per day)

Commodity	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Crude Oil	**973,352**	**1,021,430**	**1,031,262**	**1,044,543**	**1,093,324**	**1,091,043**	**1,114,896**	**1,127,501**	**1,053,467**	**1,002,754**	**1,010,515**	**979,723**
Natural Gas Liquids & LRGs	**7,476**	**11,983**	**11,889**	**12,046**	**14,286**	**14,498**	**28,574**	**32,498**	**27,823**	**27,138**	**33,396**	**36,070**
Pentanes Plus	4,179	4,571	4,773	5,029	5,473	5,394	13,594	16,660	14,560	15,064	18,373	19,641
Liquified Petroleum Gases	3,297	7,412	7,116	7,017	8,813	9,104	14,980	15,838	13,263	12,074	15,023	16,429
Ethane	0	1	0	48	536	729	57	19	15	13	22	21
Propane	2,009	4,265	4,151	4,225	4,763	4,795	4,722	4,285	3,903	3,682	3,619	3,440
Butane-Propane Mix	417	478	395								0	0
Normal Butane	651	2,411	2,449	1,974	2,548	2,535	7,503	8,537	7,041	6,300	7,746	8,220
Isobutane	220	257	121	770	966	1,045	2,698	2,997	2,304	2,079	3,636	4,748
Other Hydrocarbons/Alcohol	**4,900**	**6,520**	**5,101**	**4,293**	**5,239**	**4,442**	**4,958**	**4,587**	**5,865**	**5,313**	**7,810**	**11,921**
Total	**985,728**	**1,039,933**	**1,048,252**	**1,060,882**	**1,112,849**	**1,109,983**	**1,148,428**	**1,164,586**	**1,087,155**	**1,035,205**	**1,051,721**	**1,027,714**

(thousands of barrels per day)

Commodity	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Crude Oil	**2,666.7**	**2,798.4**	**2,825.4**	**2,853.9**	**2,995.4**	**2,989.2**	**3,054.5**	**3,080.6**	**2,886.2**	**2,747.3**	**2,768.5**	**2,676.8**
Natural Gas Liquids and LRGs	**20.5**	**32.8**	**32.6**	**32.9**	**39.1**	**39.7**	**78.3**	**88.8**	**76.2**	**74.4**	**91.5**	**98.6**
Pentanes Plus	11.4	12.5	13.1	13.7	15.0	14.8	37.2	45.5	39.9	41.3	50.3	53.7
Liquified Petroleum Gases	9.0	20.3	19.5	19.2	24.1	24.9	41.0	43.3	36.3	33.1	41.2	44.9
Ethane	0.0	0.0	0.0	0.1	1.5	2.0	0.2	0.1	0.0	0.0	0.1	0.1
Propane	5.5	11.7	11.4	11.6	13.0	13.1	12.9	11.7	10.7	10.1	9.9	9.4
Butane-Propane Mix	1.1	1.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Normal Butane	1.8	6.6	6.7	5.4	7.0	6.9	20.6	23.3	19.3	17.3	21.2	22.5
Isobutane	0.6	0.7	0.3	2.1	2.6	2.9	7.4	8.2	6.3	5.7	10.0	13.0
Other Hydrocarbons/Alcohol	13.4	17.9	14.0	11.7	14.4	12.2	13.6	12.5	16.1	14.6	21.4	32.6
Total	**2,700.6**	**2,849.1**	**2,871.9**	**2,898.6**	**3,048.9**	**3,041.0**	**3,146.4**	**3,181.9**	**2,978.5**	**2,836.2**	**2,881.4**	**2,808.0**

Source: 1981-1988: US Dept. of Energy, Petroleum Supply Annual, 1989 onward: Petroleum Supply Monthly

Table 23. PADD-V Crude Petroleum Balance, 1981-92

(thousand of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Production	2,666.7	2,798.4	2,825.4	2,853.9	2,995.4	2,989.2	3,054.5	3,080.6	2,886.2	2,747.3
Refinery Input	2,170.7	2,020.5	2,100.0	2,205.7	2,256.1	2,382.8	2,483.2	2,579.9	2,599.8	2,595.0
Imports	301.7	188.2	210.4	202.9	176.7	186.7	197.1	201.2	265.8	258.0
InterPADD Transfers	-391.8	-609.8	-709.0	-592.7	-684.0	-606.7	-604.7	-573.0	-400.2	-281.0
Exports	182.8	200.5	145.7	165.2	183.5	137.6	134.3	144.8	134.2	98.0
Stock Change	223.1	155.7	81.0	93.3	48.4	48.7	29.4	-15.9	17.8	31.3

Note: negative numbers in inter-PADD transfer category denote export
Source: USDOE/EIA Petroleum Supply Annual and Petroleum Supply Monthly

Table 24. Alaska North Slope Crude Shipments by Destination, 1983-1992

(thousands of barrels/day)

	Los Angeles	San Francisco	Calif. Total	Pacific NW	Alaska/Hawaii	PADD-V	PADDs I-IV	Virgin Is	TOTAL
1983	337	159	496	279	62	837	703	108	1,647
1984	334	228	561	325	79	966	577	118	1,661
1985	348	273	621	315	104	1,039	634	118	1,792
1986	356	288	643	360	108	1,111	577	98	1,786
1987	402	283	685	394	124	1,203	599	118	1,920
1988	527	306	833	426	125	1,384	476	135	1,994
1989	541	304	845	467	115	1,426	300	122	1,847
1990	630	250	879	478	116	1,473	184	87	1,745
1991	618	272	890	486	114	1,490	169	114	1,772
1992*	490	329	819	534	103	1,456	176	80	1,713
AAG 83-92	4.3%	8.4%	5.7%	7.5%	5.8%	6.4%	-14.3%	-3.2%	0.4%

1992 data are Jan.-Aug. average only

Source: Pacific West Oil Data, citing US Dept, of Transp. Maritime Administration, US Dept. of Energy, and Alaska State Oil and Gas Conservation Commission

Table 25. PADD-V Crude Production by State, 1970-92
(thousand of barrels per day)

	Alaska	California	Nevada	Arizona	Total
1970	229.1	1,019.7	0.4	4.9	1,254.1
1971	217.8	982.1	0.3	3.4	1,203.6
1972	199.7	950.7	0.3	2.7	1,153.4
1973	198.0	920.8	0.3	2.2	1,121.2
1974	193.0	884.9	0.4	2.0	1,080.3
1975	191.0	882.7	0.3	1.7	1,075.8
1976	173.0	893.2	0.4	1.4	1,068.0
1977	464.0	957.8	1.8	1.2	1,424.8
1978	1,229.0	951.2	3.2	1.1	2,184.5
1979	1,401.0	965.1	3.4	1.3	2,370.8
1980	1,617.0	975.2	2.4	1.1	2,595.7
1981	1,609.0	1,054.7	1.9	1.0	2,666.6
1982	1,696.0	1,100.2	1.7	0.9	2,798.8
1983	1,714.0	1,108.7	2.2	0.6	2,825.5
1984	1,722.0	1,128.8	5.2	0.6	2,856.6
1985	1,825.0	1,161.3	8.3	0.5	2,995.1
1986	1,867.0	1,114.2	8.0	0.4	2,989.6
1987	1,962.0	1,087.7	8.5	0.4	3,058.6
1988	2,017.0	1,060.3	8.7	0.4	3,086.4
1989	1,874.0	998.0	8.8	0.4	2,881.2
1990	1823.4	962	10.9	0.3	2,796.6
1991	1841	960	9.3	0.3	2,811.1
1992	1834	928	9.8	0.3	2,772.5

Average annual growth rate:

	Alaska	California	Nevada	Arizona	Total
1970-89	11.70%	-0.11%	17.55%	-12.60%	4.48%
1970-79	22.29%	-0.61%	26.56%	-13.68%	7.33%
1980-89	1.65%	0.26%	15.55%	-11.19%	1.17%
1985-89	0.66%	-3.72%	1.52%	-6.75%	-0.96%
1988-92	-2.35%	-3.26%	2.89%	-9.94%	-2.65%

Note: Federal OCS is included in California total

Source: California Division of Oil and Gas, Alaska Oil and Gas Conservation Commission, US Department of Energy

Figure 46. PADD-V Crude Petroleum Balance, 1981-92

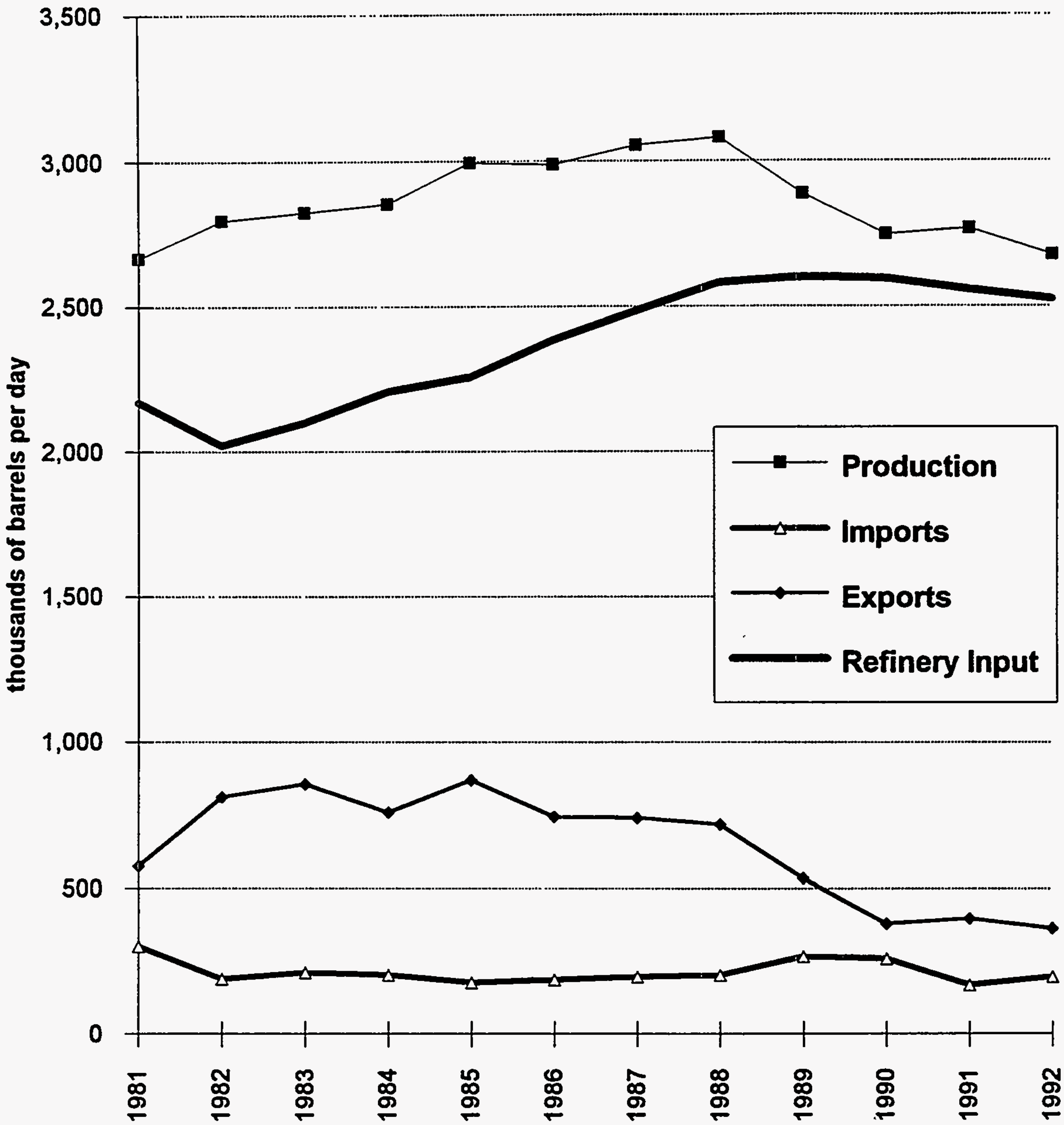
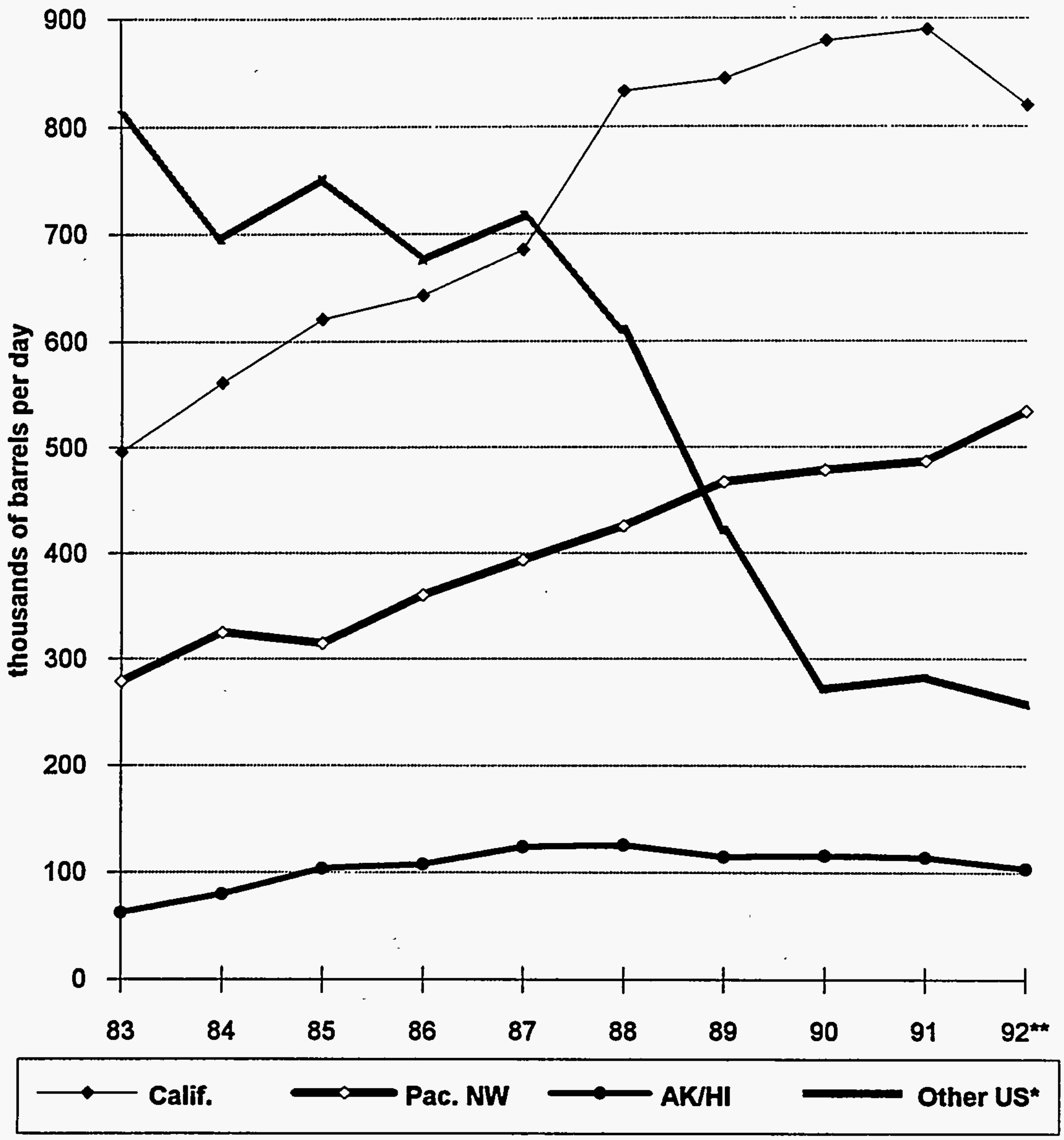


Figure 47. Shipments of Alaska North Slope Crude Oil, 1983-92



**Includes Virgin Islands **1992 figures are Jan.-Aug. only*

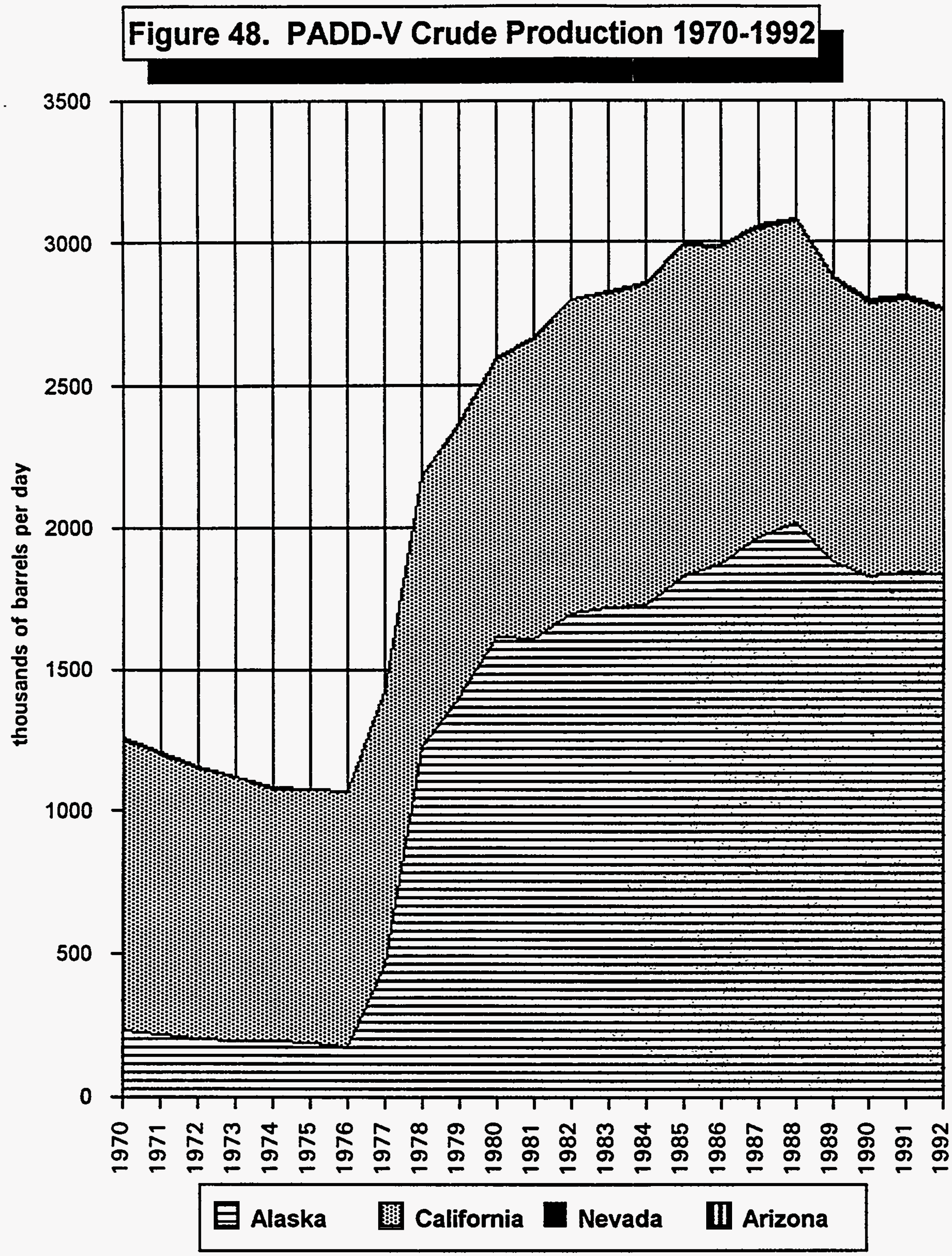


Figure 48. PADD-V Crude Production 1970-1992
thousands of barrels per day
3500
3000
2500
2000
1500
1000
500
0
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
Alaska
California
Nevada
Arizona

The surge in ANS production coincides with the surge in ANS imports into Hawaii, depicted in Figure 49. Note the sharp slope of the curve as domestic crude imports rose after 1977; it is almost identical to the slope in the previous Figure 48 displaying the rise in Alaskan oil production. As the crude surplus on the U.S. West Coast vanishes, however, it may follow logically that the decline in ANS production will have a proportional effect on Hawaii's ANS receipts. As the table indicates, Alaskan production peaked in 1988 at just over 2.0 mmb/d. Official forecasts anticipate a steady decline, depicted in Table 26 and Figure 50. By the year 2000, production is expected to fall below 1.2 mmb/d, halving again within the next six to seven years. Even the "high case" scenario merely postpones the decline a year or two.

The question is not whether but when PADD-V will become a net oil importer. Figure 51 presents a range of possibilities based on high, base, and low production scenarios and a range of possible crude runs. If production falls sharply in 1994-95, and refiners compete strongly for supplies to maximize crude throughput (for example, to fully satisfy local demand and produce an exportable surplus of refined products), the crude surplus could vanish as early as 1995. If we adopt an optimistic forecast of production and a conservative forecast of crude runs (for example, assuming some refineries close because of poor margins and the high cost of complying with environmental regulations), the crude surplus could last until the year 2000. But in all cases, it seems likely that the transition to net importer will occur during the latter half of this decade. At that point, there may be fundamental changes in the structure of petroleum prices; the marginal barrel will be arriving from foreign sources, and may be shipped over a greater distance. The price of the marginal barrel tends to pull up the prices of all crudes in the local market.

Product demand patterns and refinery capabilities influence both crude and product prices. In fact, it is only through the product market that the true "value" of crude oils can be discerned. Crude oil itself is rarely used directly (with the notable exception of Japan, which circumvents the refinery process entirely in some cases by burning crude oil directly for power generation). In general, refiners have the option to build a very simple refinery and then purchase a crude slate that suits the local demand pattern, or they may invest in

Figure 49. Pattern of Domestic and Foreign Crude Imports into Hawaii, 1970-1992

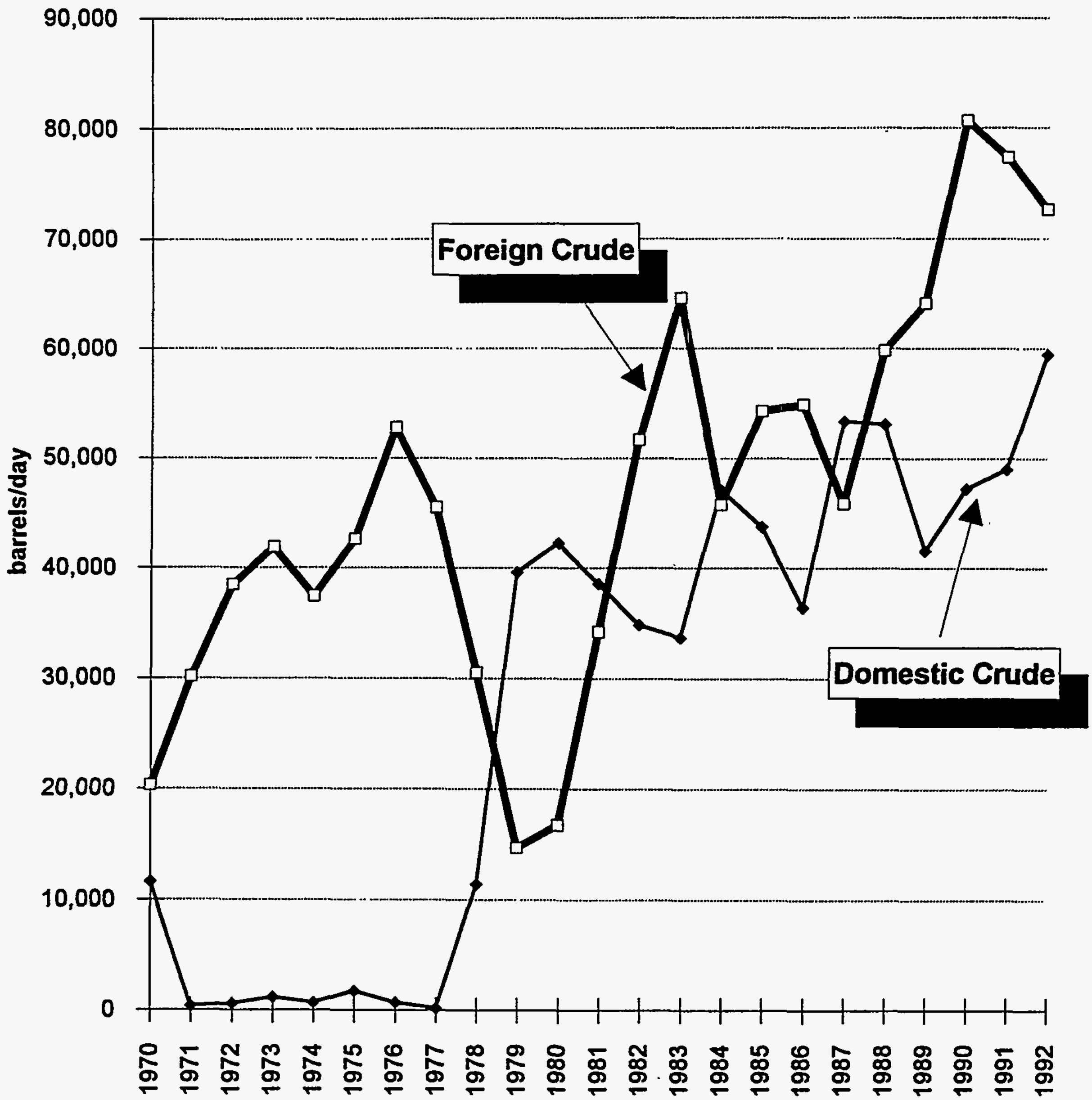


Figure 50. Alaskan Crude Production Forecast, 1990-2010

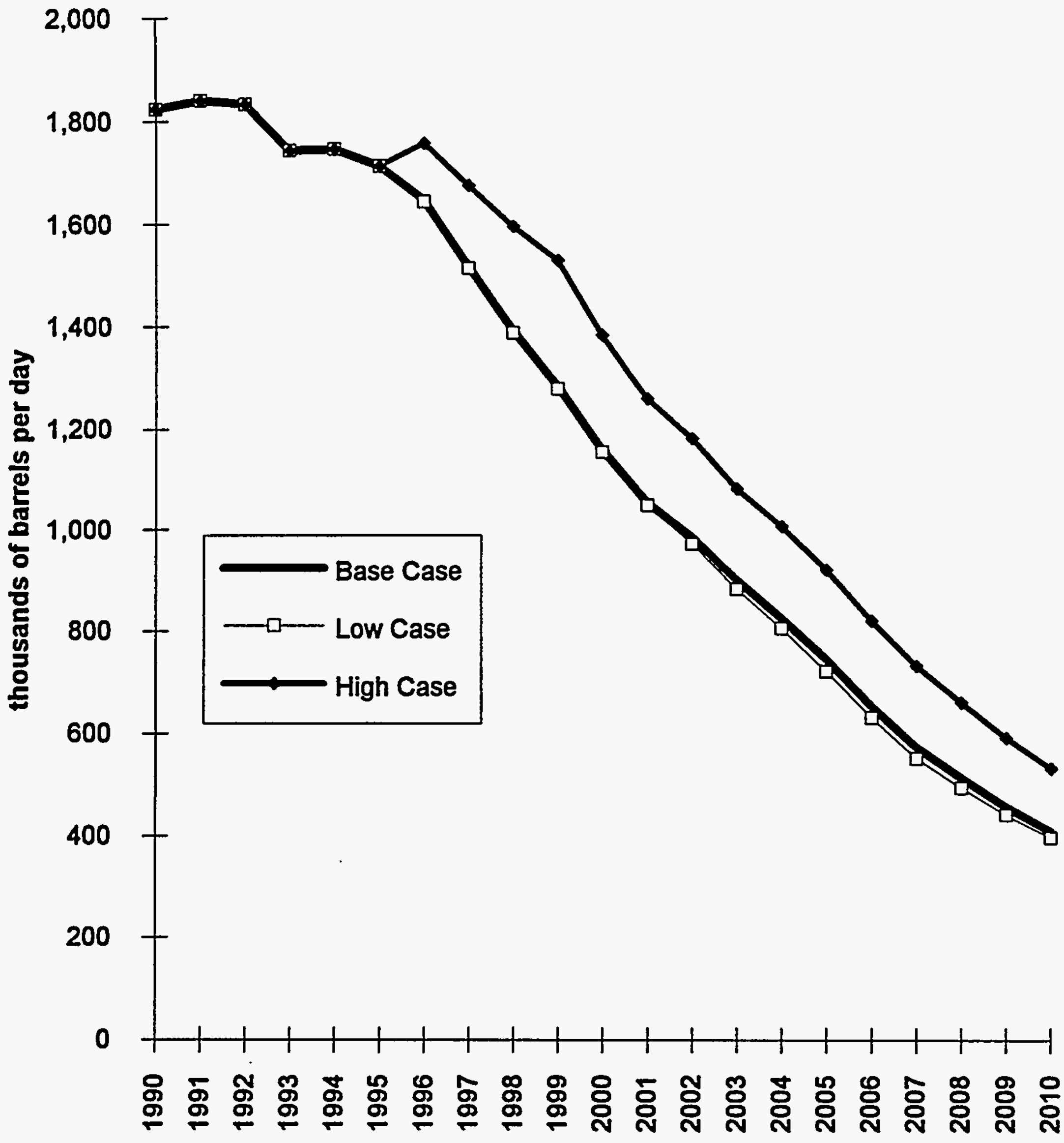


Figure 51: Scenarios of U.S. West Coast Crude Production and Crude Runs,1981-2000

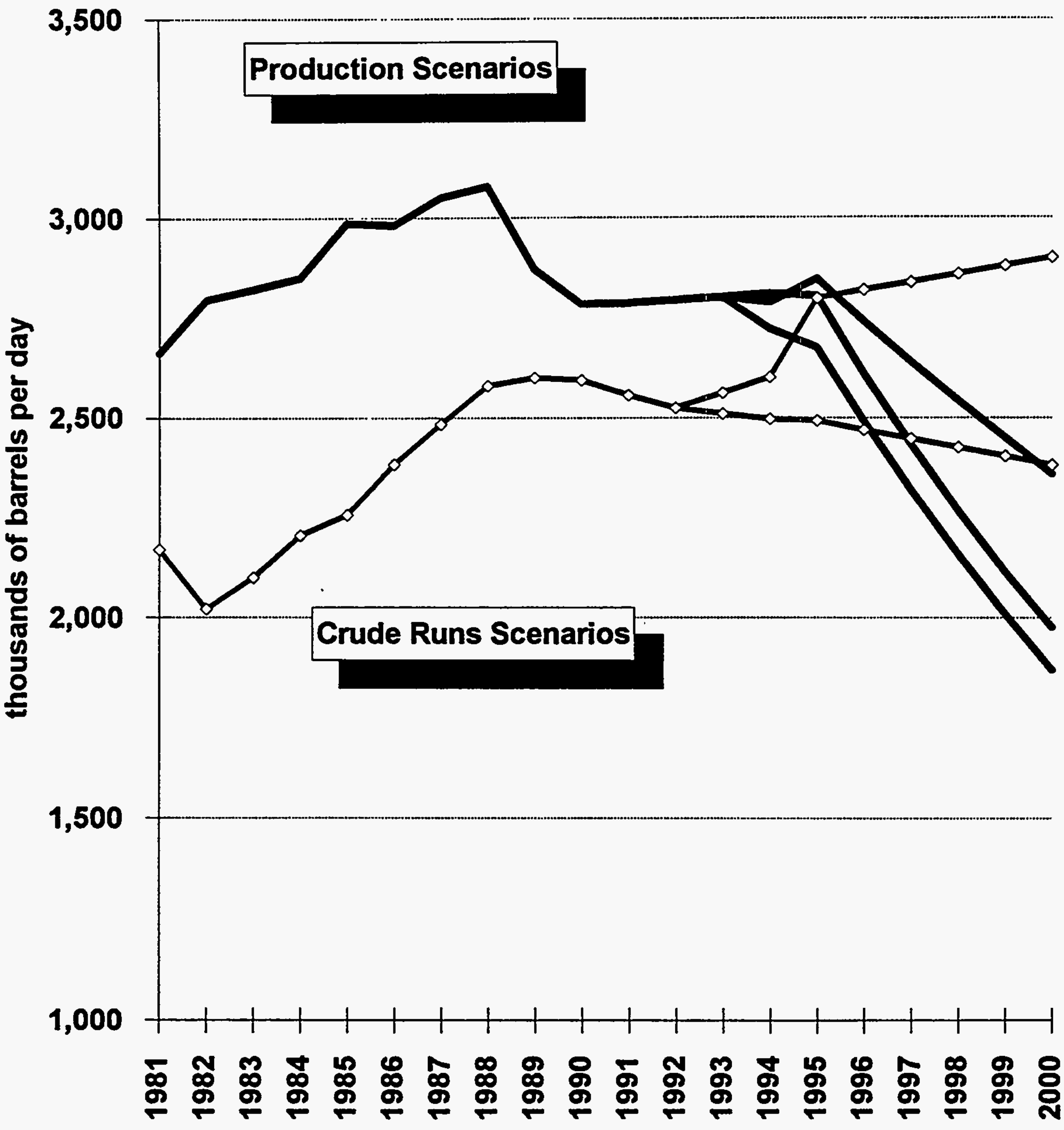


Table 26. Alaskan Oil Production Forecast, 1990-2010

(thousands of per day)

	Base Case			*Low Case*			*High Case*		
	ANS	Cook Inlet	Total	ANS	Cook Inlet	Total	ANS	Cook Inlet	Total
1990	1,793	31	1,823	1,793	31	1,823	1,793	31	1,823
1991	1,800	41	1,841	1,800	41	1,841	1,800	41	1,841
1992	1,792	42	1,834	1,792	42	1,834	1,792	42	1,834
1993	1,703	41	1,744	1,703	41	1,744	1,703	41	1,744
1994	1,704	42	1,746	1,704	42	1,746	1,704	42	1,746
1995	1,674	39	1,713	1,674	39	1,713	1,674	39	1,713
1996	1,609	38	1,647	1,606	38	1,644	1,719	38	1,757
1997	1,480	37	1,517	1,476	37	1,513	1,638	37	1,675
1998	1,357	35	1,392	1,352	35	1,387	1,560	35	1,595
1999	1,251	34	1,285	1,244	34	1,278	1,494	34	1,528
2000	1,126	32	1,158	1,120	32	1,152	1,350	32	1,382
2001	1,022	31	1,053	1,017	31	1,048	1,228	31	1,259
2002	955	30	985	941	30	971	1,149	30	1,179
2003	871	28	899	853	28	881	1,052	28	1,080
2004	797	27	824	777	27	804	978	27	1,005
2005	719	26	745	695	26	721	893	26	919
2006	629	24	653	607	24	631	795	24	819
2007	551	23	574	529	23	552	709	23	732
2008	492	22	514	473	22	495	638	22	660
2009	437	20	457	422	20	442	572	20	592
2010	391	19	410	378	19	397	514	19	533

Price assumptions, ANS wellhead price, $/barrel

	Low	Mid	High
1993	$12.66	$12.91	$13.19
1994	$12.33	$13.67	$14.98
1995	$12.89	$14.50	$15.76
2000	$16.89	$20.96	$24.32
2005	$18.21	$24.95	$32.78

Source: Alaska Dept. of Revenue "Revenue Sources Book: Forecast & Historical Data," Spring 1993.

capital-intensive refinery technology that affords great flexibility in selecting a crude slate. In essence, enough technology makes crude quality differentials almost disappear. In Hawaii's case, the optimum solution has been somewhere in the middle: the refiners are sophisticated enough to convert a fairly diverse crude slate into a high-value product slate, but are not so sophisticated that crude quality is not an important consideration.

We have noted a number of crudes commonly processed in Hawaii. Figure 52 presents the basic refinery distillation yields of some of these crudes. Hawaii's import crudes include: light sweet crudes such as PNG's Kutubu, Brunei's Seria, Malaysian Tapis, and Australian Gippsland, which yield only 20-25 percent fuel oil (low sulfur) on distillation; medium-gravity, medium-sulfur crudes such as ANS, Omani, and Ecuadorian Oriente, which yield in the range of 40-60 percent fuel oil (high sulfur) on distillation; medium-to-heavy sweet crudes such as Indonesian Minas, Cinta/Intan, and Chinese Daqing, which yield 60-65 percent fuel oil (low sulfur); a heavy sweet Indonesian crude known as Duri, which yields 80 percent fuel oil (low sulfur); and an ultra-sour, heavy Venezuelan Boscan crude, which yields 83 percent fuel oil (extremely high sulfur). Since fuel oil is a low-value product, crude oils with high fuel oil yields are generally cheaper than light crudes. A sophisticated cracking refinery can turn this to its advantage.

The other key quality characteristic affecting crude price is sulfur content. Figure 53 compares the sulfur contents of fuel oil derived from atmospheric distillation of the crudes listed above. The variation is huge; Asia-Pacific sweet crudes provide fuel oil with sulfur contents of around 0.1-0.2 percent, Omani crude yields a fuel oil of around 1.4 percent sulfur, ANS and Oriente fuel oils are around 1.6 percent sulfur, and Boscan crude yields a fuel oil with an incredible 5.86 percent sulfur content. For comparison purposes, HECO is allowed to burn fuel oil of up to 0.5 percent sulfur on Oahu, and fuel oil burned on the neighbor islands may contain up to 2.0 percent sulfur. The sulfur content is one of the main factors dictating fuel oil imports and exports in Hawaii, which we will discuss more fully in the following section on product trade.

Figure 52. Basic Yields for Key Crudes Refined in Hawaii

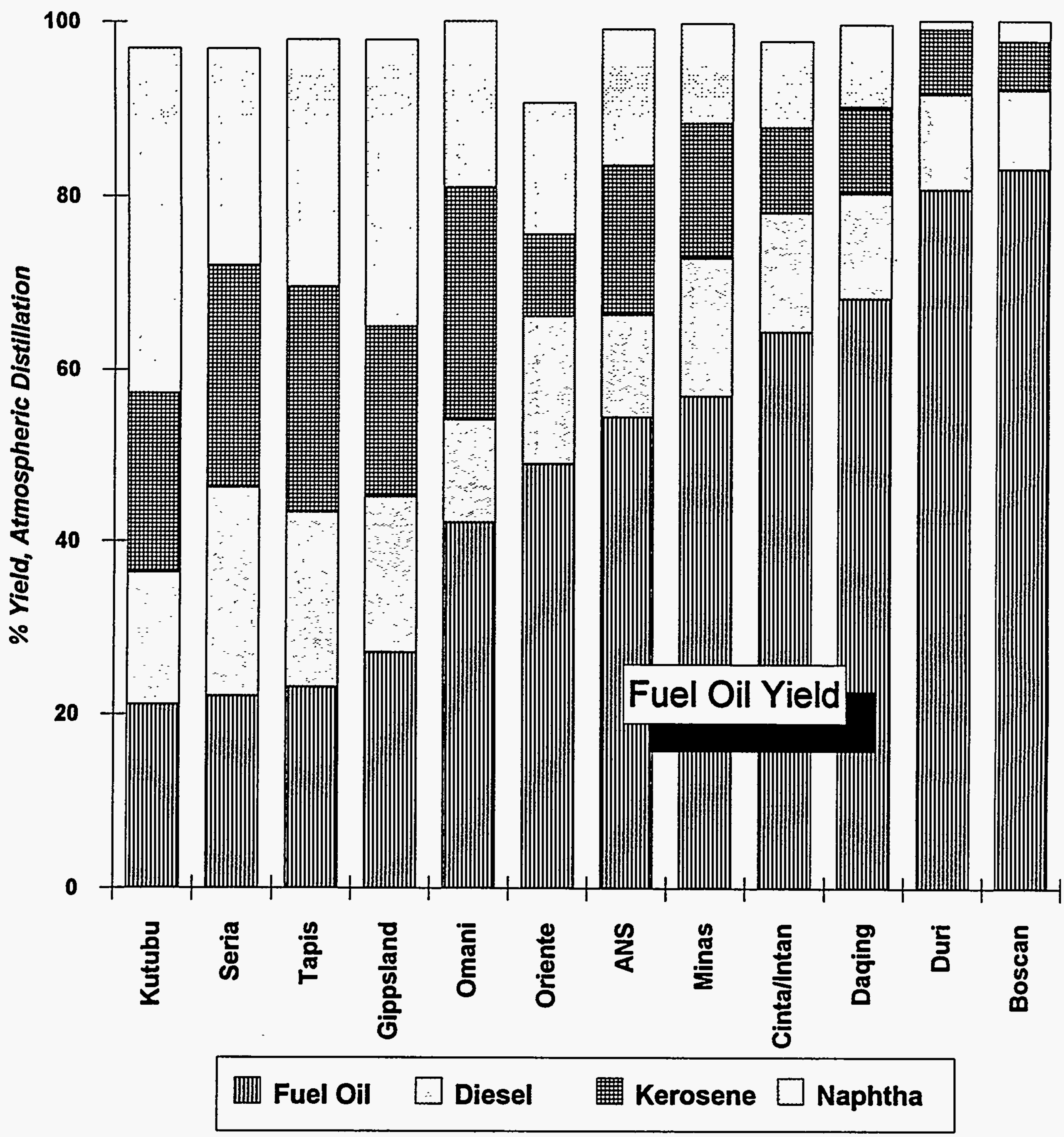
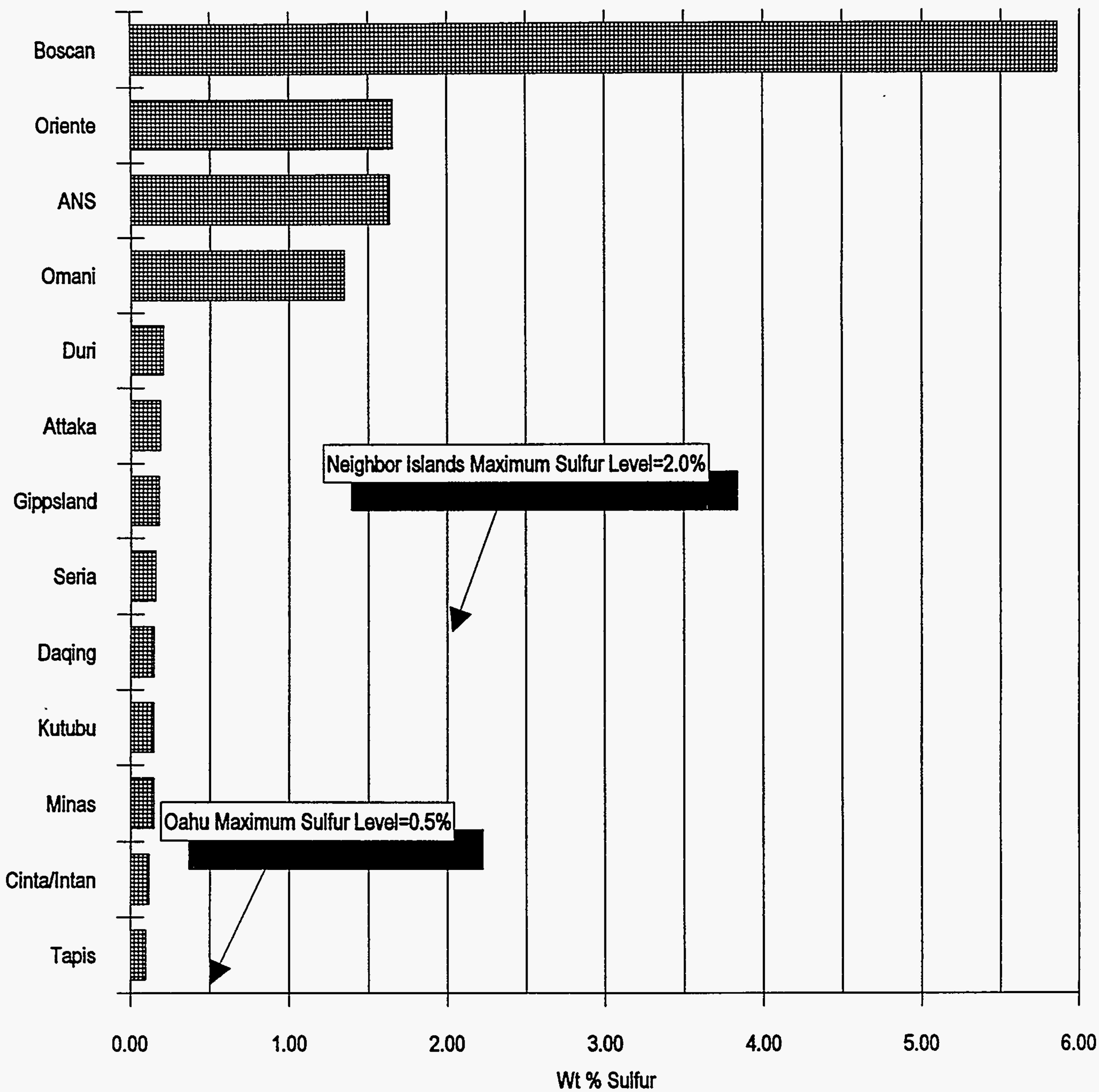


Figure 53. Oil Sulfur Contents for Key Crudes Processed in Hawaii



B. Petroleum Product Trade

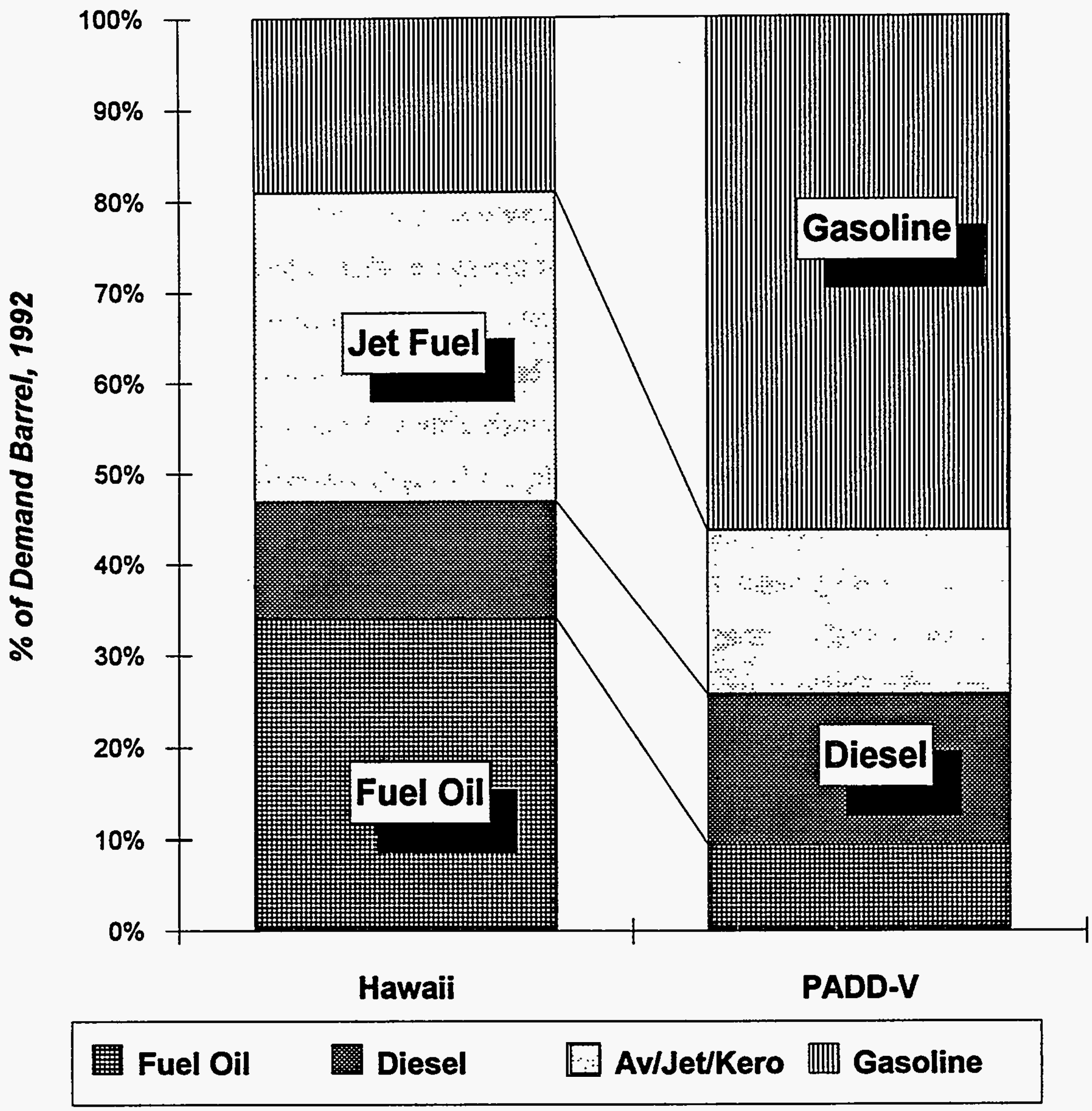
We have established that Hawaii's two refiners are relatively sophisticated, given their size and the size of the Hawaii market. We have also established that Hawaii has a somewhat unusual pattern of demand for refined oil products. In contrast to other U.S. West Coast states, Hawaii is far more dependent on aviation fuels and residual fuel oil, as Figure 54 illustrates. Producing ample fuel oil is a simple matter; numerous heavy crudes are on the market and are reasonably priced, the only real constraint being the sulfur content. Fuel oil is also the least expensive product to purchase from other refining areas. Producing sufficient supplies of jet fuel is another matter. Few crudes yield enough kerosene on basic distillation to meet Hawaii's demand pattern, and demand for kerosene/jet fuel is strong enough worldwide that it is a more expensive commodity to import.

As with the crude oil situation, Hawaii's product market is linked most closely with the U.S. West Coast and the Asia-Pacific markets. The difference with product trade dynamics is, of course, that products often are both imported *and* exported. Theoretically, it is possible for refiners to purchase an optimal crude slate and run their refineries to balance completely local supply and demand. In practice, it is rarely cost-effective to do so, and therefore it is common to see some degree of balancing trade occur at the margin. For example, as the following pages will show, the U.S. West Coast typically has a surplus of heavy fuel oil and a slight shortage of gasoline. Hawaii often is short of jet fuel and long on high-sulfur fuel oil. Trade is required to balance supply and demand. Is Hawaii overly dependent on other refining areas for its local demand? To answer this question, we must look first at the supply/demand balances in the external U.S. West Coast and Asia-Pacific markets.

1. PADD-V Product Supply/Demand Balances

The U.S. West Coast refining industry has evolved into one of the world's most sophisticated, processing a steady diet of low-quality crudes into the high-quality output slate demanded by the local market. As noted in Task I (*World and Regional Fossil Energy*

Figure 54. Demand Patterns for Key Petroleum Fuels in Hawaii and PADD-V Differ Markedly



Dynamics) of this project, California refiners are able to convert around 90 percent of each barrel of crude into transport fuels—which is fortunate because the local demand pattern is overwhelmingly dominated by transport fuels.

1.1. Gasoline

Gasoline is the main fuel in the PADD-V oil market. Table 27 and Figure 55 detail the gasoline supply/demand balance, leaded and unleaded, 1981-92. In 1992, gasoline demand was 1,278 mb/d—over 50 times as large as Hawaii's demand. Refinery production was 1,213 mb/d, so net imports amounted to around 65 mb/d. Most of the imports came in the form of inter-PADD transfers from PADD-III (the U.S. Gulf states), with smaller amounts coming from foreign sources, chiefly Canada. An unusual feature crept into the market in 1991 and 1992: gasoline exports rose from essentially nothing to around 24 mb/d. The chief cause appears to be gasoline reformulation, which is becoming more widespread as urban areas combat air pollution. Gasoline reformulation is being achieved in part through the addition of oxygenates such as MTBE (methyl tertiary butyl ether). MTBE is a high-octane, non-oil gasoline blendstock. Refiners are now finding that the addition of such a high-quality blendstock makes it so much easier to make gasoline that some of them are left with exportable surpluses. There are regional variations in the pattern of trade that support a situation where gasoline is both imported and exported: some of the transfers into PADD-V move via pipeline from U.S. Gulf refiners to landlocked Arizona and Nevada, for example, and Canadian imports are the most economical sources for certain Alaska and Washington requirements. California surpluses may therefore be exported to other regions.

Most of PADD-V gasoline is unleaded, as are most of PADD-V exports. Figure 56 traces the phaseout of lead in PADD-V. In 1981, leaded and unleaded gasoline shared the market equally. By 1992, unleaded gasoline accounted for around 95 percent of the market. Hawaii, incidentally, was the first PADD-V state to move to complete lead phaseout.

1.2. Aviation Fuels

The PADD-V aviation fuels market shows a pattern similar to that seen for gasoline. The aviation fuels balance for 1981-92 is displayed in Table 28 and Figure 57. The region

Table 27. PADD-V Gasoline Balance, 1981-1992
(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Production	962.8	940.1	978.6	1,023.7	1,023.5	1,083.8	1,145.5	1,171.4	1,187.4	1,193.8	1,232.5	1,213.1
Leaded	459.5	429.1	426.0	407.9	362.5	346.2	317.8	294.2	255.0	175.2	136.2	46.7
Unleaded	502.1	508.6	552.6	615.9	661.0	737.6	827.6	877.2	932.4	1,018.5	1,096.4	1,166.4
Inter-PADD Transfer	48.4	57.5	55.9	60.0	55.6	57.5	58.8	63.6	61.2	59.9	65.4	71.4
Leaded	30.4	32.9	33.9	32.7	29.8	27.1	24.8	22.2	17.7	15.3	15.5	19.7
Unleaded	18.0	24.6	22.0	27.3	25.8	30.4	34.0	41.5	43.5	44.6	49.9	51.7
Import	28.4	44.7	22.4	20.9	48.3	37.8	22.8	28.9	18.2	13.6	11.9	14.3
Leaded	18.0	32.2	12.0	8.4	17.6	10.3	6.3	0.8	0.2	0.8	0.0	0.0
Unleaded	10.4	12.5	10.5	12.5	30.8	27.5	16.5	28.2	18.1	12.8	11.9	14.3
Export	1.4	4.0	3.0	2.2	1.5	10.8	11.9	5.1	10.3	7.0	24.2	23.5
Leaded	1.4	4.0	3.0	2.2	1.5	2.7	1.2	0.5	1.1	0.1	0.1	0.8
Unleaded	0.0	0.0	0.0	0.0	0.0	8.1	10.7	4.5	9.2	6.9	24.0	22.6
Product Supplied	1,033.5	1,046.5	1,062.8	1,091.4	1,134.0	1,165.9	1,214.9	1,251.2	1,259.2	1,259.7	1,282.3	1,277.5
Leaded	506.4	494.5	473.5	442.2	413.5	381.3	351.3	317.1	275.0	193.1	158.4	67.4
Unleaded	526.0	549.7	589.2	649.2	720.5	784.6	863.6	934.0	984.1	1,066.6	1,123.9	1,210.1
Stock Change	4.7	-8.2	-8.8	11.0	-8.1	2.5	0.2	7.7	-2.6	0.5	3.4	-2.2
Leaded	0.1	-4.3	-4.7	4.5	-5.2	-0.5	-3.6	-0.6	-3.3	-1.9	-6.9	-1.8
Unleaded	4.6	-4.0	-4.1	6.5	-2.9	2.9	3.8	8.3	0.6	2.4	10.2	-0.4

Source: USDOE/EIA Petroleum Supply Annual and Petroleum Supply Monthly

Table 28. PADD-V Aviation Fuels Balance, 1981-92
(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Refinery Production	273.8	270.7	285.4	309.8	319.1	344.8	372.7	385.8	399.8	415.7	410.7	408.9
InterPADD Transfers	12.2	16.9	16.8	18.8	17.8	20.8	18.8	19.4	19.8	19.9	18.8	17.7
Imports	11.9	4.9	4.1	8.3	8.7	15.1	9.8	14.4	9.0	9.9	3.4	2.6
Exports	0.6	1.9	2.2	2.4	3.7	3.1	4.6	10.3	6.6	15.5	13.2	20.7
Product Supplied	296.7	296.5	303.8	333.3	345.6	373.0	394.3	409.9	422.6	429.2	421.0	409.1
Stock Change	0.5	-5.9	0.4	1.1	-3.6	4.7	2.4	-0.7	-0.6	0.8	-1.2	-0.8

Note: Includes kerojet, naphtha jet, aviation gasoline, and kerosene

Source: USDOE/EIA, Petroleum Supply Annual and Petroleum Supply Monthly

Figure 55. PADD-V Gasoline Balance, 1981-1992

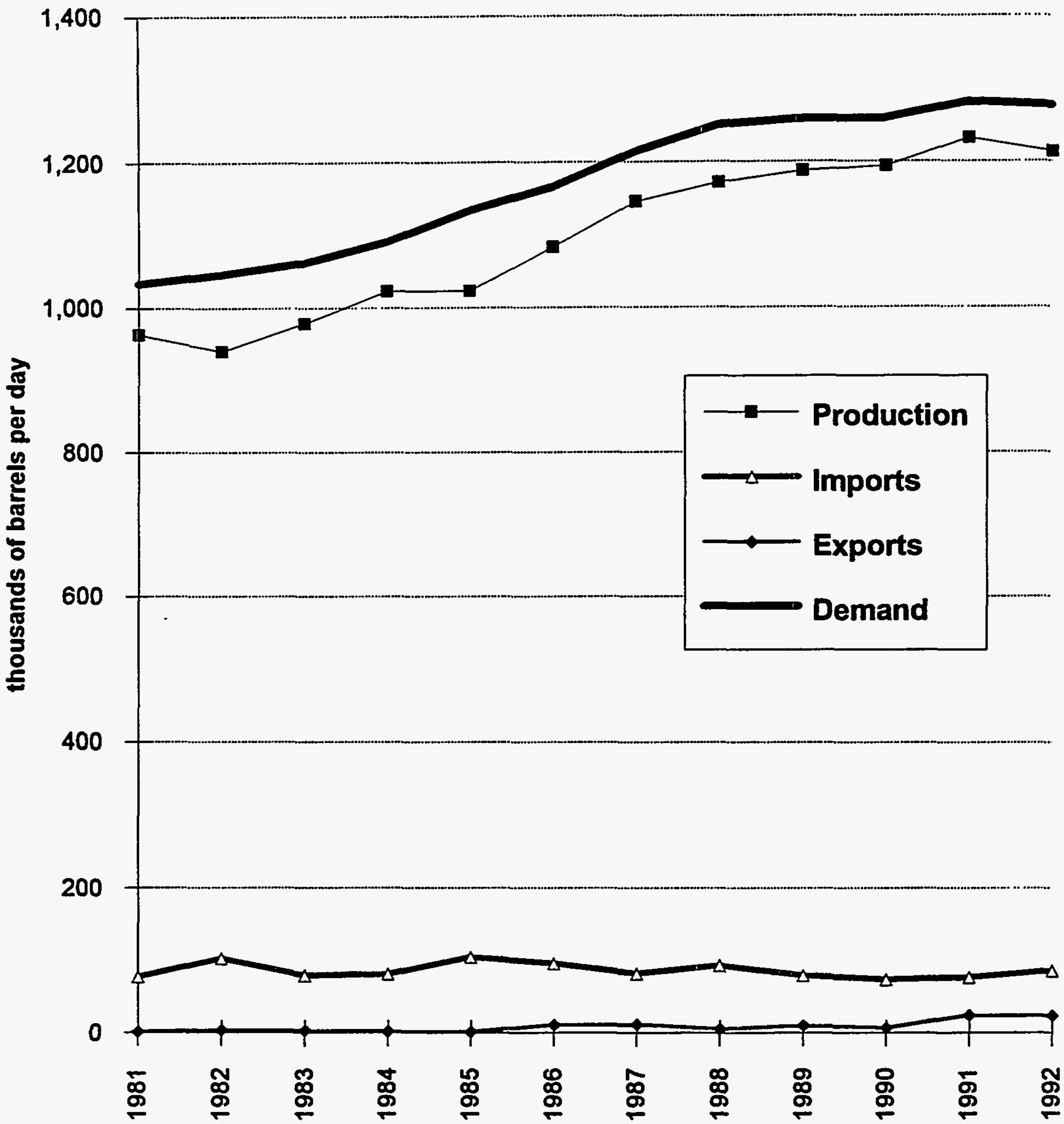


Figure 56. The Phaseout of Lead in PADD-V Motor Gasoline, 1981-92

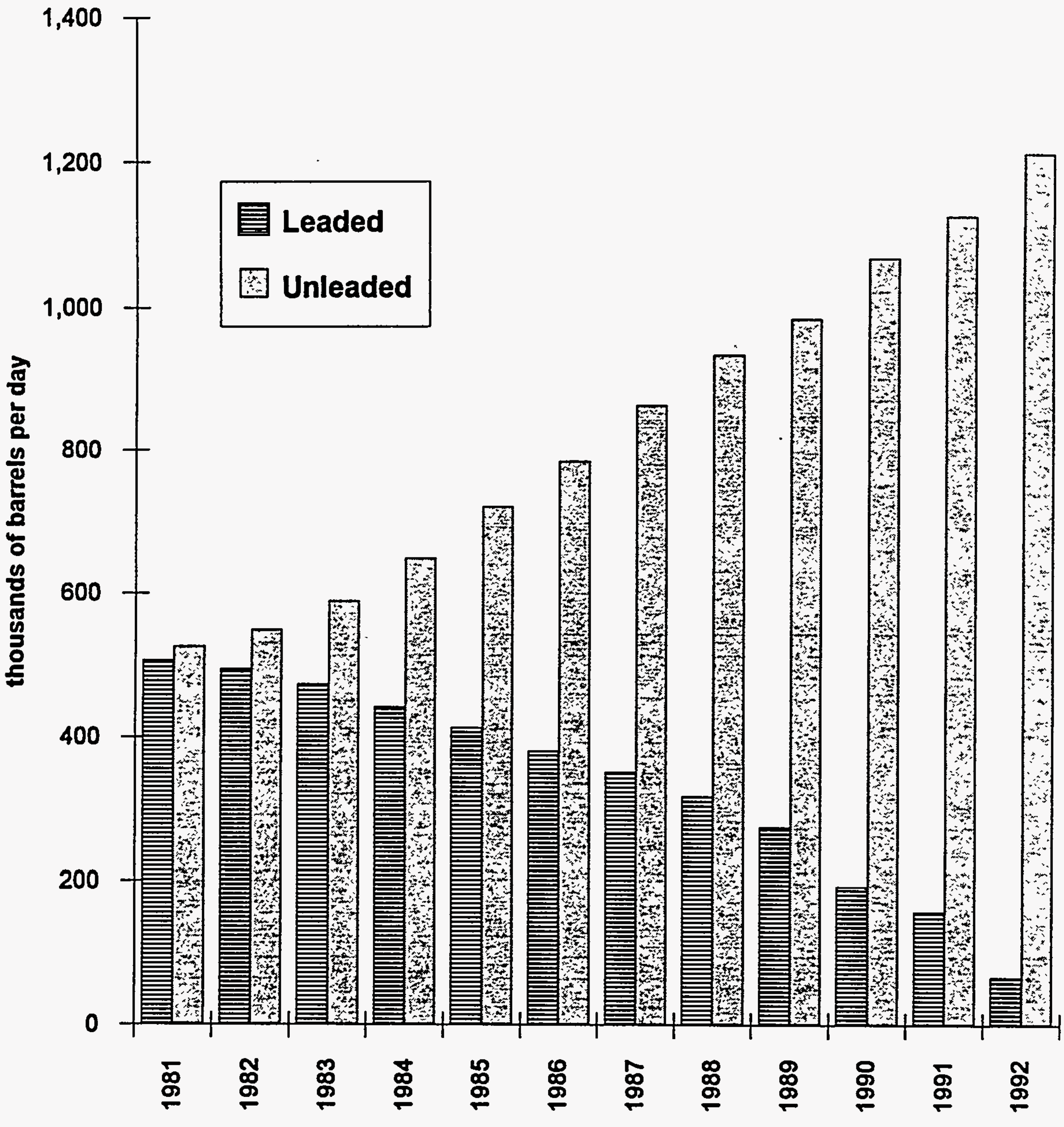
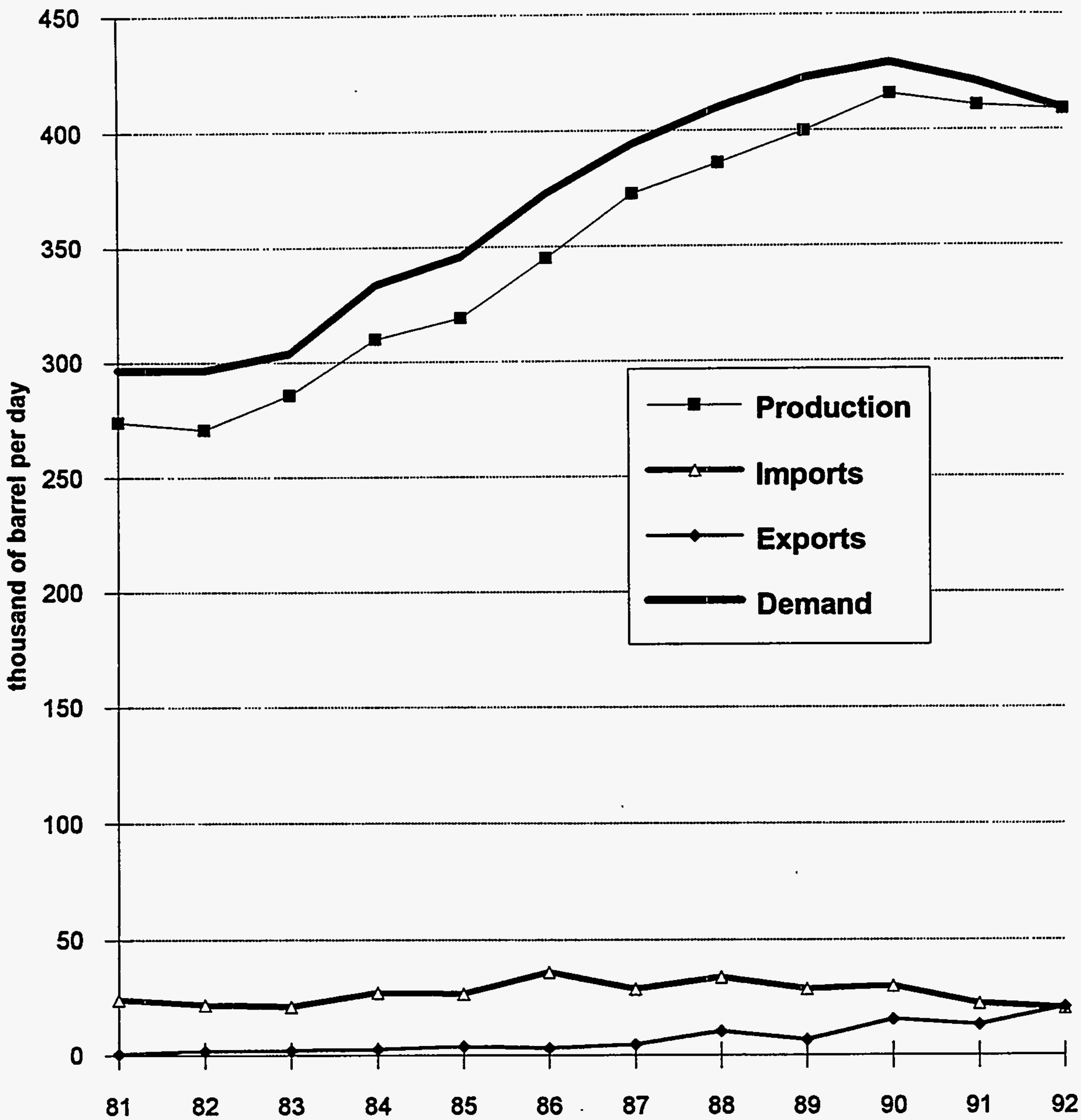


Figure 57. PADD-V Aviation Fuels Balance, 1981-1992



was consistently a net importer of jet fuel in volumes of around 20-30 mb/d, but slumping demand after 1990, combined with stable refinery production, has recently brought supply and demand into balance. For a jet fuel importer such as Hawaii, having the greater PADD-V market in balance is reassuring; in a balanced market, other states will not be competing for limited jet fuel supplies. As with gasoline, there are regional variations in trade; imports of aviation fuels have continued at historic levels partly because some of the inflows move from PADD-III to landlocked PADD-V markets. The drop in demand has not translated into import substitution, but rather into an increase in exports.

1.3. Diesel Fuels

The PADD-V diesel market is proving fascinating. As Table 29 and Figure 58 display, diesel demand has fallen off sharply between 1990 and 1992. The decline has been caused mainly by poor economic performance, leading one to conclude that demand will recover once the economy recovers. The outcome, however, may be significantly different. As with gasoline, diesel is being reformulated in California as of October 1, 1993. The new regulations call for a limit on sulfur of 0.05 percent and a cap of 10 percent on diesel aromatics content for refiners of 50 mb/d capacity or greater, and a limit of 20 percent diesel aromatics for smaller refiners. Refiners may also opt to create and gain certification for an alternative formulation that meets or exceeds the emissions standards adopted by the California Air Resources Board (CARB). Both Chevron and Texaco have qualified reformulated diesel formulae with the CARB. The aromatics restriction has been far more difficult to meet than the sulfur limitation, which is identical to the standard adopted nationwide under the U.S. Clean Air Act. The Chevron and Texaco formulae have aromatics contents in excess of the 10 percent nominally allowed them; their certified formulations contain around 20 percent aromatics, but have extremely high cetane numbers and good combustibility that reduces emissions to levels considered acceptable by the CARB.

Refinery production of diesel has remained quite stable throughout the slump in demand. The excess diesel has been, and is being, exported—in volumes approaching 100 mb/d. It is likely that many California refiners will be unable to comply fully with the

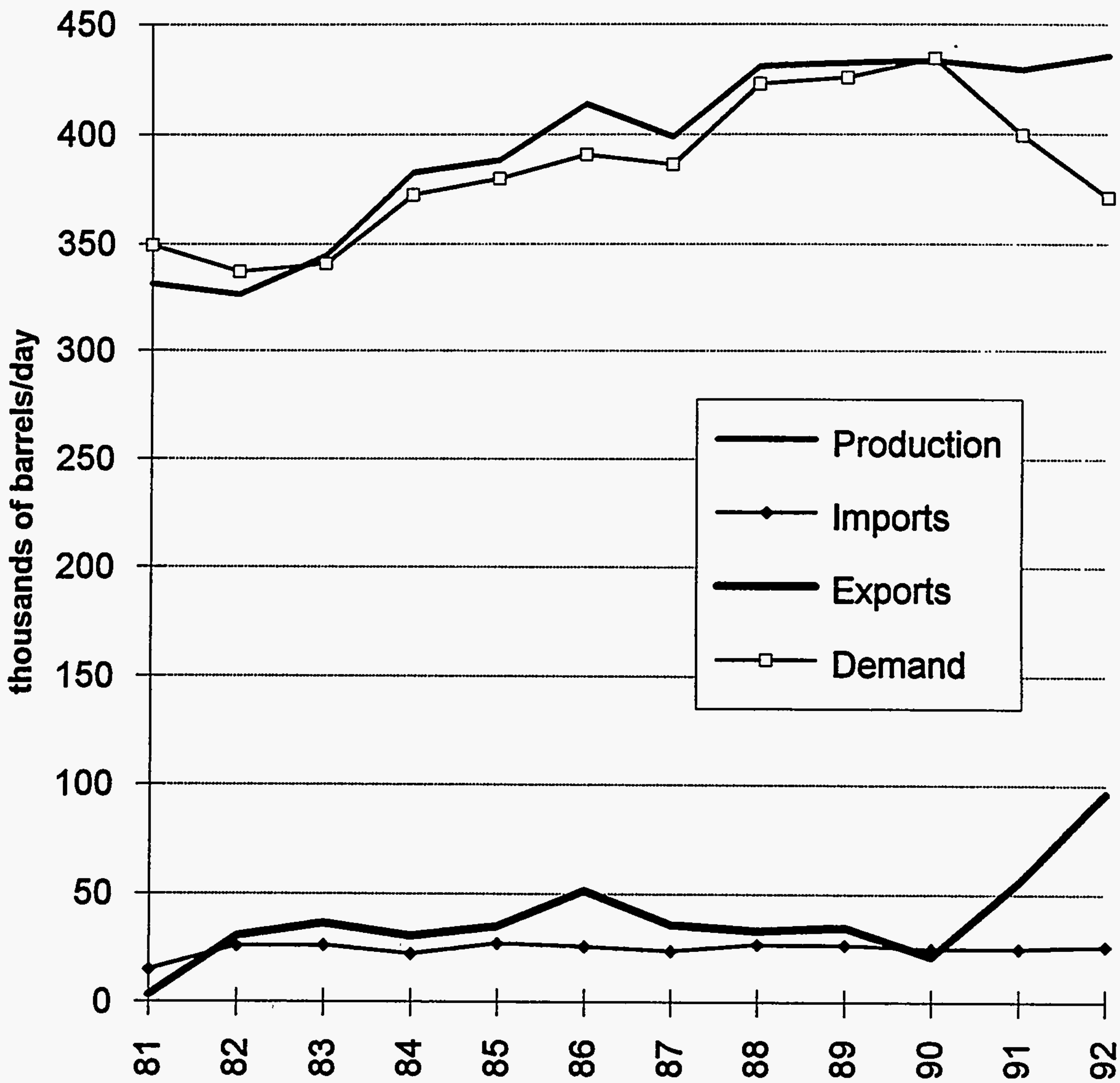
Table 29. PADD-V Diesel Balance, 1981-92

(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Refinery Production	331.6	326.3	344.7	382.3	388.1	413.8	398.7	430.7	432.5	433.2	429.0	435.6
InterPADD Transfers	11.6	19.5	21.5	16.1	17.1	16.8	20.2	22.8	20.9	20.7	21.1	22.8
Imports	3.4	6.5	4.5	6.1	10.0	8.8	3.6	3.9	5.5	4.2	3.7	3.4
Exports	3.2	30.4	36.4	30.4	34.9	51.4	35.8	33.1	34.6	21.1	55.5	96.4
Product Supplied	349.2	337.2	340.8	372.3	379.7	390.5	386.0	422.9	425.5	434.3	399.3	369.0
Stock Change	-5.9	-15.3	-6.4	1.8	0.6	-2.6	0.7	1.5	-1.3	2.7	-1.0	-3.6

Source: USDOE/EIA, Petroleum Supply Annual and Petroleum Supply Monthly

Figure 58. The US West Coast as a Major Diesel Exporter? USWC Diesel Balance, 1981-1992



impending diesel quality regulations. If the export market is attractive, however, diesel production will remain high. In fact, our refinery modeling exercises indicate that PADD-V refiners are capable of boosting diesel production even higher. If demand does not recover (because of high prices for qualifying reformulated diesel, for example), California could become one of the Asia-Pacific region's most significant diesel exporters. This takes on added significance when confronted with the ever-widening diesel supply gap in the Asia-Pacific region. As the following section on Asia-Pacific product trade will establish, diesel demand is booming in Asia. PADD-V diesel will find a ready home in Asia. The implications for Hawaii may be somewhat severe if diesel demand grows significantly (for example, if diesel is used to substitute for fuel oil in the power sector). If Hawaii needed to secure incremental supplies of diesel via imports, it could find those imports will grow more expensive than first envisioned.

1.4. Residual Fuel Oil

One of Hawaii's mainstay products is residual fuel oil, used largely for power generation. This cannot be said for the remainder of PADD-V. On the whole, PADD-V is chronically oversupplied with fuel oil, which must find its way into export markets. Exports range from around 100 to 150 mb/d, versus refinery production of 300-400 mb/d. Therefore, roughly one-third of the output is surplus, and most of the exported fuel oil is heavy, high-sulfur material that fetches low prices on international markets. Moreover, the quality of PADD-V residual oil is getting generally poorer. In 1982, production of HSFO, with sulfur contents of greater than 1.0 percent, amounted to 68 percent of PADD-V fuel oil production. By 1988, HSFO production had grown to account for 78 percent of production, and the figure remained in the area of 80 percent during the 1988-92 period. But the export markets are the only real outlet: air pollution problems in California virtually prohibit any use of oil in the power sector, and ship bunkering can only absorb so much. Even PADD-V's deep-conversion refinery industry cannot completely obliterate fuel oil, though it must be recognized that the industry is doing quite well in managing to convert the locally heavy crudes into an output slate that is only around 12 percent fuel oil. Table 30 and Figure 59 display the PADD-V residual fuel oil balance.

1.5. Liquefied Petroleum Gases

The PADD-V refinery industry also produces substantial amounts of liquefied gases, chiefly propanes and butanes. Mixed propanes and butanes are usually referred to as liquefied petroleum gas or LPG. As we note in a following section on natural gas sources, Hawaii's "LPG" is almost entirely C_3 material, with very little C_4s. Most of the propane used in Hawaii is produced at the refineries, though small amounts are also imported. The PADD-V LPG balance is presented in Table 31 and Figure 60. The region has become a modest net exporter of LPG in recent years, though demand is moving upward sharply. So far, production is moving to parallel demand, so it is possible that the region could serve as a source of supply for Hawaii even with increased West Coast demand.

A detailed description of natural gas and gas liquids is presented in Task I (*World and Regional Fossil Energy Dynamics*) of this project; however, a brief review of terms is in order. The terms LPG, LRG (liquefied refinery gases), and NGL (natural gas liquids) are imprecise and are often used interchangeably.[8] The balance presented here breaks out the gases by type to provide some clarity. LPG is generally C_3 and C_4, while LRGs often include C_5s as well. Pentanes (C_5s) are also sometimes sold separately, or are sold in a mixture of longer-chain hydrocarbons referred to as "pentanes plus," (or C_5+). NGLs can contain the gamut, from C_2 through C_5+, or can be only those C_5+ constituents that remain in liquid phase at normal temperatures and pressures. In our opinion, the sensible way to classify these light hydrocarbons is to use the term **fuelgas** to refer to C_1 and C_2 material (methane and ethane) that is gaseous unless extremely pressurized and chilled, **LPG** for C_3 and C_4 (propanes and butanes) that move readily between gaseous and liquid states, and **NGL** for C_5+ material (pentanes plus) that is liquid at normal temperatures and pressures.

[8]Other key abbreviations are LNG (liquefied natural gas) and CNG (compressed natural gas).

Table 30. PADD-V Residual Fuel Oil Balance, 1981-92

(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Refinery Production	439.0	335.4	306.9	344.8	357.2	365.3	369.2	377.3	386.1	362.9	322.7	309.0
InterPADD Transfers	-7.9	4.2	9.4	0.5	0.0	0.3	0.0	0.0	0.0	0.4	0.0	-0.3
Imports	25.4	20.6	21.4	13.0	13.4	20.3	7.6	35.7	24.0	23.2	20.7	10.8
Exports	63.5	80.8	101.3	106.4	126.4	105.1	131.2	142.6	157.4	140.9	130.1	103.4
Product Supplied	447.7	329.8	240.9	250.5	239.9	285.2	246.6	268.0	258.1	245.8	212.0	217.7
Stock Change	-54.7	-50.4	-4.5	1.4	4.4	-4.5	-1.0	2.4	-5.5	-0.1	1.2	-1.6

Note: Approximately 80% of fuel oil produced is greater than 1% sulfur

Source: USDOE/EIA, Petroleum Supply Annual and Petroleum Supply Monthly

Table 31. PADD-V LPG BALANCE, 1981-1992

(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
FIELD PRODUCTION												
Natural Gas Liquids & LRGs	7,476	11,983	11,889	12,046	14,286	14,498	28,574	32,498	27,843	27,138	33,396	36,070
Pentanes Plus	4,179	4,571	4,773	5,029	5,473	5,394	13,594	16,660	14,575	15,064	18,373	19,641
Liquefied Petroleum Gases	3,297	7,412	7,116	7,017	8,813	9,104	14,980	15,838	13,268	12,074	15,023	16,429
Ethane	0	1	0	48	536	729	57	19	15	13	22	21
Propane	2,009	4,265	4,151	4,225	4,763	4,795	4,722	4,285	3,901	3,682	3,619	3,440
Butane-Propane Mix	417	478	395								0	0
N-Butane/Butylene	651	2,411	2,449	1,974	2,548	2,535	7,503	8,537	7,046	6,300	7,746	8,220
Isobutane	220	257	121	770	966	1,045	2,698	2,997	2,306	2,079	3,636	4,748
REFINERY PRODUCTION												
Liquefied Petroleum Gases	14,561	13,416	14,577	15,409	16,375	16,696	18,967	23,053	20,487	20,687	22,643	30,088
Ethane/Ethylene		123	-3	0	14	4	192	422	527	461	101	0
Propane/Propylene		10,073	9,945	11,665	11,350	12,857	12,396	13,225	12,886	13,263	14,700	15,924
N-Butane/Butylene		2,787	3,938	3,752	4,983	3,705	4,891	7,854	6,511	6,607	7,682	13,301
Isobutane		0	0	-8	28	130	1,488	1,552	563	356	160	863
EXPORTS												
Natural Gas Liquids and LRGs	1,567	1,993	1,572	2,069	2,039	1,315	1,285	2,763	3,711	3,426	3,332	3,705
Pentanes Plus	0	0	0	0	0	0	0	0	258	22	18	19
Liquefied Petroleum Gases	1,567	1,993	1,572	2,069	2,039	1,315	1,285	2,763	3,453	3,404	3,314	3,686
Ethane/Ethylene	0	(s)	(s)	na	(s)	(s)	2	1	13	2	0	0
Propane/Propylene	778	806	629	na	816	529	518	1,233	2,686	3,350	2,426	1,224
N-Butane/Butylene	789	1,187	943	na	1,223	786	765	1,529	754	52	888	2,462
Isobutane	0	0	0	na	0	0	0	0	0	0	0	0
Natural Gas Liquids and LRGs	5,379	5,820	5,835	6,171	3,825	5,567	3,834	3,822	2,298	1,649	817	437
Pentanes Plus	225	96	632	1,097	0	851	0	0	1	0	0	0
Liquefied Petroleum Gases	5,154	5,724	5,203	5,074	3,825	4,716	3,834	3,822	2,297	1,649	817	437
Ethane/Ethylene	0	0	0	1	4	119	34	38	0	0	0	0
Propane/Propylene	789	1,458	1,418	756	488	307	433	567	947	876	463	175
N-Butane/Butylene	4,365	4,266	3,785	2,590	2,000	2,574	2,020	2,089	899	409	129	82
Isobutane	0	0	0	1,727	1,333	1,716	1,347	1,128	451	364	225	180
PRODUCT SUPPLIED												
Natural Gas Liquids and LRGs	13,670	16,482	20,915	20,423	21,904	23,327	31,014	31,082	23,210	23,722	24,383	30,647
Pentanes Plus	510	1,253	2,295	3,266	2,532	3,178	11,345	6,232	4,660	4,934	5,036	4,806
Liquefied Petroleum Gases	13,160	15,229	18,621	17,157	19,372	20,149	29,669	24,850	18,550	18,788	19,347	25,841
Ethane	na	na	na	na	na	na	na	na	529	472	83	21
Propane	na	na	na	na	na	na	na	na	na	14,344	12,904	18,846
N-Butane/Butylene	na	na	na	na	na	na	na	na	na	5,737	5,428	8,104
Isobutane	na	na	na	na	na	na	na	na	na	-1,765	-1,951	-1,130

Source: USDOE Petroleum Supply Annual and Petroleum Supply Monthly

Figure 59. PADD-V Residual Fuel Oil Balance, 1981-92

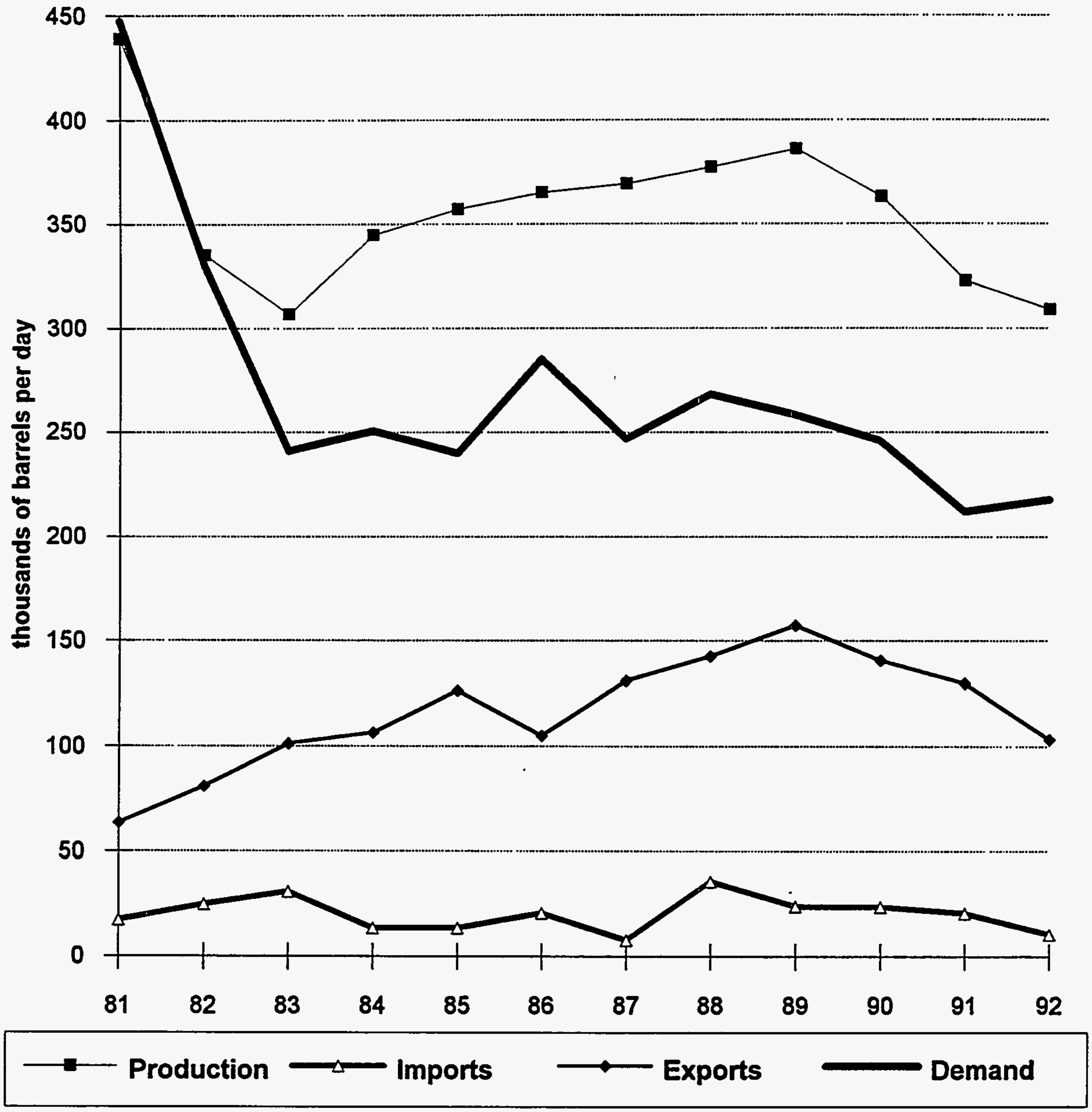
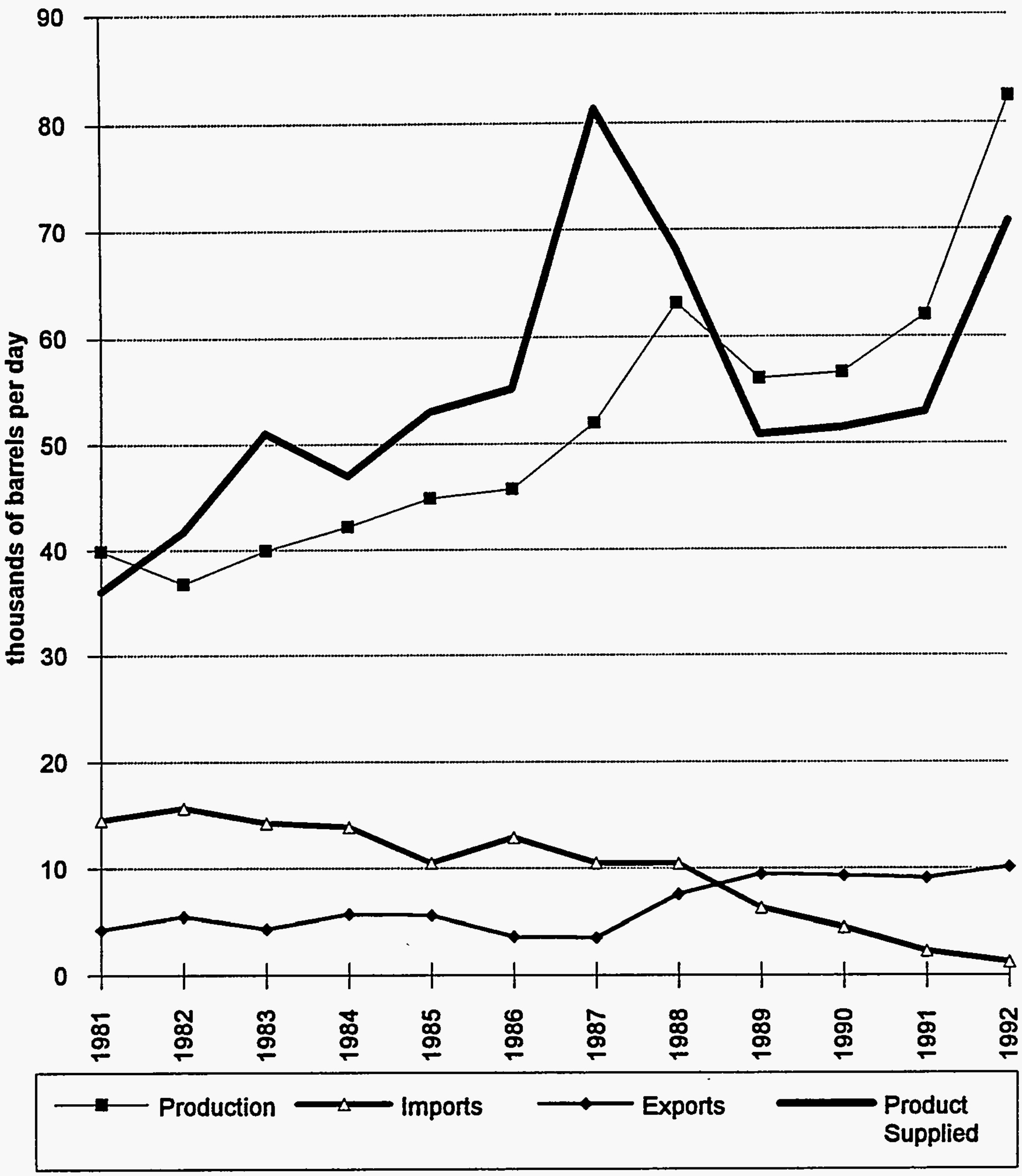


Figure 60. PADD-V LPG Balance, 1981-92



1.6. Petroleum Coke

A final product which should be mentioned is petroleum coke, since, like fuel oil, this product is continually in surplus on the West Coast. Table 32 and Figure 61 present the PADD-V petroleum coke balance, 1981-92. Coke is produced, predictably enough, by coking units. As discussed in Task I of this project, coking is a thermal cracking process employed to convert the heaviest vacuum bottoms into lighter fractions in the naphtha, kerosene and diesel range—though these streams are poorer in quality than straight-run material or hydrocracked material. Hawaii does not produce coke, nor does it require any. The reason it is mentioned here is that, in some cases, petroleum coke may be burned much like coal; there is a "clean coke" plant in California that uses coke as a boiler fuel. Boiler fuel use is not the highest value use. Finer grade coke is almost pure carbon, and is used to make the electrodes used in processing aluminum. There are various grades of coke suited for various uses. The steel industry often uses the poorer grades of coke since it can tolerate, and sometimes can benefit from, the higher levels of metals and sulfur that concentrate in petroleum coke. For example, coke may include metals such as vanadium, cobalt, manganese, nickel, and zinc, which may be useful in producing steel alloys.

2. Asia-Pacific Product Supply/Demand Balances

The other major product market influencing Hawaii is the Asia-Pacific market. This market differs from the PADD-V market in a number of fundamental ways, all of which affect the local supply/demand balance:

1. the local crude resource is very low in sulfur;
2. the region already is a significant net importer of oil;
3. the refinery industry is below the world average in flexibility;
4. demand is growing for all products;
5. middle distillates dominate the demand barrel;
6. product specifications and environmental regulations are more lax; and
7. oil markets are often regulated to some degree.

Table 32. PADD-V Petroleum Coke Supply/Demand Balance, 1981-92
(thousands of barrels per day)

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Refinery Production	100.3	105.7	105.5	113.5	118.8	125.4	125.8	133.7	129.9	137.5	142.8	144.6
Exports	58.9	74.6	77.6	80.3	74.1	90.1	86.4	88.2	93.1	84.3	97.9	102.7
Imports	0.0	0.0	0.0	0.0	0.0	0.5	0.7	0.6	0.5	1.2	1.4	0.7
Product Supplied	40.6	29.0	28.4	34.5	44.1	35.9	39.6	46.5	37.6	53.4	45.9	40.0
Stock Change	0.8	2.1	-0.5	-1.3	0.6	-0.1	0.5	-0.4	-0.2	1.0	0.3	2.6

Source: USDOE/EIAPetroleum Supply Annual and Petroleum Supply Monthly

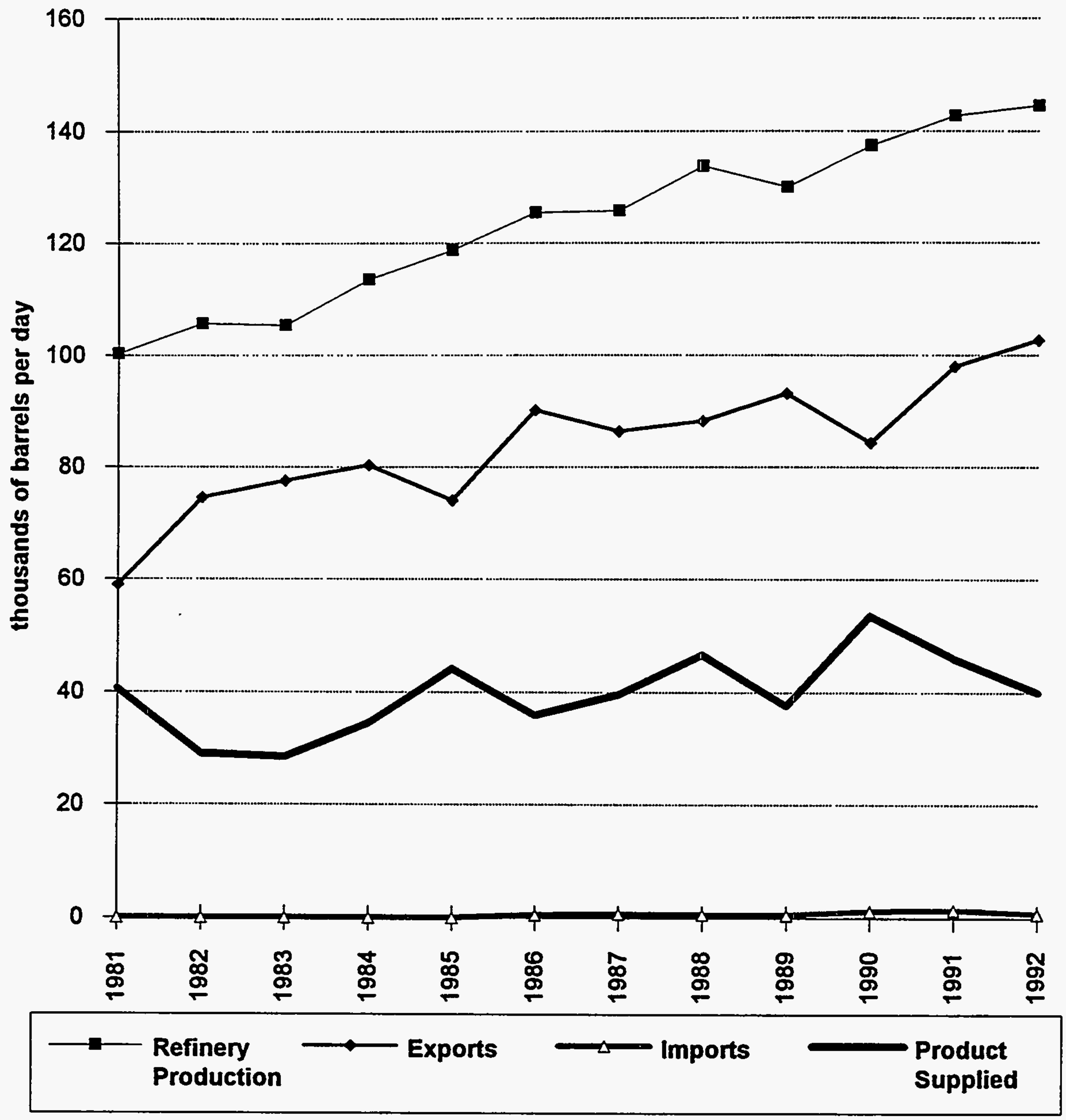
U.S. West Coast Petroleum Coke Exports by Destination, 1992
(thousands of barrels per day)

	Wash.	SFO	L.A./S.D.	Total
East Asia	1.6	9.0	36.5	47.0
Southeast Asia	0.0	0.3	0.3	0.6
N. America	1.2	0.0	0.0	1.2
Latin America	0.2	0.0	0.2	0.5
Australasia	3.3	0.4	4.3	8.1
Europe	2.3	2.0	27.0	31.3
TOTAL	8.6	11.7	68.4	88.7

(Note: Totals do not match USDOE figures, but are shown to provide a picture of sources and destinations)

Source: Pacific West Oil Data

Figure 61. PADD-V Petroleum Coke Balance, 1981-92



As we look to the Asia-Pacific market as a source of oil and oil products, and as an outlet for our own surplus products, all of these factors must be kept in mind. The implications of the first factor, low-sulfur Asia-Pacific crudes, may imply that low-sulfur products or blendstocks are available. But the second factor, import dependence (chiefly on the Middle East) indicates that many refining centers will be producing high-sulfur products and blendstocks. On the third point, the fact that refinery flexibility is below average foretells a future of difficulty in meeting demand for light and middle distillates through cracking of fuel oil. Fourth and fifth, growing demand across the barrel translates into an expectation that the region will have limited product exports and may become a significant importer, particularly of diesel. Sixth, there may still be opportunity to trade product with Asia-Pacific refiners based on quality, with products that cannot meet stringent U.S. and California standards finding ready markets in Asia. Finally, even though there is a clear trend toward privatization and free-market economics in Asian oil markets, many countries still regulate the market via price controls, cross-subsidization of fuels, or control of imports and exports.

2.1. Asia-Pacific Petroleum Product Balances

Table 33 provides a look at recent petroleum product balances for the Asia-Pacific region, followed by Table 34, which provides our forecast of 1995 and 2000 balances. These forecasts are the results of simple refinery modeling exercises designed for each refining country. In volume terms, refinery production consistently falls below demand, meaning that the region is a net importer of products as well as crude. We expect that net product imports will remain in the range of 1 million b/d for the remainder of the decade. There is variation, naturally, among the products. The following charts depict trends for each major product.

2.1.1 Naphtha

Figure 62 presents the naphtha supply/demand balance. Demand exceeded local supply by around 200 mb/d in 1991, and we foresee this supply gap widening to around 400 mb/d by 1995 and over 600 mb/d by the year 2000. The bulk of the naphtha imported goes

Figure 62. Asia-Pacific Naphtha Balance, 1990-2000

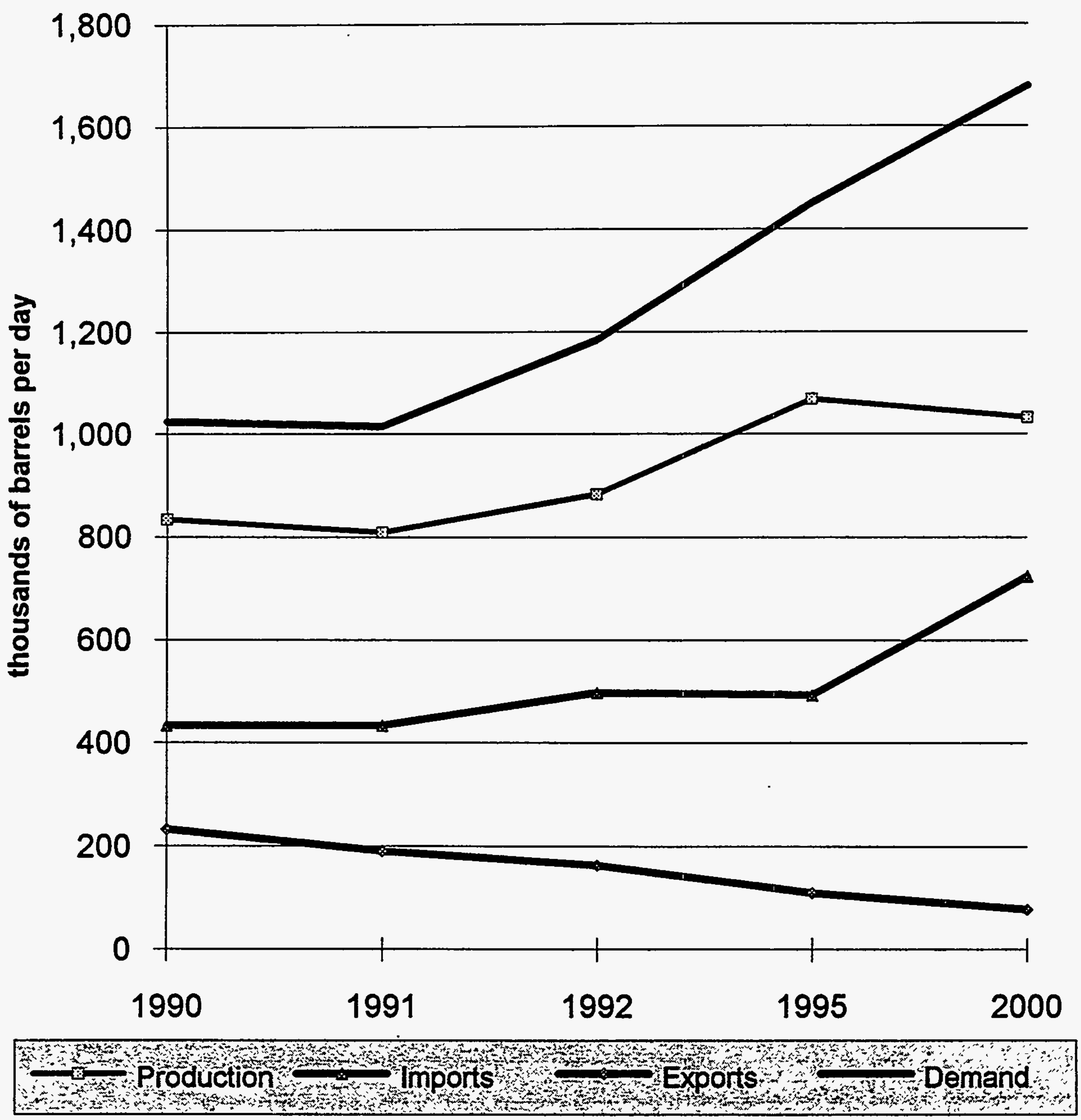


Table 33. Asia-Pacific Petroleum Product Balance, 1990-91
(thousands of barrels per day)

	Production	Imports	Exports	Demand
LPG	489	604	58	1,031
Naphtha	833	433	232	1,025
Gasoline	2,111	238	173	2,171
Kero/Jet	1,368	317	267	1,387
Diesel	3,185	611	410	3,392
Fuel Oil	2,639	1,131	496	3,197
Others	519	61	64	509
TOTAL	11,144	3,395	1,700	12,711

1991 Balance

	Production	Imports	Exports	Demand
LPG	514	615	52	1,095
Naphtha	808	432	190	1,014
Gasoline	2,233	249	184	2,298
Kero/Jet	1,438	279	310	1,442
Diesel	3,592	616	457	3,759
Fuel Oil	2,795	691	611	2,891
Others	598	82	75	600
TOTAL	11,979	2,964	1,880	13,100

Source: East-West Center Program on Resources

Table 34. Asia-Pacific Forecast Petroleum Product Balances, 1995 and 2000

(thousands of barrels of day)

1995 Balance	Production	Imports	Exports	Demand
LPG	1,217	491	386	1,322
Naphtha/BTX	1,068	493	110	1,451
Gasoline	2,875	139	186	2,828
Kero/Jet	1,775	185	202	1,757
Diesel	3,943	1,103	223	4,823
Fuel Oil	3,378	320	425	3,274
Others	498	196	47	647
TOTAL	14,754	3,008	1,580	16,102

2000 Balance	Production	Imports	Exports	Demand
LPG	1,358	540	362	1,537
Naphtha/BTX	1,032	724	78	1,678
Gasoline	3,559	149	231	3,477
Kero/Jet	2,046	160	182	2,024
Diesel	4,819	1,509	263	6,065
Fuel Oil	3,638	232	515	3,355
Others	580	187	53	714
TOTAL	17,031	3,592	1,684	18,850

Source: East-West Center Program on Resources

to feed the giant petrochemical industries of Japan, South Korea, and Taiwan. Hawaii uses no naphtha for petrochemical purposes and typically has a small amount for export; it seems likely that any surplus naphtha produced in Hawaii in the future will find markets easily, though the cost of shipping small cargoes may reduce the cost-effectiveness of such exports.

2.1.2 Gasoline

Figure 63 provides a look at the Asia-Pacific gasoline supply/demand balance. In recent years, the region has been somewhat short on gasoline supplies. As Task I notes, however, much of the refinery capacity now being built in the area is geared toward gasoline production. According to our modeling efforts, the region should be able to produce a small exportable surplus of gasoline by 1995, and may expand output even further by the year 2000. Referring back to the Task I section on fuel quality, it is likely that the Asian gasoline would be unleaded material of suitable octane level for a Hawaii market. The barrier to achieving *any* level of gasoline exports, however, is the naphtha deficit described above. With such extreme pressure at the light distillate end of the barrel, it may be less cost effective to export gasoline while importing such large quantities of naphtha. The price differential between gasoline and naphtha will be the key determinant.

2.1.3 Aviation Fuels

The situation with kerosene and jet fuel is similar to that seen in the gasoline market. Figure 64 presents the Asia-Pacific kero/jet balance. Strong growth in demand should be slightly more than matched by growth in output, both in 1995 and 2000. Any exportable surplus, however, would be quite minor. Still, this is worth noting in jet fuel-intensive Hawaii, since it may at least mean that Asian jet importers will not necessarily be competing strongly for marginal supplies of jet fuel.

2.1.4 Diesel Fuel

The single most important factor likely to shape trade is the growing deficit in Asia-Pacific diesel. The region is historically a net importer of diesel, but current trends point to a massive widening of the supply gap. Imports in 1991 amounted to around 150 mb/d; if trends continue, 1995 import requirements may reach around 900 mb/d, and imports in 2000

Figure 63. Asia-Pacific Gasoline Balance, 1990-2000

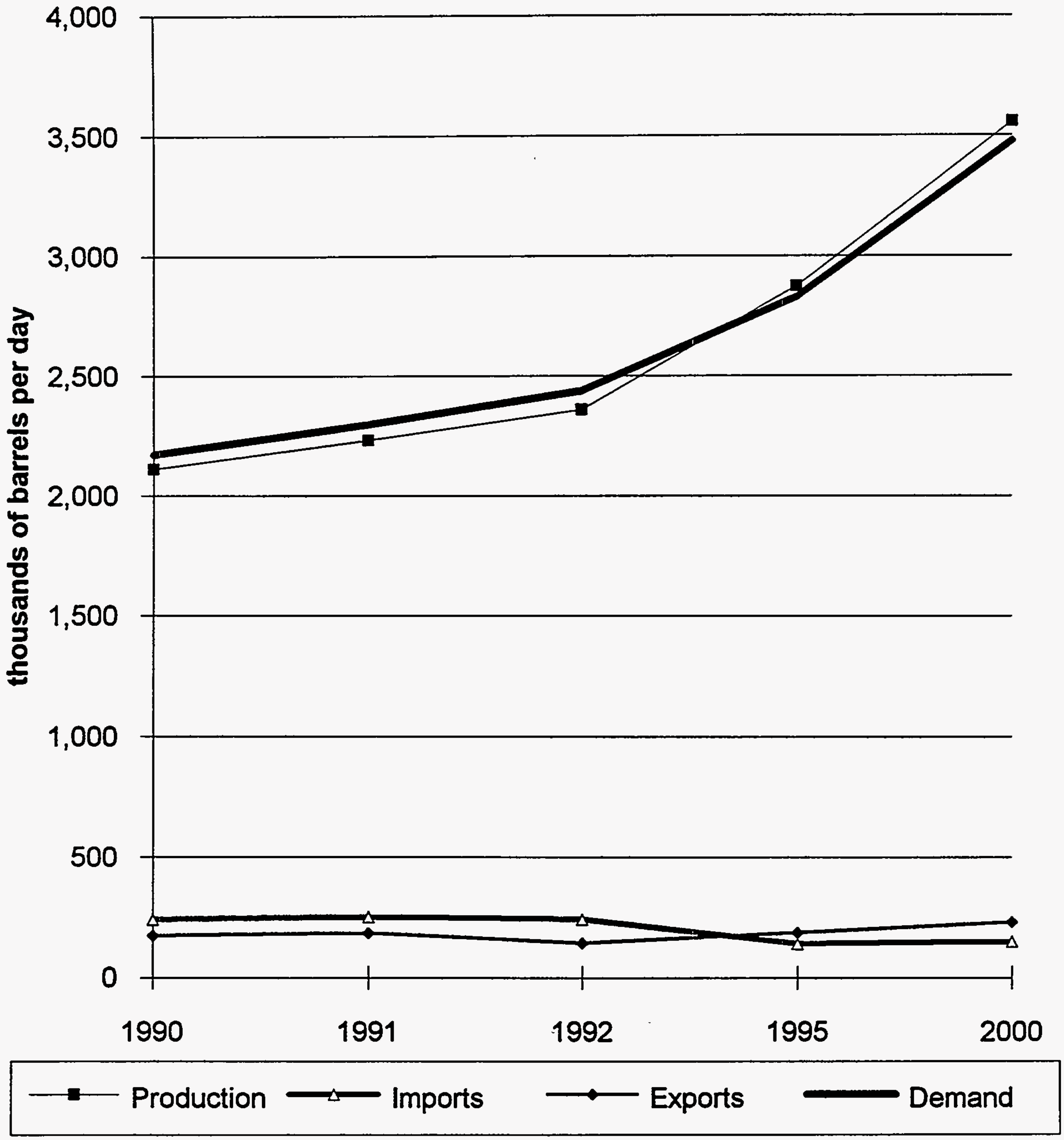
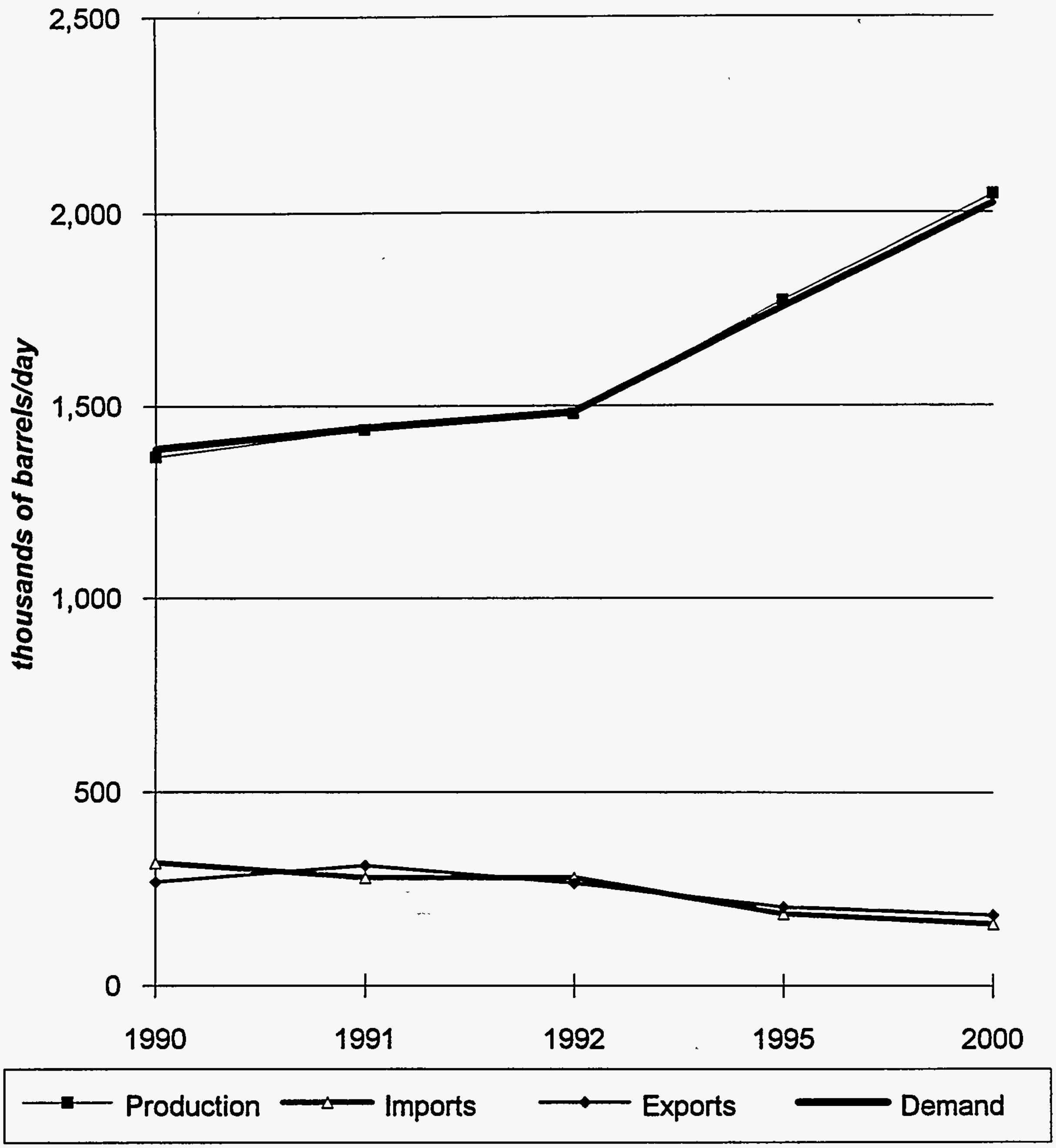


Figure 64. Asia-Pacific Kero/Jet Balance, 1990-2000



may exceed 1,200 mb/d. This will create serious supply pressures and will inevitably result in higher diesel prices. If Hawaii is not able to meet local demand for diesel within the local refining centers, the marginal barrel purchased abroad may be increasingly expensive. The Asia-Pacific diesel balance is presented in Figure 65.

2.1.5 Residual Fuel Oil

As noted, the Asia-Pacific refining industry is less flexible than the world average in terms of producing transport fuels. This translates into imbalances such as the diesel situation and it also affects the fuel oil balance, since the refiners are without the capability to thoroughly convert fuel oil into lighter products. Figure 66 shows the residual fuel oil balance. In 1990, the region was a net importer of fuel oil. During the 1995 to 2000 period, we expect the region to be marketing excess fuel oil, since refinery crude distillation capacity is expanding faster than downstream cracking/conversion capacity. Much of the region's surplus will be high-sulfur material, generally not suitable for Hawaii markets, but there will still be supplies of LSWR and LSFO at a price. The chronic oversupply of HSFO on the U.S. West Coast combined with the emerging surplus in Asia should serve to weaken HSFO prices, but LSWR/LSFO prices should remain fairly strong.

2.2 Asia-Pacific Summary and Forecast Balances

Figure 67 summarizes the product trade balances forecast for the Asia-Pacific region, 1990, 1995 and 2000. Seen side-by-side, it is easy to see how the impending diesel deficit, and to a lesser degree the naphtha deficit, dwarfs the slight surpluses possible in gasoline, jet fuel, and fuel oil. Even though Hawaii is a small market, it appears that it will be an easier task to export products to Asia than to rely on Asia as a source of refined product imports.

3. Fuel Oil Imports and Exports: An Example of Fuel Quality Directing Trade

Hawaii both imports and exports fuel oil. In 1992, Hawaii imported around 5.4 mb/d of fuel oil while exporting 5.3 mb/d, mainly to foreign destinations (notably Taiwan, South Korea, the Pacific Islands, and Mexico). This behavior is a persistent feature of the market and offers an interesting example of how fuel quality can influence trade. The first factor

Figure 65. Asia-Pacific Diesel Balance, 1990-2000

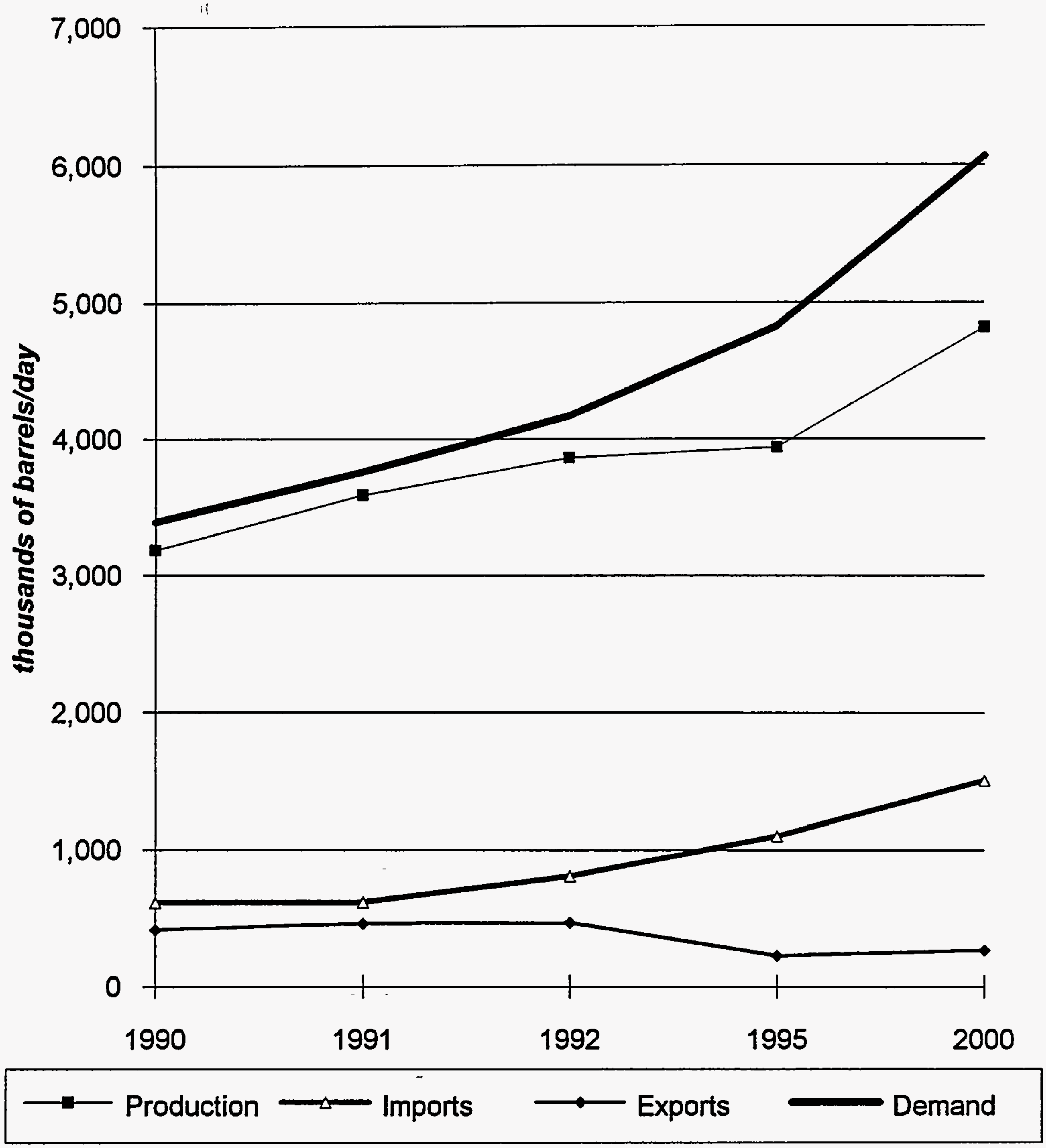


Figure 66. Asia-Pacific Fuel Oil Balance, 1990-2000

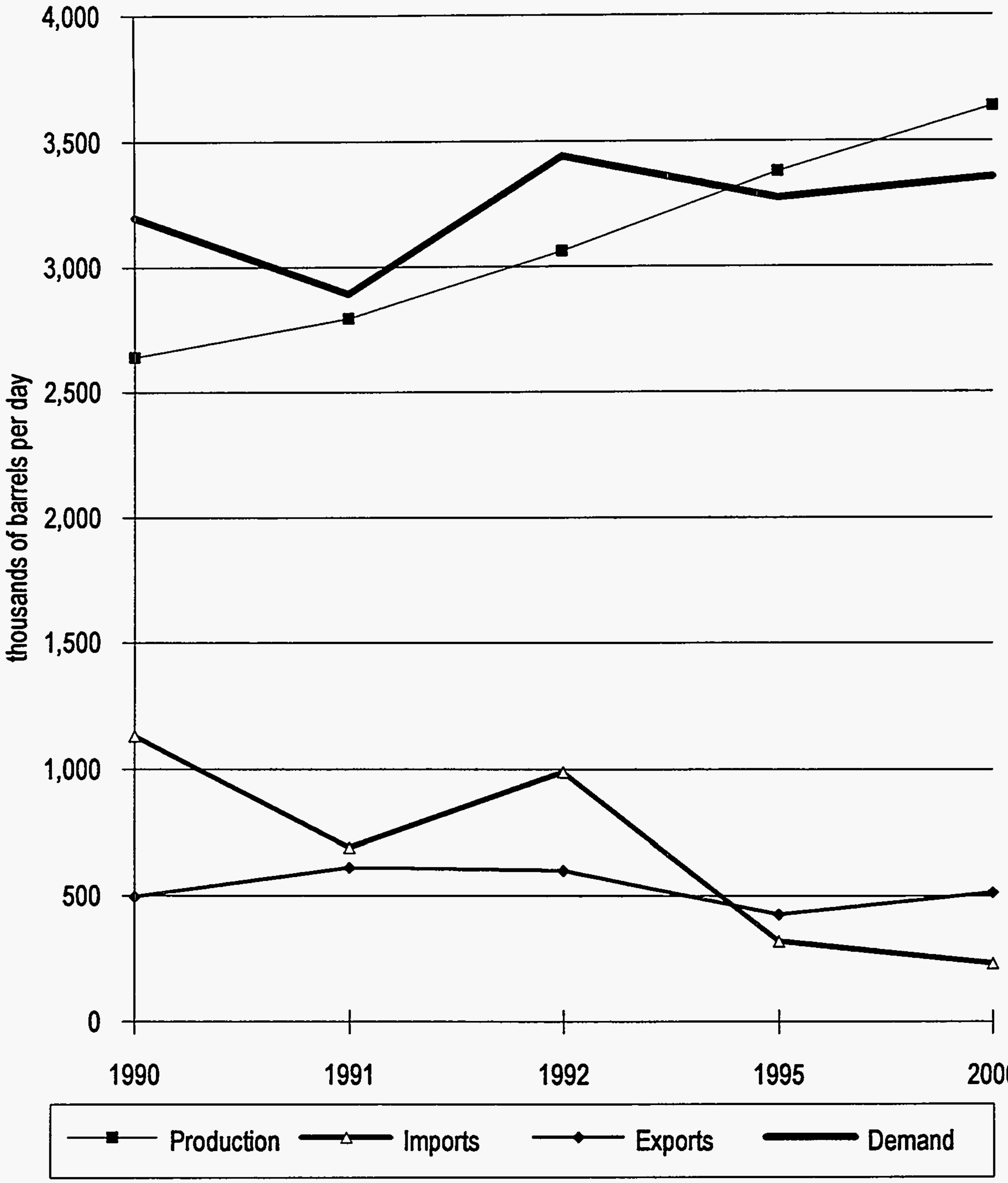
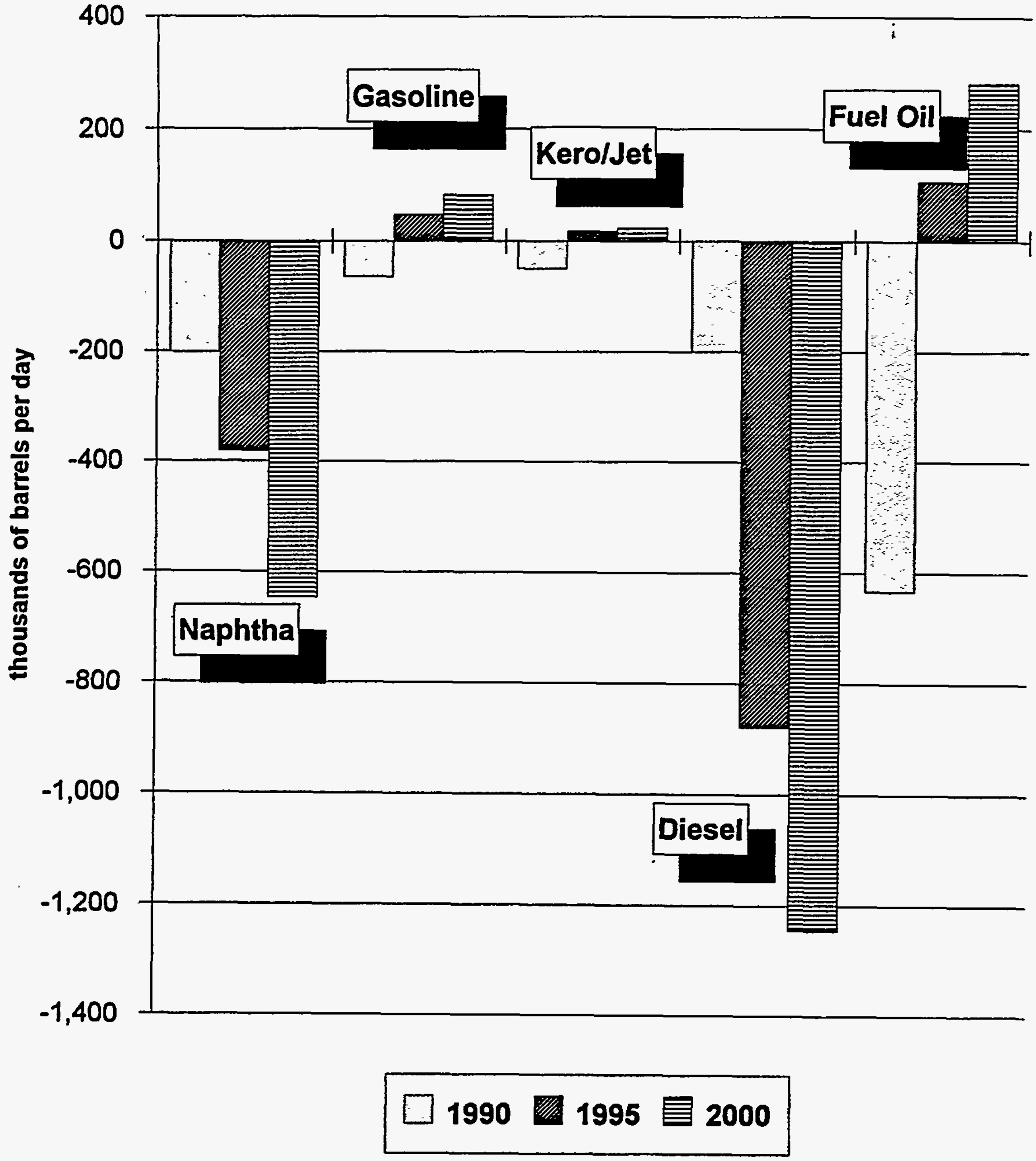


Figure 67: Asia-Pacific Product Import/Export Forecast, 1990-2000



coming into play is the boiling range of the fuel oil. "Straight-run" resid refers to fuel oil that is left behind after the atmospheric crude distillation process. It typically is a mixture of complex hydrocarbons with boiling ranges above 650° F. In a simple refinery, this material is simply fuel oil. In a complex refinery, this material can be further separated in a vacuum distillation unit to yield light vacuum gasoil (LTVGO, with a boiling range typically 650° F to 800° F), heavy vacuum gasoil (HVVGO, or just HGO, with boiling range typically 800° F to 1,000° F) that serve as feed for downstream cracking units, plus vacuum bottoms (VB, 1,000°+ F) that represent truly the bottom of the barrel. A complex refinery is able to extract more value from straight-run resid, also known as "virgin resid" or "whole resid." The heavy fuel oil sold by a complex refinery is generally unsuited for anything other than boiler fuel. On the other hand, the fuel oil produced at a simple refinery may be purchased as feed for the cracking units of more sophisticated refineries. It is therefore quite common to see refiners both importing and exporting fuel oil. Some California refineries have such advanced deep-conversion capability that they can easily process fuel oil far in excess of what they produce internally through the distillation process. Since fuel oil has been considerably cheaper than crude, it is often advantageous for these refiners to purchase and crack straight-run resid or VGO rather than purchasing and processing whole crude. Hawaii refiners from time to time have sold VGOs to U.S. West Coast refiners.

The second factor affecting fuel oil trade is the sulfur content. The majority of the fuel oil exported by Hawaii is high-sulfur material that cannot be used by local utilities. The sulfur standard on Oahu is 0.5 percent sulfur by weight (0.5%S) maximum, and the limit on the neighbor islands is 2.0%S. Fuel oil imports are typically low sulfur. Table 35 and Figure 68 provide a look at Hawaii's fuel oil imports from foreign sources, 1981-92. The import series paints an interesting picture; in the early and mid 1980s, fuel oil with sulfur contents between 0.3 percent and 1 percent was the dominant grade imported, with significant quantities of 1 percent+S HSFO also imported. In the latter half of the decade, the pattern switched to a reliance on LSFO imports of under 0.3 percent sulfur. Moreover, the levels of imports have dropped, partly because of increased use of heavy crudes (such as

Table 35. Hawaii's Residual Fuel Oil Imports by Sulfur Content, 1981-92

(thousands of barrels per day)

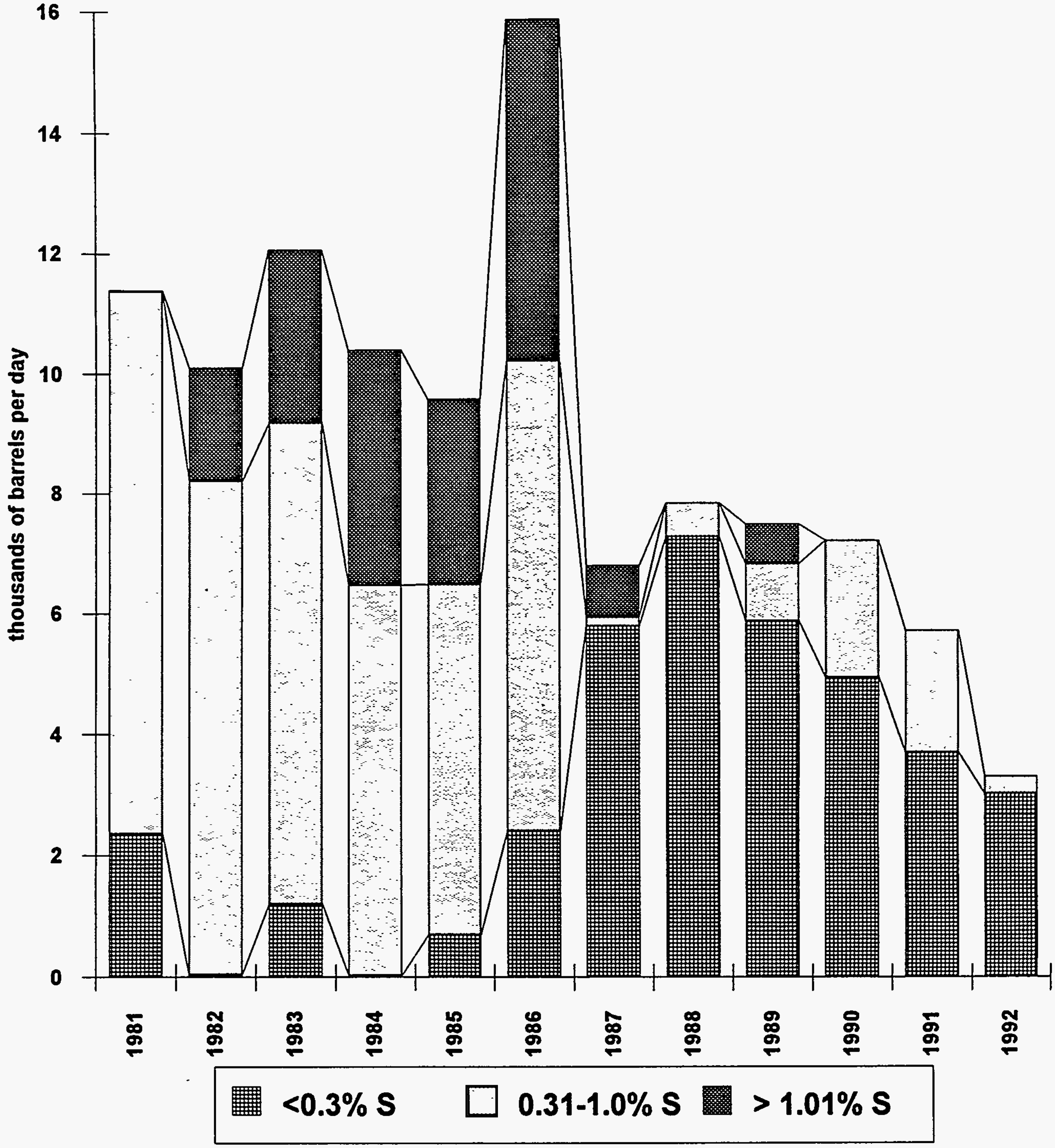
	< 0.3% S	0.31-1.0% S	> 1.01% S	Total	% < 0.3% S	% 0.31-1.0% S	% > 1.01% S
1981	858	3,294	8	4,160	20.6%	79.2%	0.2%
1982	16	2,980	693	3,689	0.4%	80.8%	18.8%
1983	442	2,909	1,054	4,405	10.0%	66.0%	23.9%
1984	11	2,358	1,436	3,805	0.3%	62.0%	37.7%
1985	259	2,106	1,128	3,493	7.4%	60.3%	32.3%
1986	878	2,846	2,059	5,783	15.2%	49.2%	35.6%
1987	2,115	52	312	2,479	85.3%	2.1%	12.6%
1988	2,662	205	0	2,867	92.8%	7.2%	0.0%
1989	2,143	346	240	2,729	78.5%	12.7%	8.8%
1990	1,801	828	0	2,629	68.5%	31.5%	0.0%
1991	1,350	736	0	2,086	64.7%	35.3%	0.0%
1992	1,101	106	0	1,207	91.2%	8.8%	0.0%

(thousands of barrels per day)

	< 0.3% S	0.31-1.0% S	> 1.01% S	Total
1981	2.35	9.02	0.02	11.40
1982	0.04	8.16	1.90	10.11
1983	1.21	7.97	2.89	12.07
1984	0.03	6.44	3.92	10.40
1985	0.71	5.77	3.09	9.57
1986	2.41	7.80	5.64	15.84
1987	5.79	0.14	0.85	6.79
1988	7.27	0.56	0.00	7.83
1989	5.87	0.95	0.66	7.48
1990	4.93	2.27	0.00	7.20
1991	3.70	2.02	0.00	5.72
1992	3.01	0.29	0.00	3.30

Source: USDOE "Petroleum Supply Annual" and "Petroleum Supply Monthly"

Figure 68. Fuel Oil Imports into Hawaii by Sulfur Content, 1981-92



Indonesian Duri) and reduced fuel oil demand in the electric power sector. (Since 1990 a significant amount of power has been generated by solid waste, coal, and geothermal energy.)

The crude slate is the prime factor affecting Hawaii's fuel oil production and quality. Running all sweet crude would yield only LSFO and/or LSWR (low-sulfur waxy resid, obtained from processing waxy crudes like Minas and Duri). Running only sour crude would yield only HSFO. Hawaii's refiners run a variety of crudes and blend the appropriate streams to meet local requirements, importing and exporting to balance supply and demand. Figure 69 presents a simple fuel oil blending exercise to demonstrate how the crude slate affects fuel oil output. Referring back to the table presenting crude distillation yields and fuel oil sulfur levels, we find that ANS crude yields around 45 percent fuel oil with a sulfur content of 1.64 percent—suitable for use on the neighbor islands but well in excess of the allowable sulfur limit on Oahu. In 1992, Hawaii imported around 27 million barrels of ANS, indicating a yield of 12 mmb of 1.64%S straight-run fuel oil. Assume for the sake of simplicity that 2 mmb of this material is shipped to the neighbor islands and 10 mmb remains on Oahu. Oahu's total fuel oil demand is 10 mmb, but the sulfur limit is 0.5 percent. How much Duri resid (0.2%S) is required to blend with how much ANS resid to meet Oahu demand? A simple arithmetic calculation reveals that 8 mmb of Duri resid is required and only 2 mmb of ANS resid may be used. In this simple example, 10 mmb of Duri crude must be imported to produce 8 mmb of LSWR, and 8 mmb of ANS resid is surplus and must be exported.

C. Possible Sources of Gas and Gas Liquids

1. Introduction

Propane-based liquefied petroleum gas (LPG) and synthetic natural gas (SNG)[9] are the two major types of gases that are currently used in Hawaii. These two types of gases are

[9]SNG is gas synthesized from liquid hydrocarbons such as low-octane light naphthas.

Figure 69. Fuel Oil Blending: A Simple Example

1. Refining 27 million b/y of ANS Crude
   Yields 12 million b/y of Fuel Oil (1.64% Sulfur)
2. Oahu Power Generation
   Requires 10 million b/y of Fuel Oil (0.5% Sulfur)
3. Neighbor Islands Power Generation
   Requires 2 million b/y of Fuel Oil (2.0% Sulfur)
4. Refining Indonesian Duri Crude
   Yields 80.5% Fuel Oil (0.21% Sulfur)

QUESTION: How much ANS Fuel Oil (FO) can be used?
How much Duri Fuel Oil is required to meet the sulfur limit?

	(mmb/y) Volume	% Sulfur	
ANS FO in System	12	1.64	
Neighbor Island FO Demand	2	2.00	(ANS FO)
ANS FO Remaining	10	1.64	
Target for Oahu	***10***	***0.50***	
Duri FO required	***8***	0.21	
ANS allowed in Oahu blend	***2***	1.64	
Excess ANS FO	8		
Amount of Duri Crude Required	10		

Note: In 1992, LSFO Imports=	1.2 mmb
HSFO Exports=	1.5 mmb

mainly provided by the local refineries, with a certain amount of propane being imported each year. Hawaii's "natural gas" is actually therefore an oil product. So far, there have been no direct imports of natural gas to the state. The possibility of importing and marketing liquefied natural gas (LNG) is examined fully in Task III (*Greenfield Options*) of this project.

In this chapter, we will focus our discussion on LPG, and, to a lesser extent, SNG, in Hawaii. The term "LPG" is commonly used to encompass a variety of propane-butane mixes. It can be easily confused with the term natural gas liquid (NGL). There is some possible overlap between the two, since NGLs typically contain C_3 and C_4. The nomenclature of NGL was discussed in the previous chapter under "World Gas Industry". In a broader sense, NGL refers to hydrocarbons heavier than methane (C_1). It can also be more narrowly defined as the hydrocarbon liquids containing pentanes (C_5) and heavier. For the purpose of this discussion on the Hawaii situation, the first definition of NGL will be used.

The rest of this section is organized as follows. Part 2 discusses the current gas (LPG and SNG) market in Hawaii and its major players, i.e., suppliers, distributors and users. The prospects for future gas consumption in Hawaii will be discussed in Part 3. Depending on the future changes in scales and configurations of the local refineries, three scenarios will be examined to determine the possible propane import requirements of Hawaii in the future. Potential LPG suppliers to Hawaii will be studied in Part 4. In the same section, the possible sources of NGL supply will be briefly discussed. Summary and concluding remarks are presented last.

2. Hawaiian Gas Market

Chevron and BHP Petroleum Americas (Hawaii), Inc. (formerly Pacific Resources, Inc.) are the two local refineries that supply propane to the Hawaiian gas market. These two refiners provide commercial and engine-grade propane to three major gas wholesalers and bulk retailers: The Gas Company (GASCO), Oahu-Maui Gas Service Inc. and Aloha LP Gas Inc. GASCO receives propane from both refineries and sells bottled propane as non-utility gas. At the same time, it uses propane vapor—a mixture of propane and air—to supplement its SNG supply through pipelines as utility gas. Oahu-Maui Gas and Aloha Gas receive their propane from Chevron and BHPPA (Hawaii), respectively, and sell as non-utility gas (Figure 70). BHPPA (Hawaii) also provides low-octane light hydrocarbons to GASCO, its subsidiary, as the feedstock to manufacture SNG. The total local LPG production for 1992 was 1.431 million barrels (5.5 trillion Btu). A substantial portion of the local LPG output has been used for other purposes, such as gasoline blending, power generation and heating within the refineries. The information on the volume of LPG used for each of these purposes is not available.

Hawaii also imports some propane. At present, BHP-Australia and Shell-Philippines provide all propane imports to Hawaii. GASCO is the only propane importer. While Australia does have extra LPG for exports, the Philippines is mainly a transfer port as it does not actually export any propane. The propane exported to Hawaii from the Philippines probably comes originally from the Middle East. According to GASCO, in 1992, 110 thousand barrels of propane were imported. This import level adds up the total propane-LPG supply to 1.541 million barrels (5.9 trillion Btu) in 1992.

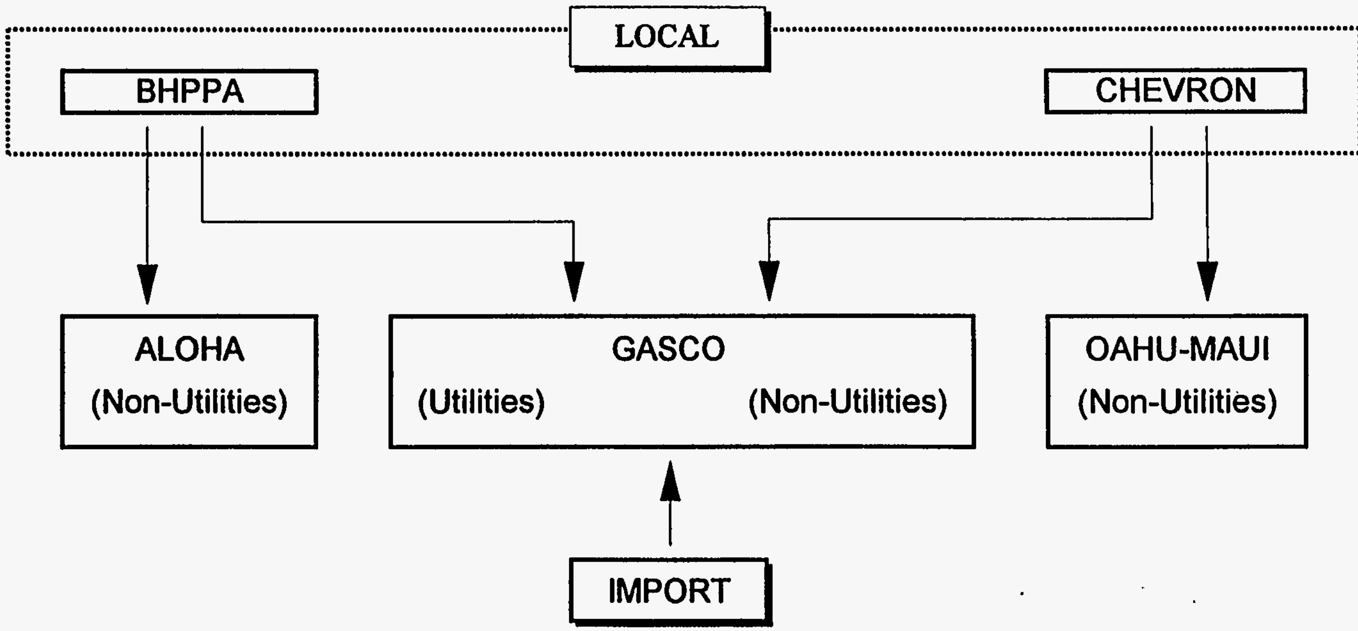
There have been no exports of LPG from Hawaii. However, the state does ship surplus light hydrocarbons out of the isles for sales as petrochemical feedstocks.

2.1. Use of Gas Products

There are two different sectors of gas consumption in the state, utility and non-utility. The utility sector is regulated by the state government. Gas service in this sector uses mostly SNG which is distributed through pipelines. The non-utility sector is largely market oriented and uses only propane, distributed by small tankers and bottles. Propane is also transported to the neighbor islands by barges from Oahu or if imported, by small ships.

The information available on gas consumption below does not directly come from the end users. Instead, it is the amount of gas products distributed by the three major gas wholesalers and bulk retailers. In general, there are two classes of gas user in Hawaii: the residential sector and the commercial/industrial sector. The electric power sector does not

Figure 70. Propane Flows in Hawaiil



use gas, nor does heavy industry, agriculture, or transport (outside of a few propane-fueled vehicles).

Since Hawaii is an isolated market where oil is the source of SNG and the majority of the propane, Hawaiian customers pay extremely high prices. To put matters into perspective, Table 36 compares gas prices experienced by Hawaii's commercial and residential consumers to prices in the other PADD-V states. Hawaii's gas prices are generally 200 percent to 600 percent higher. For example, during the first ten months of 1992 (the latest data available as of this writing), Hawaii's residential consumers paid $18 per thousand cubic feet (ft^3), whereas California consumers paid around $6/thousand ft^3. Alaskan consumers paid under $4/thousand ft^3. Hawaii's commercial customers fared little better, paying $13.29/thousand ft^3 as compared to $5.05/thousand ft^3 in California and $2.61/thousand ft^3 in Alaska. This, surprisingly, is rarely mentioned in Hawaii. It is taken for granted that most imported or highly processed goods will be more expensive, but the price differential in the case of SNG is quite remarkable. Consumers in Hawaii complain when the price of gasoline is, say, $0.30-$0.40/gallon above Mainland prices, representing a price around 20 percent higher than a Mainland price. If Hawaii's gasoline prices paralleled SNG prices, consumers could expect to pay at least $4.50/gallon.

2.1.1 The Utility Gas Sector

The utility sector is served only by GASCO, which is the largest gas company in the market. In 1992, GASCO provided 3.4 trillion Btu utility gas on Oahu, Hawaii, Maui and Kauai. Oahu accounted for over 90 percent of this service (Table 37). Of this 3.4 trillion Btu utility gas, 17 percent went to the residential sector and 83 percent to the commercial/industrial sector (Figure 71).

As mentioned earlier, the distribution involves two different forms of gas products: SNG and propane. Each of these forms will be discussed below.

Synthetic Natural Gas (SNG)

The SNG gas distribution system serves only the Honolulu service territory. This service territory accounted for almost 90 percent of the customers in the utility sector in

Table 36. PADD-V Price of Natural Gas Delivered to Residential and Commerical Consumers, 1985-92
($ Per Thousand Cubic Feet)

Residential Consumers	Alaska	Arizona	California	Hawaii	Nevada	Oregon	Washington
1985	2.81	7.00	5.72	**18.12**	7.04	6.93	6.60
1986	3.27	6.38	5.07	**16.09**	5.91	6.63	5.93
1987	3.21	6.11	5.26	**15.90**	5.31	6.62	5.42
1988	3.46	6.99	5.64	**15.69**	5.87	6.79	5.5
1989	3.63	6.90	5.58	**15.66**	5.51	6.19	5.49
1990	3.79	6.85	5.78	**16.45**	5.66	6.27	5.02
1991	4.18	6.99	6.27	**22.93**	5.61	6.13	4.68
1992	***3.92***	***8.29***	***6.07***	***18.01***	***6.26***	***6.62***	***5.68***
Jan	3.69	6.39	6.13	**18.12**	5.10	5.81	4.52
Feb	3.68	6.47	6.01	**17.92**	5.18	5.91	4.67
March	3.69	6.84	5.74	**17.48**	5.29	6.02	4.81
April	3.75	7.43	5.50	**17.07**	5.68	6.20	5.00
May	3.83	8.52	5.97	**18.04**	6.41	6.47	5.46
June	4.03	9.02	6.26	**17.71**	6.81	6.94	6.24
July	4.20	9.53	6.25	**18.19**	6.89	7.30	7.17
August	4.54	9.87	6.19	**18.52**	7.37	7.62	7.04
September	4.02	9.63	6.27	**18.46**	7.06	7.25	6.34
October	3.79	9.19	6.33	**18.60**	6.76	6.65	5.56
November							
December							

PADD-V Price of Natural Gas Sold to Commercial Consumers
($ Per Thousand Cubic Feet)

	Alaska	Arizona	California	Hawaii	Nevada	Oregon	Washington
1985	2.36	5.57	6.63	**14.44**	6.12	6.25	5.45
1986	2.16	4.71	5.61	**12.03**	4.88	5.63	5.13
1987	2.41	4.54	5.42	**11.76**	4.29	5.31	4.50
1988	2.60	4.97	4.68	**11.52**	4.62	5.36	4.59
1989	2.58	4.93	4.87	**11.44**	4.42	4.89	4.66
1990	2.63	4.79	5.12	**12.25**	4.38	4.85	4.14
1991	2.89	5.07	5.50	**13.36**	4.34	4.75	4.06
1992	***2.61***	***4.95***	***5.05***	***13.29***	***4.36***	***4.78***	***4.37***
Jan	2.68	5.13	4.80	**13.46**	4.30	4.65	4.13
Feb	2.70	2.14	8.64	**13.51**	4.29	4.65	4.17
March	2.70	5.26	5.93	**12.87**	4.26	4.67	4.18
April	2.65	5.33	5.92	**12.57**	4.33	4.70	4.28
May	2.61	5.77	3.77	**13.34**	4.40	4.72	4.37
June	2.54	5.38	3.91	**12.95**	4.41	4.81	4.51
July	2.48	5.08	4.39	**13.24**	4.37	4.94	4.52
August	2.63	5.29	4.40	**13.44**	4.45	5.01	4.58
September	2.50	4.87	4.21	**13.67**	4.42	4.88	4.49
October	2.59	5.29	4.53	**13.83**	4.37	4.72	4.44
November							
December							

Source: USDOE/EIA "Natural Gas Monthly"

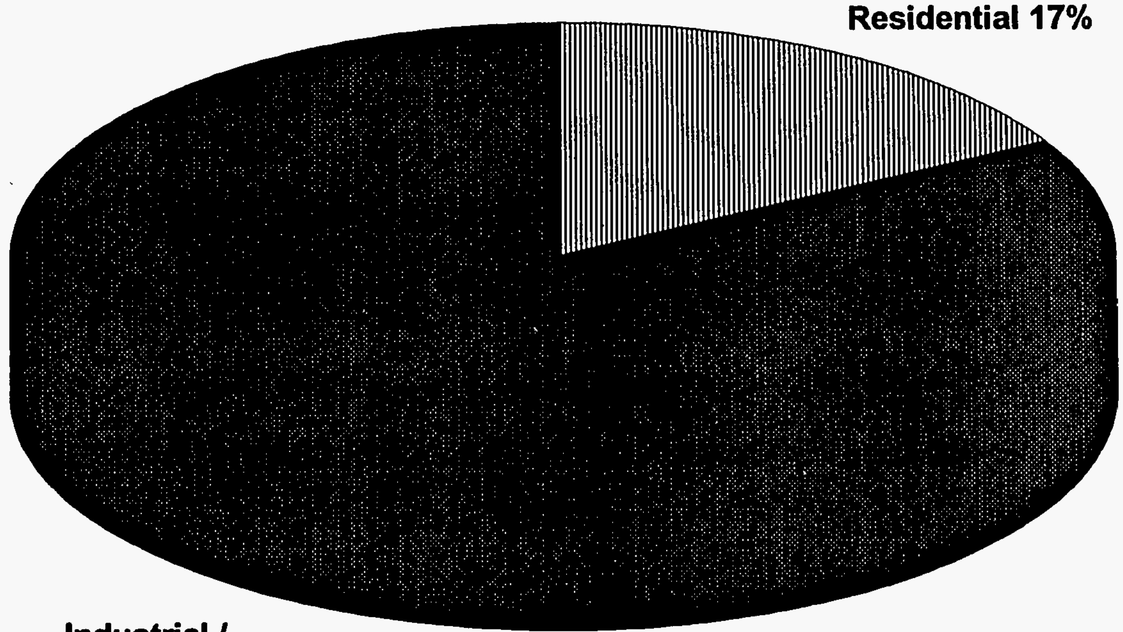
Table 37. Gas Utility Service by GASCO on Oahu, 1985-91

Year	Gas Sold /a (billion Btu)	Share in Hawaii's Total Gas Utility
1985	2,826	90.6%
1986	2,814	90.4%
1987	2,935	90.5%
1988	2,969	90.7%
1989	3,078	90.9%
1990	3,165	90.9%
1991	3,087	90.9%

a. Includes propane.

Sources: State of Hawaii Databook 1991 and 1992.

Figure 71. Utility Gas Consumption by Sector, 1992



1992. SNG consumption (2.9 trillion Btu in 1992) accounted for approximately 86 percent of the total gas sales in this sector (Table 38).

The SNG plant is operated by GASCO. It produces SNG from low-octane hydrocarbons purchased from BHPPA (Hawaii). The plant has a capacity of 15 billion Btu per day. Currently operating at 54 percent of its capacity, the plant can easily increase the amount of SNG production if necessary. Furthermore, according to GASCO, expansion of the plant could be done relatively easily in case of further demand growth.

At the current operation rate, the SNG plant uses only about 25 percent of the light hydrocarbons produced by BHPPA (Hawaii). The light hydrocarbons are by-products of the petroleum refining process, being unsuited for gasoline manufacture. Surplus naphtha-range material is exported. Since about half of the state's naphtha production was exported in 1992, and is therefore already available as a feedstock, no additional imports of crude oil would be needed, even if the current capacity of the SNG plant were doubled.

Propane (C_3)

One way to utilize propane is by mixing it with air to produce propane vapor. It is used as a source of supplemental supply during peak periods in the SNG distribution system of the Honolulu service territory. The amount of propane consumption for this purpose is unclear.

In the other utility gas service territories, i.e., outlying areas of Oahu and the neighbor islands, propane vapor is the only form of gas distributed. In 1992, there were 43 propane vapor distribution systems operated by GASCO statewide. These systems provided 492 billion Btu of propane vapor, approximately 14 percent of GASCO's total utility gas sales.

2.1.2. The Non-Utility Gas Sector

Propane is the only form of gas product used in this sector. In 1992, GASCO, Aloha Gas and Oahu-Maui Gas distributed 2.7 trillion Btu of propane to the non-utility sector. GASCO is by far the largest of the three distributors. The residential sector accounted for

Table 38. Gas Utility Service in Hawaii, 1981-1992

(billion Btu)

Year	SNG /a	Propane	Total
1981	2,732	507	3,240
1982	2,738	484	3,222
1983	2,659	471	3,131
1984	2,635	458	3,093
1985	2,657	463	3,120
1986	2,650	462	3,112
1987	2,764	476	3,241
1988	2,789	485	3,273
1989	2,895	491	3,387
1990	2,977	504	3,481
1991	2,907	491	3,397
1992	2,930 /b	492	3,422

a. SNG is used in the Honolulu service territory only.
b. Estimate.

Sources: State of Hawaii Databook 1992 and GASCO.

17 percent and the commercial/industrial sector for 67 percent of the total non-utility propane consumption (Figure 72). The rest was used for other purposes, such as propane-fueled fleet vehicles owned by the tour companies, governments, and corporations.

3. Gas Product Consumption Forecast for Hawaii

Because of the way that gas is distributed and regulated, the growth of demand in the utility and non-utility sectors follow different patterns. Generally speaking, the demand for gas is growing faster in the non-utility sector than in the utility sector. The available information indicates that demand for non-utility gas products has changed rapidly in the past two or three years. This could be the source of fast-growing gas demand in Hawaii in the future.

3.1. Prospects for Gas Demand in the Utility Sector

According to the forecast by GASCO, the demand for SNG and propane in the utility sector is expected to rise at an annual rate ranging from 1 to 1.5 percent between 1992 and 2014. The actual consumption from 1981 to 1991 and the year-by-year forecast for the period of 1992-2014 are shown in Figure 73. According to this forecast, which is based on GASCO's estimates, the demand in this sector will increase from 3.4 trillion Btu in 1992 to 3.8 trillion Btu in 2000, and 4.6 trillion Btu in 2014.

As suggested by GASCO, SNG is the major form of gas that the company intends to promote in order to meet the moderately growing demand in this sector. Propane will continue to serve as a supplementary fuel for SNG. From 1981 to 1992, the use of propane in the utility sector slightly declined, while the overall consumption of SNG increased over the same period.

3.2 Prospects for Gas Demand in the Non-Utility Sector

Non-utility gas consists exclusively of propane and propane-based LPG. Less gas is used in the non-utility sector in Hawaii than in the utility sector. However, the gap between

Figure 72. Non-Utility Gas Consumption by Sector
1992

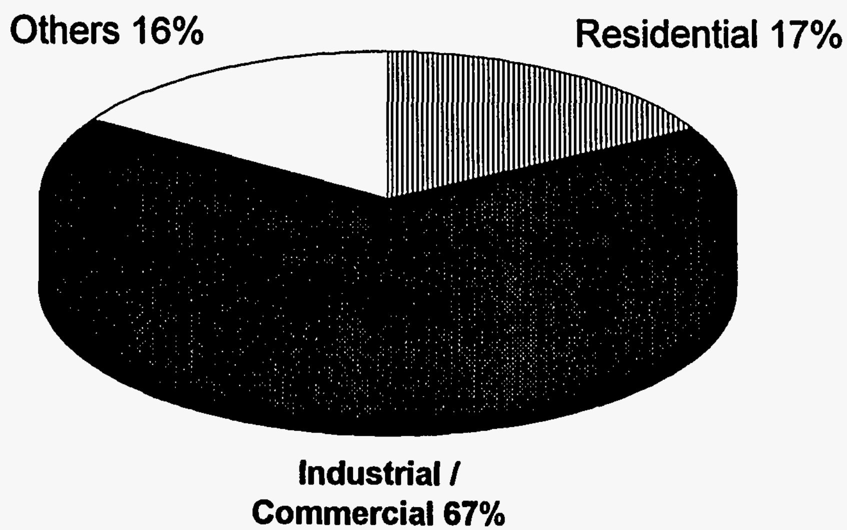
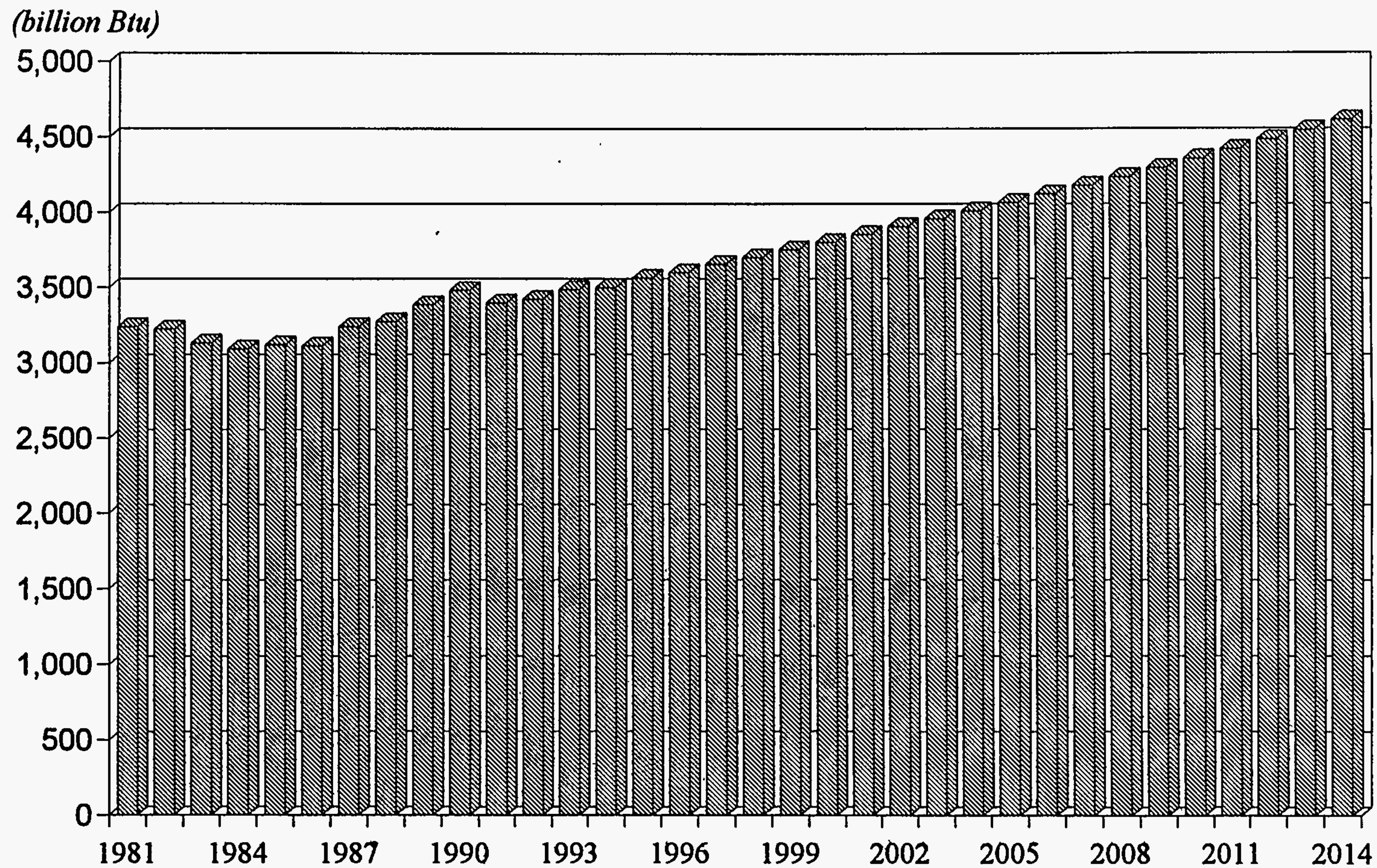


Figure 73. Gas Demand in the Utility Sector in Hawaii, 1981-2014



the two consumption figures is expected to narrow, since gas demand in the non-utility sector is expected to grow faster than in the utility sector over the next two decades. The following factors may contribute to the high demand for gas by the non-utility consumers in Hawaii in the future:

a).**Demand for LPG in the Neighbor Islands.** Currently, this demand is rather small but is growing rapidly. It is expected to continue to grow at a fairly rapid rate.

b). **Competitiveness of the Market.** The non-utilities gas market is unregulated and thus more competitive than the utility gas market. Higher competition will benefit any potential users of propane in Hawaii.

c). **Environmental Concerns.** Growing environmental concern may accelerate the substitution of gas for electricity use in home cooking and heating, since the electricity is being produced from oil and coal. Additionally, there may be better thermal efficiencies associated with direct use of gas rather than electricity.

d). **Potential New Markets for LPG.** In Hawaii, transportation propane is used by tourism company, government, and corporate vehicle fleets. In other parts of the world, propane has been successfully fueling vehicles for more than 60 years. About 85 million barrels a year are used worldwide for this purpose, principally in the United States, Canada, Italy, the Netherlands, and Japan. It is expected that the current market for transportation propane in Hawaii will be expanded, and new markets developed in the future, particularly since this can help offset demand growth for gasoline.

Taking these factors into consideration, the annual average growth rate of propane consumption in the non-utility sector is expected to reach 3.3 percent between 1992 and 2000, and 2 percent between 2000 and 2014. As a result, gas consumption in the non-utility sector will increase from 2.7 trillion Btu in 1992 to 3.5 trillion Btu in 2000 and 4.5 trillion Btu in 2014 (Figure 74). As suggested in Figure 75, gas consumption in the non-utility sector is expected to exceed the utility sector's consumption around the year 2010.

3.3. Outlook for Future Propane Imports to Hawaii

The prospects for future propane imports into Hawaii depend on demand growth as well as changes in local refineries. Importation of NGL is another factor that can influence the volume of propane imports into Hawaii. Based on the forecasts outlined in the previous section, annual propane consumption in the utility and non-utility sectors is expected to grow

Figure 74. Gas Demand in the Non-Utility Sector in Hawaii, 1981-2014

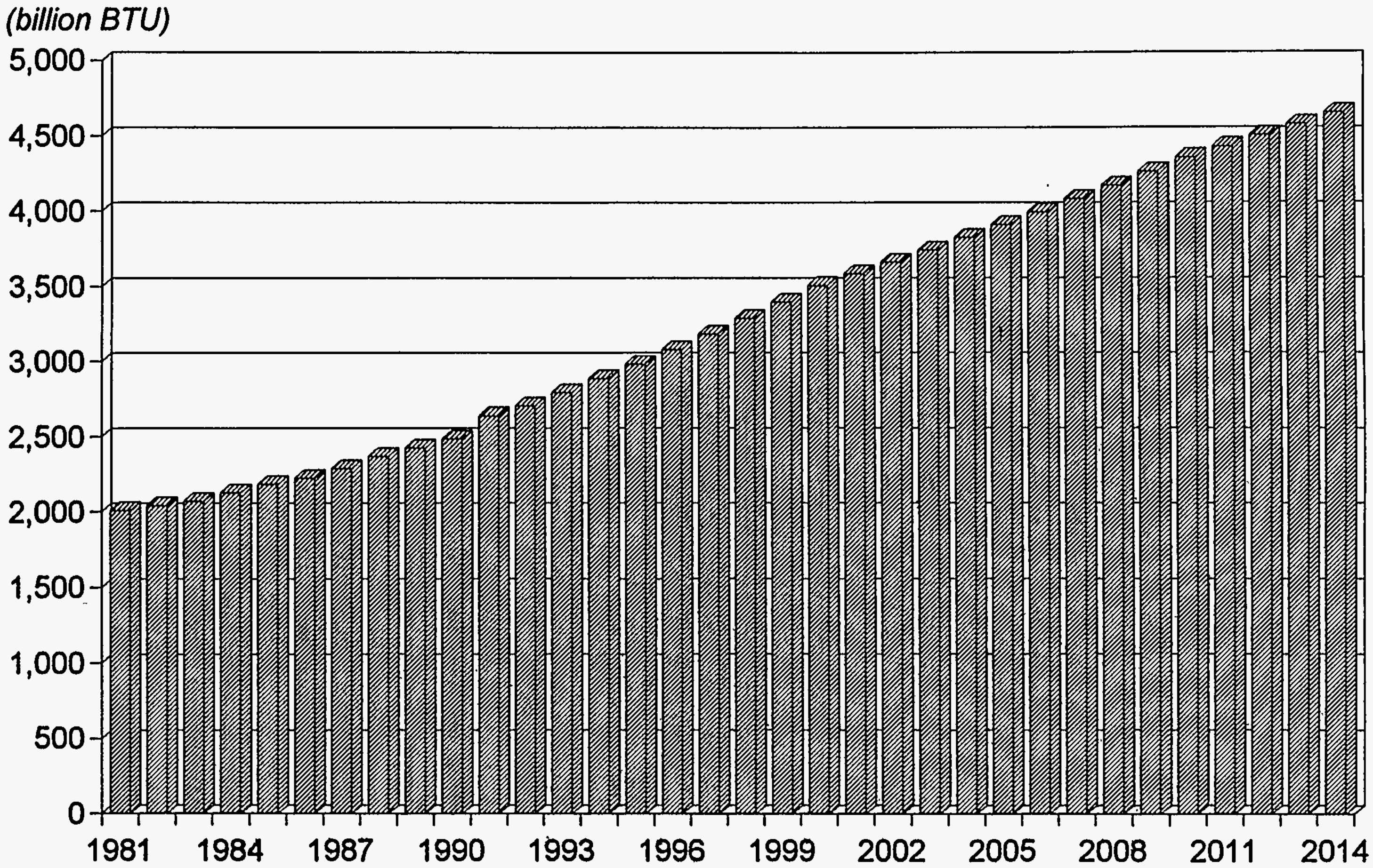
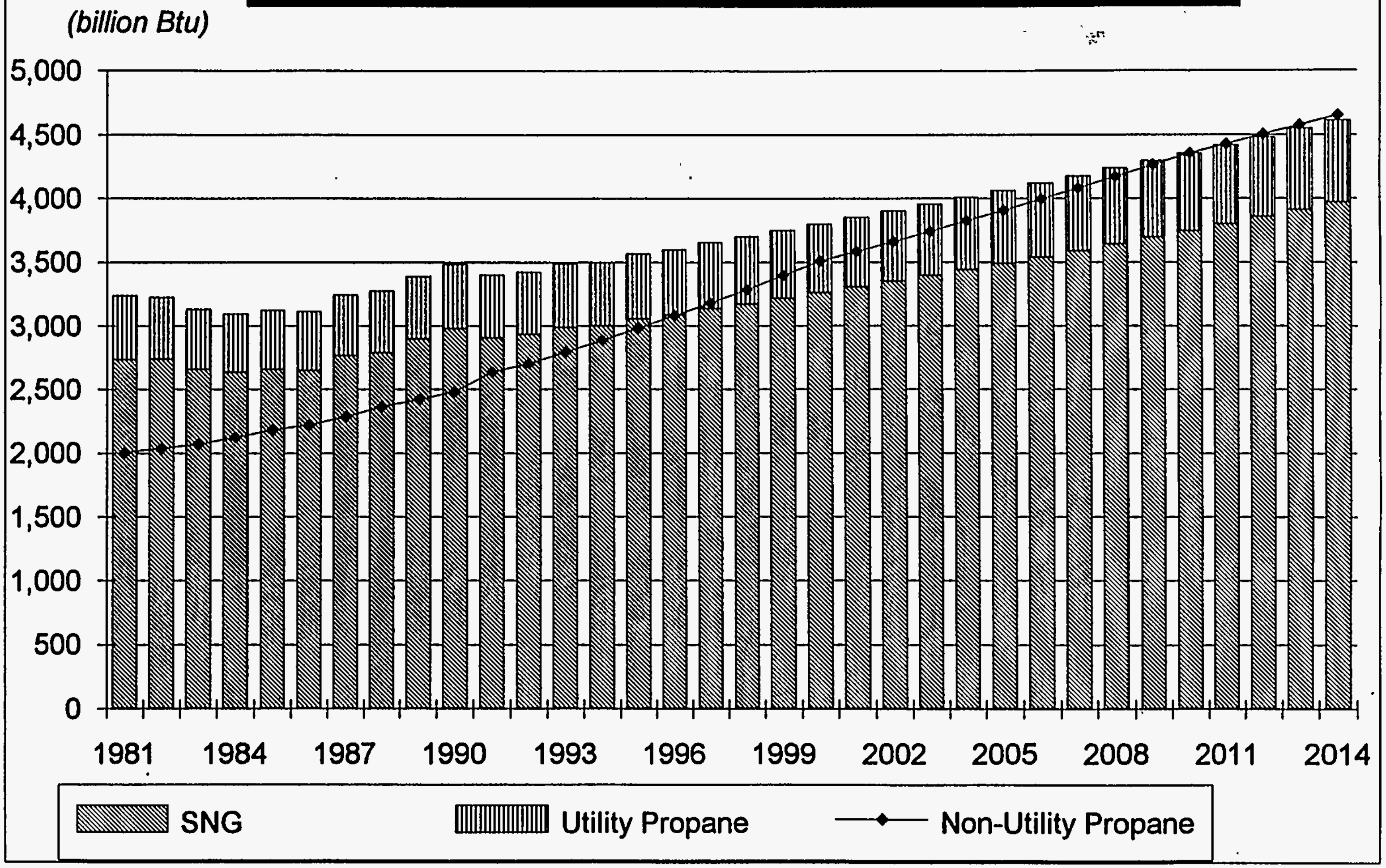


Figure 75. SNG and Propane Consumption in Hawaii, 1981-2014



from 833 thousand barrels (mb) in 1992 to 1.04 million barrels (mmb) in 2000, 1.28 mmb in 2010 and 1.37 mmb in 2014. Current propane production from the two local refineries in Hawaii is about 1.43 mmb. The partial reconfiguration of Chevron's refinery plant is nearly completed and may add a small amount to LPG production. However, nearly half of the current LPG production is used for other purposes as mentioned earlier. Assuming that propane use for these purposes remains stable or increases slightly, total propane demand in Hawaii is expected to reach 1.82 million barrels (mmb) in 2000, 2.14 mmb in 2010 and 2.26 mmb in 2014. Under these circumstances, propane import requirements will vary according to the availability of propane from local refineries and the possibility of NGL imports to Hawaii.

There are three scenarios for forecasts of propane import requirements in Hawaii:

Scenario I

Propane production from local refineries remains largely unchanged. During the next few years, the current reconfiguration in Chevron's refinery may result in a slightly higher propane supply. Under this scenario, Hawaii needs to import 299 mb of propane in 2000, 583 mb in 2010 and 688 mb in 2014).

Scenario II

This scenario assumes a certain degree of reconfiguration and capacity expansion by the two local refineries, in addition to Chevron's latest reconfiguration. LPG produced locally would then reach 1.6 mmb in 2000, 1.9 mmb in 2010, and 2 mmb in 2014. Import requirements in 2000, 2010 and 2014 are expected to be 178 mb, 236 mb and 279 mb, respectively.

Scenario III

LPG imports would be kept at current level and the additional demand would be met through imports of NGL. In this case NGL would be mixed with crude oil as feedstock for the refineries.

Refineries generally do not process NGL as they would crude. NGLs are often mixed with crudes, however, to lighten the crude slate. The volume of NGL that could be mixed into the crude oil will depend on each refinery's configuration and crude slate. The availability of NGL in foreign markets is another issue which may have a notable impact on the feasibility of NGL imports.

As shown in Figure 76, under the first two scenarios, future propane import requirements in the year 2000 and beyond will be several times higher than the current level of 110 mb. But, who will supply the growing propane import requirements in Hawaii? Or, should NGL be imported into Hawaii, where are the possible sources of supply? These issues are examined in the paragraphs following.

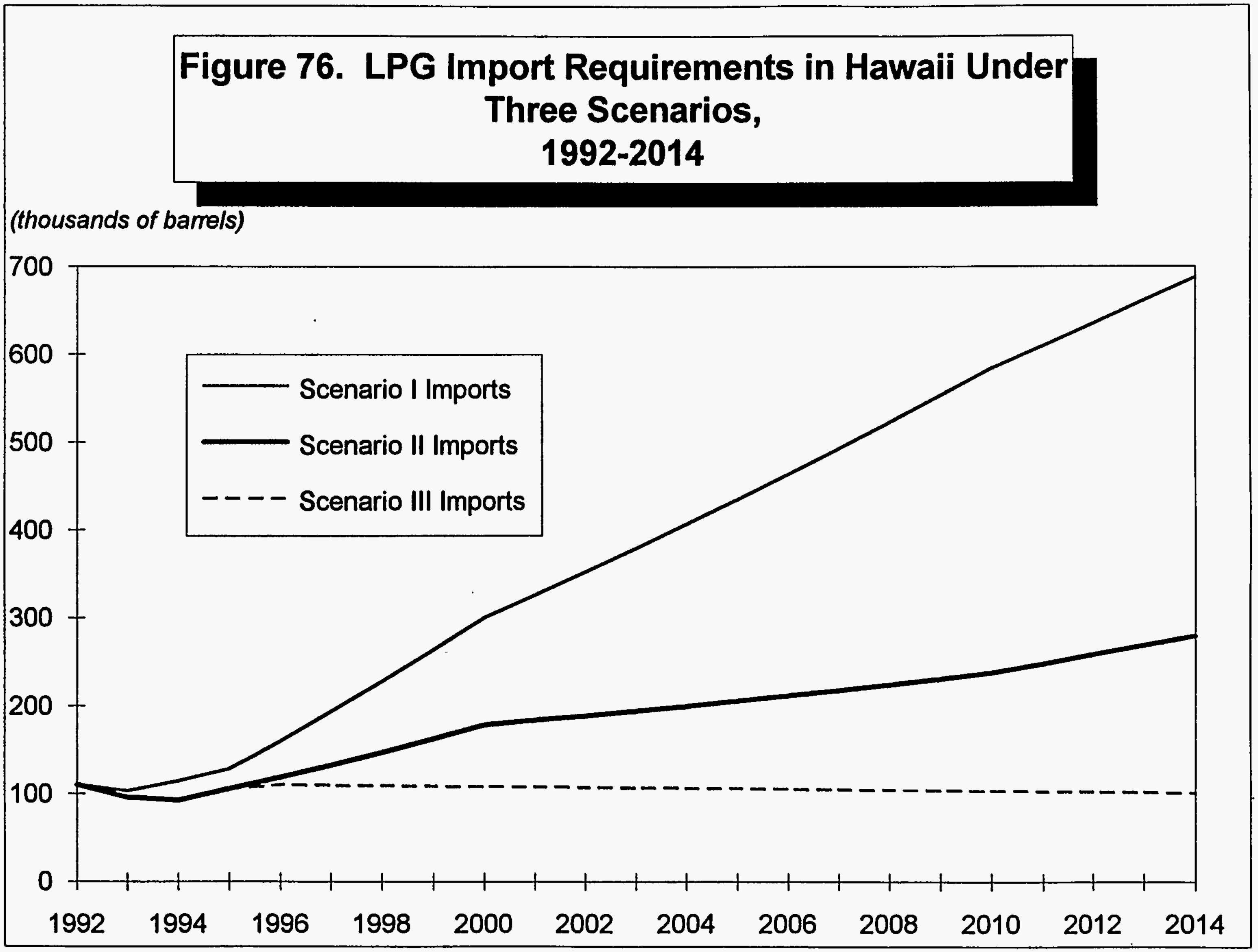
4. The Potential Gas Suppliers For Hawaii

Imports of LPG (propane) and NGL to Hawaii are two separate issues. If enough unprocessed NGL (including everything heavier than methane) can be imported and used in local refineries, then Hawaii may not need to import LPG at more than current levels in the future. So far Hawaii has not yet imported any NGL. The possibility of doing so and the potential sources of supplies will be briefly discussed here. Following this discussion will be a detailed study of the potential suppliers of LPG.

4.1. Natural Gas Liquids (NGL)

As briefly discussed earlier, NGL is a vague term which can mean anything ranging from ethane and propane to pentane and higher. Since our concern is the growing demand for propane in Hawaii, the most likely way that the state would import NGL would be before it was fully processed. If NGL is fully processed in a gas plant, a mix of propane, ethane, butanes, and LP-gas will be recovered, under usual circumstances, and not much of the raw or residual NGL (pentane and higher) will be left. If Hawaii needs to increase propane production, such heavy NGL (also called "pentanes plus") will not be very helpful.

NGLs are typically associated with "wet" natural gas, and can be separated from dry gas at gas processing plants. NGL material may also be associated with oil production, and



Note: See text for the assumtions under each scenario.

may be separated out from the dry gas and oil streams. The three countries in the Asia-Pacific region that have substantial gas reserves and production—Indonesia, Malaysia, and Australia—all have large gas processing plants and produce significant amount of LPG (Table 39). As a result, each country produces large amounts of raw NGL mix as products (such as ethane, propane, butane, and natural gasolines) are recovered. However, it is still possible that a mixture of natural gasoline and lighter hydrocarbons will be exported from these countries if there is a need for it. For Hawaii, while the importation of NGL (unfractionated) for the purpose of producing more propane for local markets remains possible, actually doing so will depend on the availability and composition of the NGL, the configuration of the current refineries and the demand for the other products that are recovered while refining NGL. Since the state already has a surplus of light, low-octane hydrocarbons, the attractiveness of additional NGL processing may diminish if this processing adds to the surplus.

4.2. LPG (Propane)

We have noted that LPG generally refers to propane-butane mixes (C_3 plus C_4). In Hawaii, the LPG used is almost entirely C_3—propane and propene. Up to now, propane is the only gas product that Hawaii has ever imported. Since the state's propane import requirements are likely to increase in the future, the availability of this product will become ever more important in the future. There are many potential sources for Hawaii, ranging from countries in the Asia-Pacific region to some Latin American countries in the Western Hemisphere. Each of the regions is examined below.

Asia-Pacific Region

Because of their geographical proximity and fairly extensive natural gas reserves, the countries of the Asia-Pacific region are widely considered as the most viable choice as gas suppliers to Hawaii. Some of the largest and most developed gas production facilities are located in this region. Table 40 shows the gas processing capacity and propane and LPG production of a number of countries, including those in the Asia-Pacific region, which could be possible suppliers to Hawaii.

Table 39. Gas Processing Capacity of Selected Producers in 1992

Producer	Gas Processing Capacity /a (Million cubic feet/day)
North America	
Alaska	6,370
British Columbia	2,532
Sub-total	8,902
Latin America	
Argentina	1,488
Bolivia	474
Mexico	4,649
Venezuela	2,913
Sub-total	9,524
Asia-Pacific Region	
Australia	2,333
Brunei	1,082
Indonesia	3,900
Malaysia	282
New Zealand	1,441
Thailand	850
Sub-total	9,888
Middle East	
Qatar	579
Saudi Arabia	4,300
U.A.E.	940
Subtotal	5,819

a. As of 1 January 1992

Source: Oil & Gas Journal

As mentioned earlier, Hawaii already imports propane from Australia and the Philippines. The Philippines produces a small amount of gas, which is not actually exported, and is itself a net importer of LPG. The Philippines actually serves as a transfer port for shipments of LPG (probably of Mid-East origin) to Hawaii.

Unlike the Philippines, Australia has proven gas reserves of 15.1 trillion cubic feet (tcf) and a gas processing capacity of 2,333 million cubic feet per day (mmcf/d) (Table 39). Australia's natural gas production in 1991 amounted to 2,578 mmcf/d, next only to Indonesia in the Asia-Pacific region.[10] As shown in Table 40, Australia produced a total of 27.8 mmb of propane in 1991 and net exports amounted to 5.7 mmb. The country also has plans to produce LPG from its northwest continental shelf gas fields starting in 1996. This additional production is estimated to be in the range of 3.5-8.0 mmb. The destination of this gas is currently under discussion. The reason is that most of the participants in the project are Japanese companies who are already involved in LNG production from these fields, and they would like to import all of this LPG production into Japan. The most important gas producer of the Asia-Pacific region is Indonesia. It has a gas production capacity of 3,900 mmcf/d. In 1991, Indonesia produced 20 mmb of LPG from its gas processing plant alone (see Table 40), most of which was exported to other countries in the region, including the Philippines. However, all of the LPG produced by Indonesia's refineries was consumed domestically.

Malaysia is the next most important gas producer and exporter in the region but its production is mainly in the form of LNG. In 1991, Malaysia produced 5.5 mmb of LPG from its refineries, of which 2.2 mmb were exported. But in the same year, the country also imported 1.8 mmb of LPG. It is expected that LPG use in Malaysia will increase in the future.

In 1991 Australia, Indonesia, and Malaysia produced a combined total of 56.5 mmb of LPG and consumed about 30.2 mmb, leaving a net 26.3 mmb available for exports. These three exporters are the possible suppliers of propane to Hawaii within the Asia-Pacific

[10] See *BP Statistical Yearbook of World Energy 1992.*

Table 40. Estimated LPG Production and Consumption For Selected Countries, 1991

(thousand of barrel)

Country	Production			Consumption
	Refinery	Gas-Processing	Total	
Asia-Pacific Region				
Australia	4,644	23,168	27,812	22,192
Indonesia	2,738	20,495	23,233	2,811
Malaysia	1,314	4,161	5,475	5,183
Sub-total	8,696	47,824	56,520	30,186
Latin America				
Argentina	6,484	11,057	17,541	14,268
Bolivia	439	1,978	2,417	1,957
Mexico	25,188	64,506	89,694	84,040
Venezuela	1,681	35,006	36,687	26,104
Sub-total	33,792	112,547	146,339	126,369
Middle East	N/A	N/A	288,424	59,917

N/A=not available.

Source: EWC Data File

region, although not all of their LPG is propane-based. The Philippines plays a special role as a transfer port, because the shipping cost of LPG from the Middle East to the Philippines is among the lowest in the eastern Asia. According to GASCO, the cost of purchasing LPG from the Philippines is also among the lowest in any of the possible markets in the region.

North America

Alaska and British Columbia (Canada) can also be potential gas suppliers to Hawaii. They both have huge gas processing plants (see Table 39), but their propane production is very small. In 1990 Alaska produced 220 mb of propane from its refineries and 1.5 mmb from its gas processing plants. British Columbia produces even less propane from its gas processing plants as most of the output from these plants is dry gas (C_1 and C_2).[11] It should be noted that the Alaskan gas is relatively expensive to produce and this makes it vulnerable in competition against the gas produced from much cheaper sources such as the Middle East. As noted in the section above on petroleum product trade, however, PADD-V is currently a net exporter of LPG, and if the surplus situation persists, the U.S. West Coast could serve as a source of supply to Hawaii.

Latin America

Latin America also has substantial gas reserves. As of January 1992, the region had a total gas capacity of 10,300 mmcf/d. Mexico, Venezuela, and Argentina are the three largest gas producers of the region. These three countries also have substantial gas processing capacities. These three, plus Bolivia, are all net LPG exporters (see Table 40) and are possible sources of LPG supply to Hawaii. However, not all of the LPG that they produce is purely propane. In most cases it is a propane and butane mixture. In 1991 Mexico produced 89.7 mmb but consumed only 84 mmb. Consequently, a net 5.7 mmb of LPG were available for export from Mexico. In the same year, net exports of LPG from Argentina, Bolivia, and Venezuela amounted to 3.3 mmb, 460 mb and 10.6 mmb, respectively.

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[11]The coastal provinces of Canada, as potential suppliers of LNG to Hawaii, are discussed in Task III (*Greenfield Options*) of this project.

Gas processing plants play a significant role in LPG production in the four Latin American countries. These plants accounted for 95 percent of Venezuela's LPG production (the highest proportion of total LPG production found in the four countries) and for 63 percent in Argentina (the lowest portion, as shown in Table 40). For the moment, the gas trade in Latin America is operating mainly on a regional basis. There are several plans to expand gas processing and refinery capacities. However, growing environmental concerns in the region imply that most of the future gas production will be absorbed by domestic markets. Therefore the amount of gas products available for trade outside the region may not sharply increase, despite these expansions. Still we do not rule out the possibility of Latin American propane exports to Hawaii, since the size of the Hawaiian propane market is so small that it should be possible to supply its demand without much difficulty.

The Middle East

Despite reluctance of the major importing countries of the Pacific Rim to increase their import dependence, the Middle East will soon become a source of gas (including LPG) supply to the region. Middle Eastern proven natural gas reserves currently stand at 1,520 trillion cubic feet, and the reserves-to-production (RP) ratio is 426 years. This figure is based on the current natural gas production level, which is not very high compared to other regions in the world. Even if the production is intensified, however, the Middle Eastern RP ratio will remain the highest worldwide.

The Middle East is similar to many Latin American countries in that gas processing is the source of most LPG production, and the Middle East has a huge LPG surplus. In 1991, for instance, the region produced nearly five times as much as it consumed. Saudi Arabia has the largest gas processing capacity in the Mideast. In addition, it is expected that supplies of LPG in Iran and Kuwait will increase substantially, adding to the region's LPG export capacity. Other LPG expansion projects in Qatar and Abu Dhabi will further enhance the position of the Middle East as the world's biggest LPG exporter. The Middle East is important to Hawaii because it is, and will continued to be, the largest LPG supplier to the Asia-Pacific region, from which Hawaii is mostly likely to import LPG. The very low cost of production in the Middle East helps to offset transportation costs, thereby ensuring that the Middle East will be one of the largest gas suppliers of the twenty-first century.

The Commonwealth of Independent States (CIS) and Eastern Europe

The world's largest natural gas reserves are located in CIS and Eastern Europe. This region is a large LPG producer (162 mmb in 1992), although its gas processing facilities are still relatively underdeveloped. A major consideration to bear in mind is the unstable political and economic situation in the CIS, which makes any major new gas projects unlikely to come on stream until perhaps the end of the first decade of the next century. In addition, with the exception of the Russian Far East (which includes the producing fields of Sakhalin Island and its offshore reserves), the transport costs from CIS and Eastern Europe to the Pacific puts the region in last place as a choice of LPG supplier to Hawaii.

5. Summary and Concluding Remarks

In this section, we have examined the supply and demand situation in the Hawaiian gas product market. Propane is, and will continue to be, the major gas product used in this market, especially in the non-utility sector. While gas (mainly SNG) demand in the utility sector is projected to grow slowly, but steadily, over the next two decades, propane demand in the non-utility sector is expected to grow faster. Unless an expansion of local refineries is carried out, Hawaii's import requirements of propane within two decades could be more than five times higher than the present level, given the current forecasts of demand. Even with moderate refinery expansion, propane imports still double by 2014. Importing NGL (unfractionated) instead of propane is a possibility but would only happen under favorable supply, price, and quality conditions. Finally, the Asia-Pacific region remains the direct source of LPG, and possibly NGL, supply to Hawaii.

In conclusion, we believe that the expected shortage in the local supply of LPG can be balanced through imports from various sources around the world. Hawaii is a very small market, and therefore it will not be very difficult to fill in the gap from elsewhere in case the local refineries' LPG production is not sufficient. Previous imports from Australia and the Philippines prove the feasibility of such projects. An increase in volume of imports should not incur too great an increase in shipping costs. Larger shipments could, as a matter of fact, reduce the per-unit gas supply costs if the Hawaiian market becomes large enough to justify use of larger ships. It is nevertheless important to bear in mind that, at the present time, the Hawaiian gas market is still too small to be able to reap the benefits of economies of scale.

D. Coal and Coal Sources

As discussed in Task I (*World and Regional Fossil Energy Dynamics*) of this project, coal is one of the most widely available and stable sources of energy in the world. Coal resources are spread over many geographic and political boundaries, and, at present production levels, coal will be available for hundreds of years in the future. Politically stable countries such as the United States, Australia, and Canada make up about one-third of the world's total coal reserves and over half of the total seaborne coal trade. Coal prices in both real and constant dollar terms have fallen over the past decade.

Hawaiian coal consumers have a wide range of options to choose from in fulfilling possible coal requirements, and the quality and quantity requirements of individual coal users vary considerably. Depending on a consumer's situation, emphasis may be placed on contract terms and duration, cost, pollutant constraints, or other considerations. Thus, such variables as price, length of contract, or source will differ substantially among consumers. For example, the terms and price of coal used in Hawaii's cement industry differ from those of coal used in Hawaii's coal-fired electricity generating plant.

There are ten major coal exporting countries in the world. Each of these countries, and others as well, has many individual mines that produce coal for export. A significant amount of coal reserves are found in relatively stable countries, and because of the competitive nature of the international coal market, coal sourcing can be thought of in terms of acquiring supplies from individual coal producing firms rather than from a country.

Producers and coal qualities can vary substantially within a country, and competition usually exists among a country's producers. For example, coal from Wyoming's Powder River Basin varies significantly in heat and sulfur contents from coals mined in Colorado. Mines in these areas compete to supply coal to U.S. and Asia-Pacific consumers. A similar situation exists in Australia between mining corporations in the east-Australian states of Queensland and New South Wales. Because of these considerations, the task of securing stable sources of supply is much easier for coal users than for consumers of oil or natural gas.

1. Coal Use in Hawaii

Coal's history in Hawaii dates back more than a hundred years to 1848. British coal was shipped via Boston and stored to provide fuel for the steam powered commercial ships that called at Hawaiian ports. At one time, Pearl Harbor served as a large coal bunkering depot. By about 1917, Hawaii was importing coal from mines on the mainland United States, Australia, and Japan. Coal has been used in Hawaii for many purposes, from fueling railroad locomotives to its use as a boiler fuel in sugar plantations. HECO's use of coal dates back to 1894. In 1902 HECO began importing about 5,000 tons[12] of coal for electricity generation from Australia. HECO's coal use was short lived however, with oil-fired plants becoming dominant after 1905.

The use of coal in Hawaii all but disappeared until the energy crises of the 1970s, when planners and business leaders began to consider coal as an alternative to Hawaii's almost total dependence on oil. Cement companies and, to a lesser degree, sugar plantations began using coal in the early 1980s. The cement industry currently consumes about 25,000-

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[12]All references to tonnages in this volume (Task II, *Fossil Energy in Hawaii*) have been converted to short tons, since this volume deals specifically with the case of Hawaii. The coal data in the international market survey in Task I (*World and Regional Fossil Energy Dynamics*) is given in the system of metric tons, which is the standard for international trade. For purposes of conversion, 1 short ton = 0.9072 metric tons; 1 metric ton = 1.102 short tons.

35,000 tons per year, while the coal-burning sugar plantations on Maui and the Big Island together used about 9,000 tons in 1991. However, in 1992, the use of coal by sugar plantations jumped to 56,500 tons. From 1982 to late 1992, total coal consumption in Hawaii averaged about 40,000 tons per year. This figure jumped to about 700,000 tons per year after the start-up of the AES Barbers Point coal-fired power plant in September 1992. Most of the coal consumed by the cement and sugar industries came from Australia, while the coal-fired plant at Barbers Point burns coal from Indonesia's Kaltim Prima mine. Kaltim Prima coal is probably the highest-quality coal sold internationally for thermal uses. Table 41 shows a comparison of typical coals traded in the Asia-Pacific. The heat content of a typical Kaltim Prima coal is 12,000 Btu per pound; the sulfur content is a very low 0.4 percent and the ash content is about 5.0 percent, which is less than half the percentage of ash found in most traded steam coal.

Coal currently arrives in Hawaii aboard Panamax bulk carriers of around 50,000 tons. The construction of the AES Barbers Point plant entailed the addition of a large coal off-loading and conveyance system, which is enclosed to reduce airborne coal dust.

Coal specifications vary substantially for Hawaii's users. For example, cement producers usually use coal of a higher ash content than an electricity generating plant, because ash may be used as an input to the cement making process. In an electricity generating plant, ash is a waste by-product which must be either disposed of or transformed into a usable material. The AES Barbers Point generating plant has found various markets for its ash.

Hawaii's coal use patterns changed dramatically in 1992. As shown in Figure 77, the cement and sugar industries accounted for virtually all of Hawaii's coal use until the start-up of the AES Barbers Point plant, which now dominates coal imports. Coal-fired capacity in Hawaii could increase substantially in the future, either through the construction of a utility-built plant or another privately built plant. A very rough guide to estimating coal use is that for every 1,000 MW (equal to 1 gigawatt) added to generating capacity, 2.5-3.0 million tons

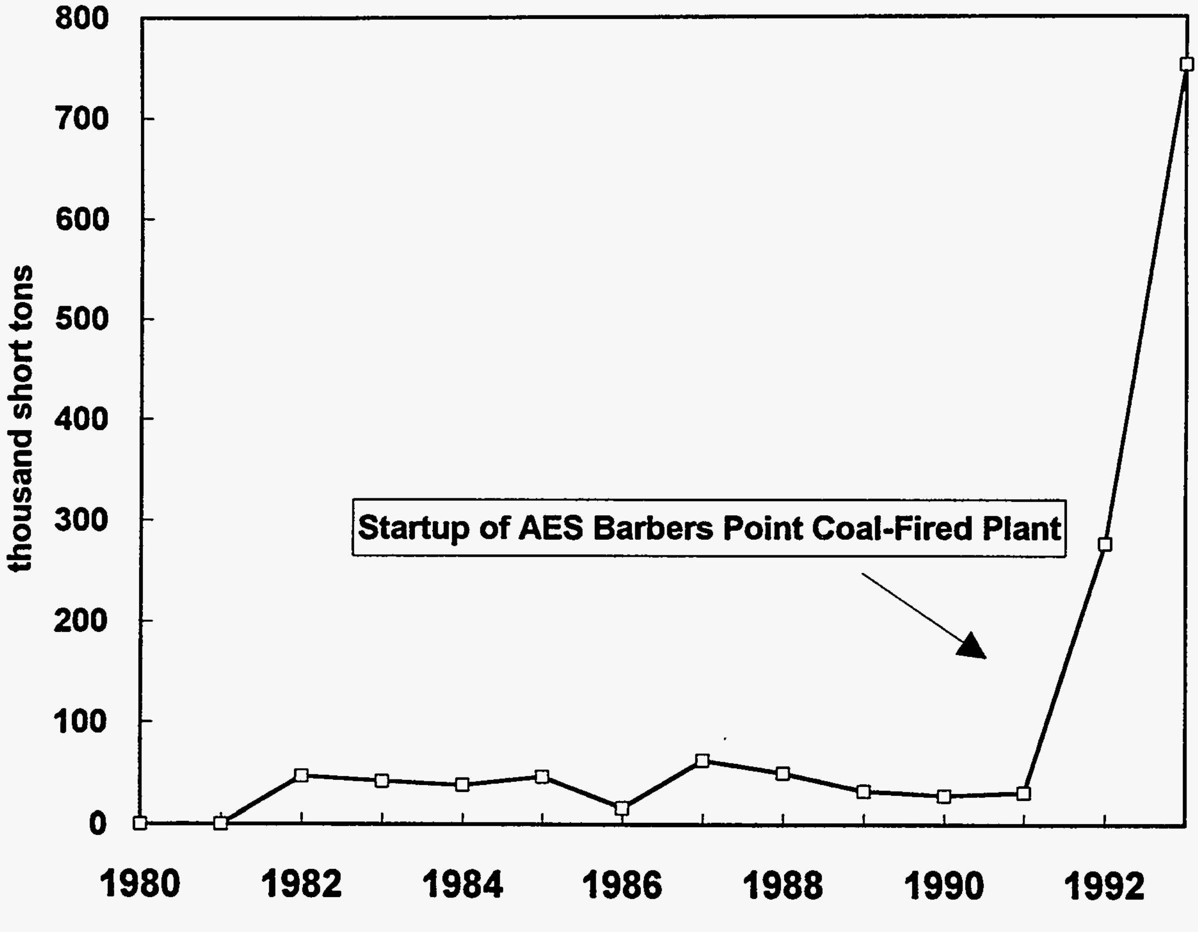
Table 41. Typical Coal Specifications in Select Coal Producing Countries

	Percent				Heat Content	Hardness
	Sulfur	Total Moisture	Ash	Volatile Matter	(Kcal/Kg)	(HGI)
Alaska	0.2	27.0	9.5	42.7	5250	35
Australia New South Wales	0.6	8.4	15.7	29.7	6742	54
Australia Queensland	0.5	11.4	11.3	29.0	6792	55
Canada	0.5	8.3	11.7	30.3	6340	48
China	1.0	8.0	14.9	30.1	6793	55
Columbia	0.7	8.4	8.6	34.9	6720	49
Indonesia	0.5	15.6	5.9	39.8	6419	47
Russia	0.3	9.0	15.5	18.3	6700	80
South Africa	0.6	8.6	13.1	27.3	6679	51
United States (West)	0.6	10.3	9.5	37.1	6521	49
Venezuela	0.5	8.0	7.0	34.0	6900	56
Typical World Export Coal	0.6	10.3	11.8	31.3	6649	52
Typical Asia-Pacific Export Coal	0.5	10.6	12.2	30.9	6617	52

Source: Coal Manual, 1992 Keal/kg = kilocalories per kilogram.

Notes: HGI = Hardgrove Grindability Index. Heat Content in Btu per pound is shown in Figure 81.

Figure 77. Hawaii's Coal Imports 1980-93



Source: US DOE, 1990, 1991, 1992, and AES Barbers Point, 1993 of additional steam coal will be required annually. This scale roughly holds true in Hawaii, where the 180-MW coal-fired plant consumes approximately 600,000 tons of coal per year.

2. Coal Quality

In this section, coal quality characteristics are briefly reviewed. The focus is on steam coal that will be primarily used for electricity generation. A more in-depth discussion of the supply characteristics of the individual countries will appear in a later section.

Coal quality needs vary widely with each user. To provide a general idea of the range of acceptable coal quality specifications, the following illustrates the ranges for typical coal-fired power generating units:

Heat content or calorific value: 11,000-12,200 Btu per pound

Volatile matter: 25-36 percent

Total moisture: 10-15 percent

Ash content: 10-16 percent

Sulfur content: 0.6-1.0 percent

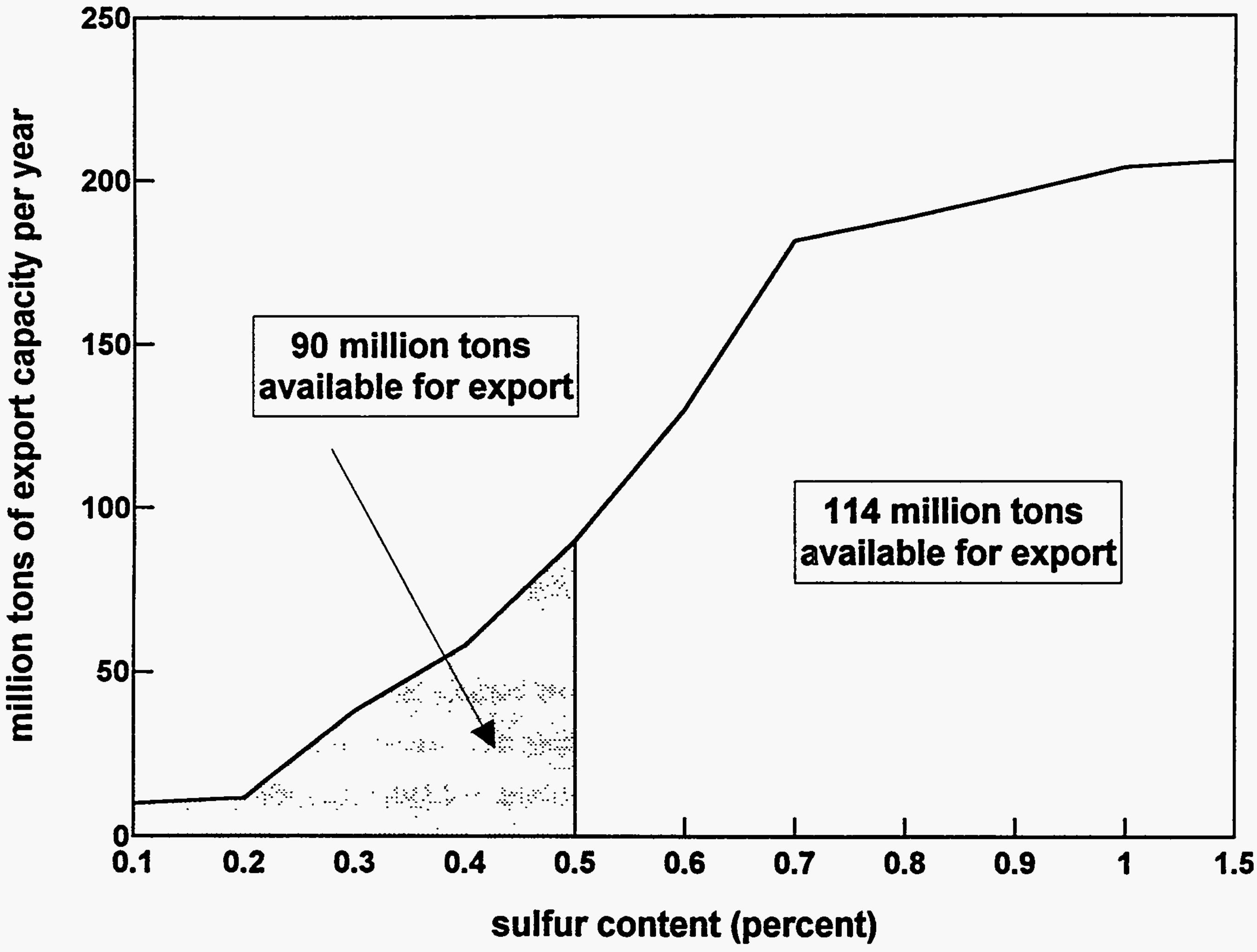
Hardness: greater than 44 Hardgrove grindability index (HGI)

Ash fusion: minimum 1,200-1,300°C

A more comprehensive description of coal specification terms appears in Chapter IV (entitled "The World Coal Industry") of Task I (*World and Regional Fossil Energy Dynamics*) of this project.

The emission of pollutants associated with coal burning is a key consideration for Hawaii's energy planners, and coal users are reflecting this concern in their coal choices. Imports of coal to Hawaii have originated from Australia and Indonesia, which together comprise about three-fourths of the world's export capacity of 0.5 percent or lower sulfur content coal. The Indonesian coal used at the AES Barbers Point plant is of excellent quality with respect to sulfur, ash, and heat content. It should be noted, however, that most of the coal with a sulfur content of 0.5 percent or lower in Indonesia and the western United States is of lower heat content than most internationally traded steam coal. Figure 78 represents a

Figure 78. Survey of More Than 60 Percent of World Steam Coal Export Capacity

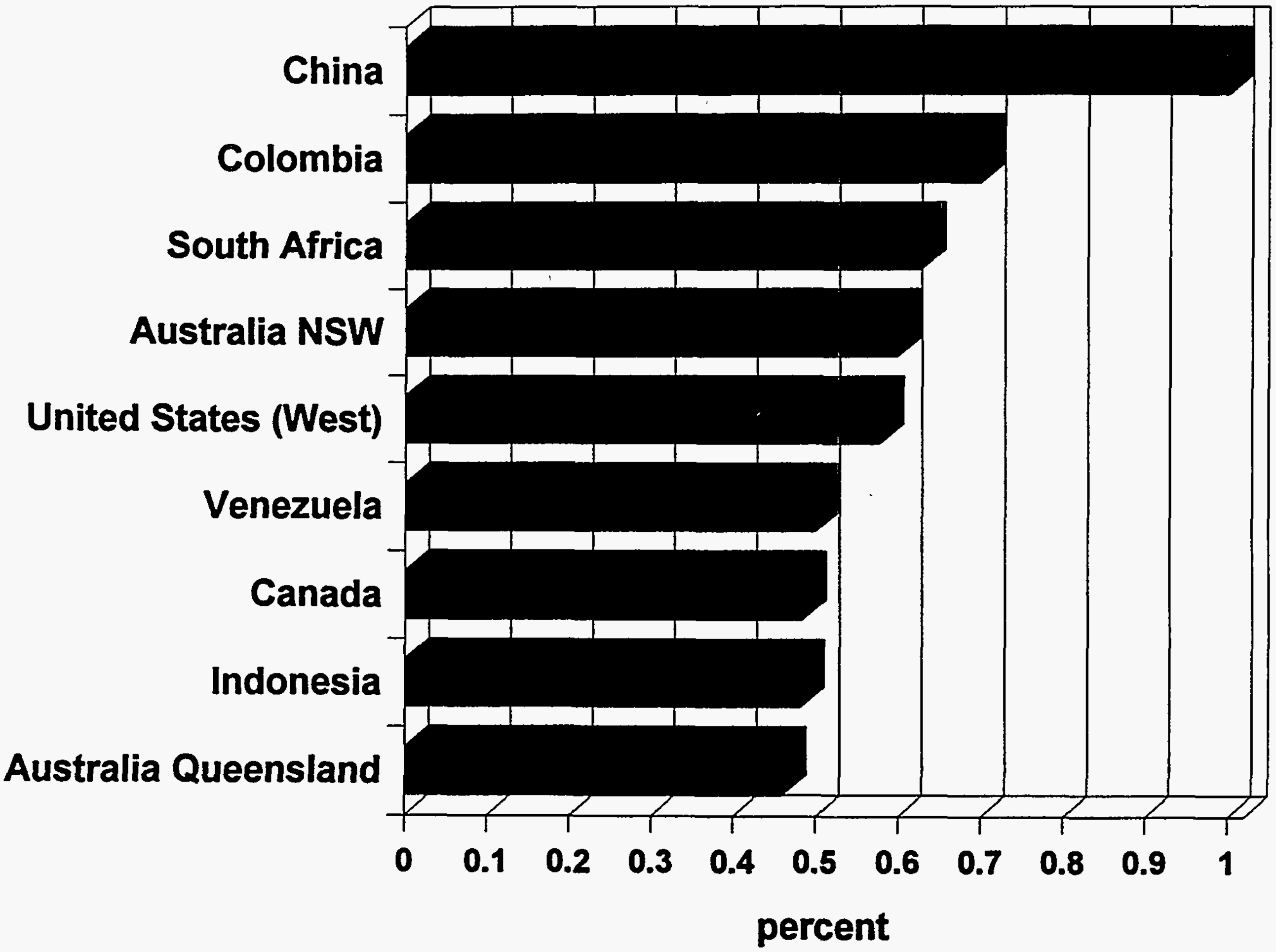


Source: Coal Manual, 1992

majority of the world's traded steam coal export capacity. Forty-four percent of total export capacity has a maximum sulfur content of 0.5 percent. At present, there are abundant supplies of low sulfur export coal available to Hawaii consumers. As more importance is placed on environmental concerns worldwide, however, demand for these coals will increase substantially. The increased demand may result in a significant premium being paid for very low sulfur coal in the future.

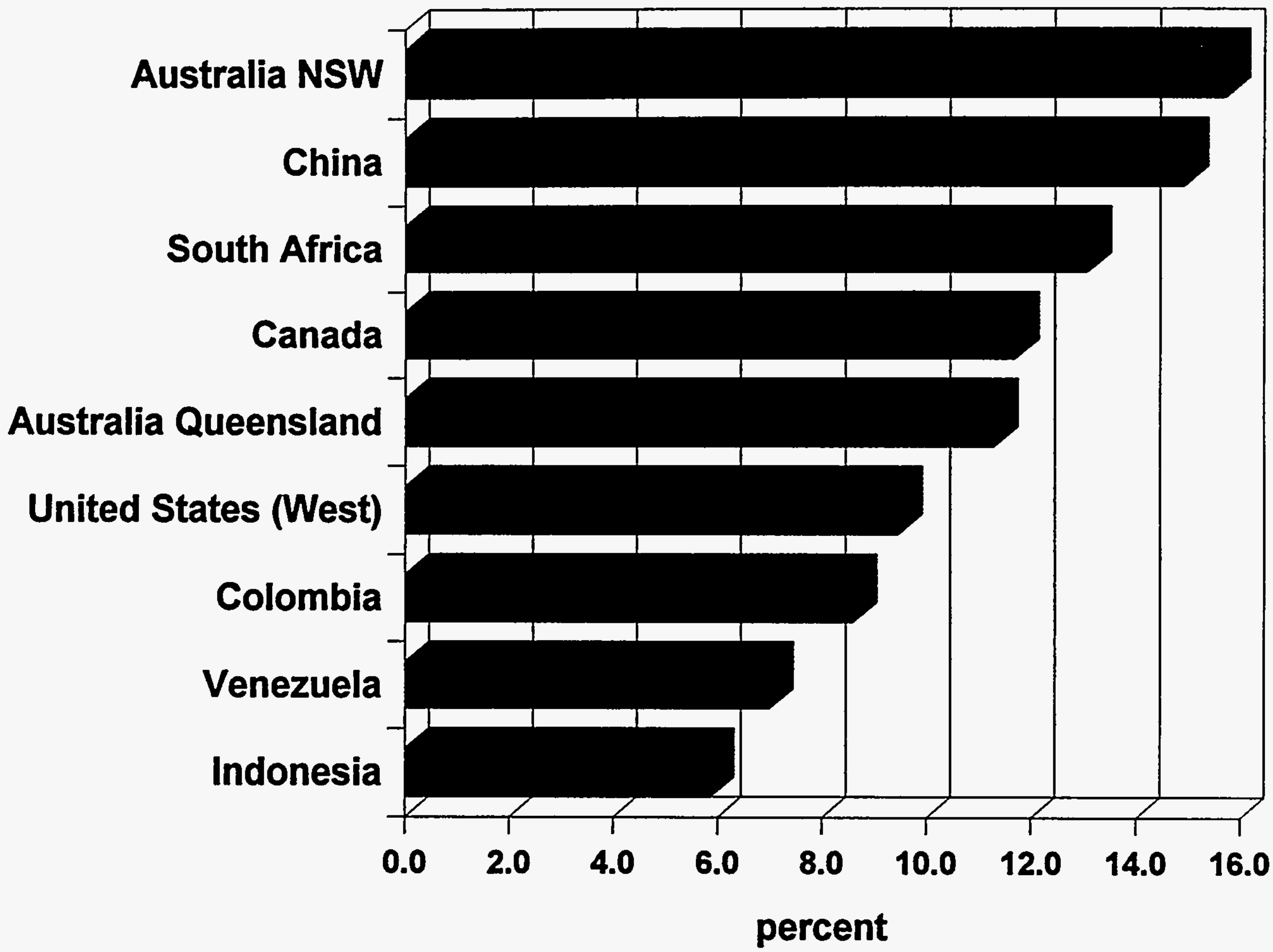
Figure 79 ranks the coal sulfur contents of typical export coal in the major coal producing countries. Indonesia and the Australian state of Queensland have the lowest sulfur content coals of any producing region, followed closely by Venezuela and Canada. Almost all coal traded internationally is below 1 percent sulfur. China is the only country with a typical export coal approaching the one percent sulfur level. Alaskan coal, which is not shown, illustrates a common problem in evaluating coal quality. The coal has a very low sulfur content, but the heat content is correspondingly low. This forces consumers to use a greater quantity of coal to produce the same amount of heat produced in the combustion of an average coal. When more coal is used, more sulfur is emitted, which negates the advantage of purchasing what seems to be a low sulfur coal. Another key concern involves coal ash content. Although ash is an inert substance, its disposal could presents problems to Hawaii where finding a place to dispose of or use ash is difficult due to the scarcity of land and the isolation of the islands. At the present level of coal use, ash disposal has not been a problem. If coal use expands significantly, however, ash disposal may become a consideration. Figure 80 indicates the typical ash content of coal in the major coal producing countries. Coal from Indonesia, Venezuela, and the western United States has a typical ash content at or below 10 percent, while coal from the other producers is above 10 percent. Indonesia stands out as the lowest cost and lowest ash potential coal supplier to Hawaii. However, the supplies of high quality, low ash coal from Indonesia appear to be limited when viewed from a long term (10-20 years) perspective. Most Indonesian coal is relatively low in heat content and more of the coal must be utilized to provide the same heating source as the average heat content coal. Thus, as was the case with Alaskan low

Figure 79. Typical Sulfur Contents of Export Coals in Select Coal Producing Countries



Source: Coal Manual, 1992

Figure 80. Typical Ash Contents of Coals in Select Coal Producing Countries



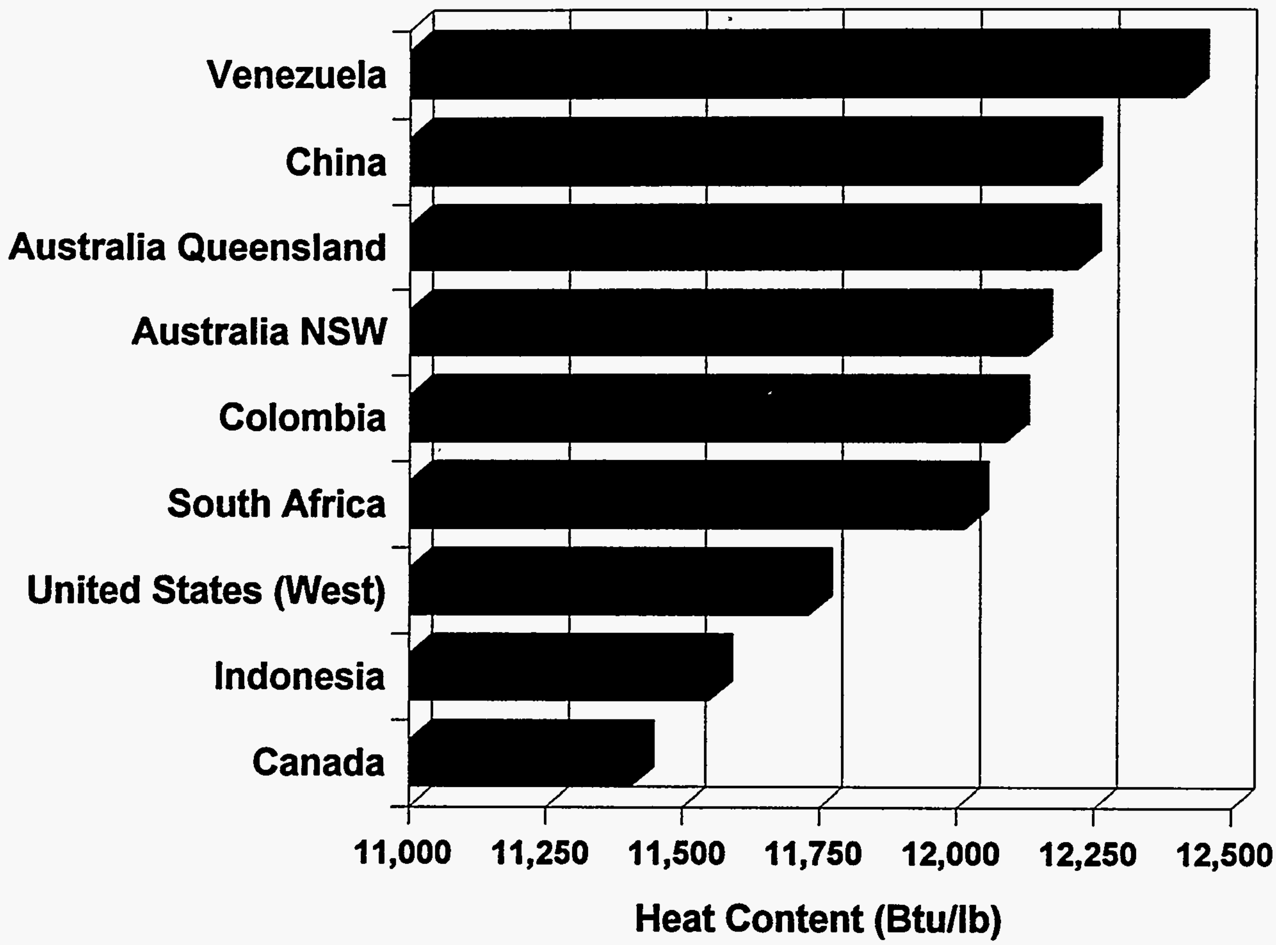
Source: Coal Manual, 1992

sulfur content coal, the advantage of producing a low ash coal is mostly negated. Venezuela also has low ash coal but very limited export capacity and is presently not a likely sourcing option to Hawaiian consumers. Securing supplies of coal having ash contents in the 10 - 16 percent range will pose no problem to Hawaiian consumers, however, coal with an ash content below 10 percent will most likely command a premium in the future. The premium would arise mainly due to increased international demand for the coal and, in Hawaii, due to the costs of transporting the low ash coals long distances from producing regions.

The heat content of coal plays a vital role in the selection of a coal supply source. Aside from the obvious fact that with a higher heat content, greater amounts of heat will be given off in combustion, most coal-fired power plants are designed to burn coals that have a certain range of heat content. So without alterations in equipment, a plant is limited to burning certain coals throughout its life. Heat content also effects how consumers must think about other specifications, which was illustrated earlier in the discussion of sulfur and ash contents.

Figure 81 ranks typical heat content coals for the major coal producing regions. Venezuela appears at the top of the figure, but as explained above, imports of Venezuelan coal are not presently a consideration in Hawaii's coal sourcing decisions because of limited export capacity. China and the coal producing states of Australia have the highest heat content coal, with Colombia and South Africa closely following. In recent history, however, there have been quality problems associated with exports of coal from China. The main problem seems to be the amount of non-coal matter combined with exports. Consumers in Japan have received shipments that contained as much as one-third earth. The main reason for the unburnable matter existing in Chinese exports is the lack of proper coal washing practices and facilities. This problem may improve in the future, but problems such as political uncertainty and the inconsistent availability of export supplies must also be solved. The western United States, Indonesia, and Canada all have relatively low heat content coal. Indonesia's Kaltim Prima, which supplies the AES Barbers Point plant, is the exception among Indonesian coals.

Figure 81. Typical Heat Contents of Coals in Select Coal Producing Countries



Source: Coal Manual, 1992

An overview of the typical coal qualities of the major coal producers is shown in Table 41 above. The table includes the specifications discussed above and the total moisture content, the volatile matter portion, and the Hardgrove grindability index (HGI) of typical coals from the countries indicated. HGI is a measure of coal hardness or grindability. The table also includes some regions or countries not mentioned in the previous figures. Russia's coal specifications in particular should be used with caution because the numbers are inferred from a small percentage of total export capacity. As shown in the table, the moisture content and volatile matter percentage of typical Indonesian and Alaskan coals are relatively high. High moisture content reduces the amount of heat given off by the coals during combustion, and thus causes the coal to be less marketable internationally. Many Indonesian and possibly Alaskan coals can be used as a blend with other coals that may have a high sulfur content or lack in other attributes. Also shown in the table are the weighted average specifications for coal traded worldwide and for coal traded in the Asia-Pacific region. These specifications provide a general guide to the characteristics of an average traded coal, but, as stated earlier, the needs of an individual user are unique to the situation and qualities may vary significantly from the average.

3. Coal Prices and Costs

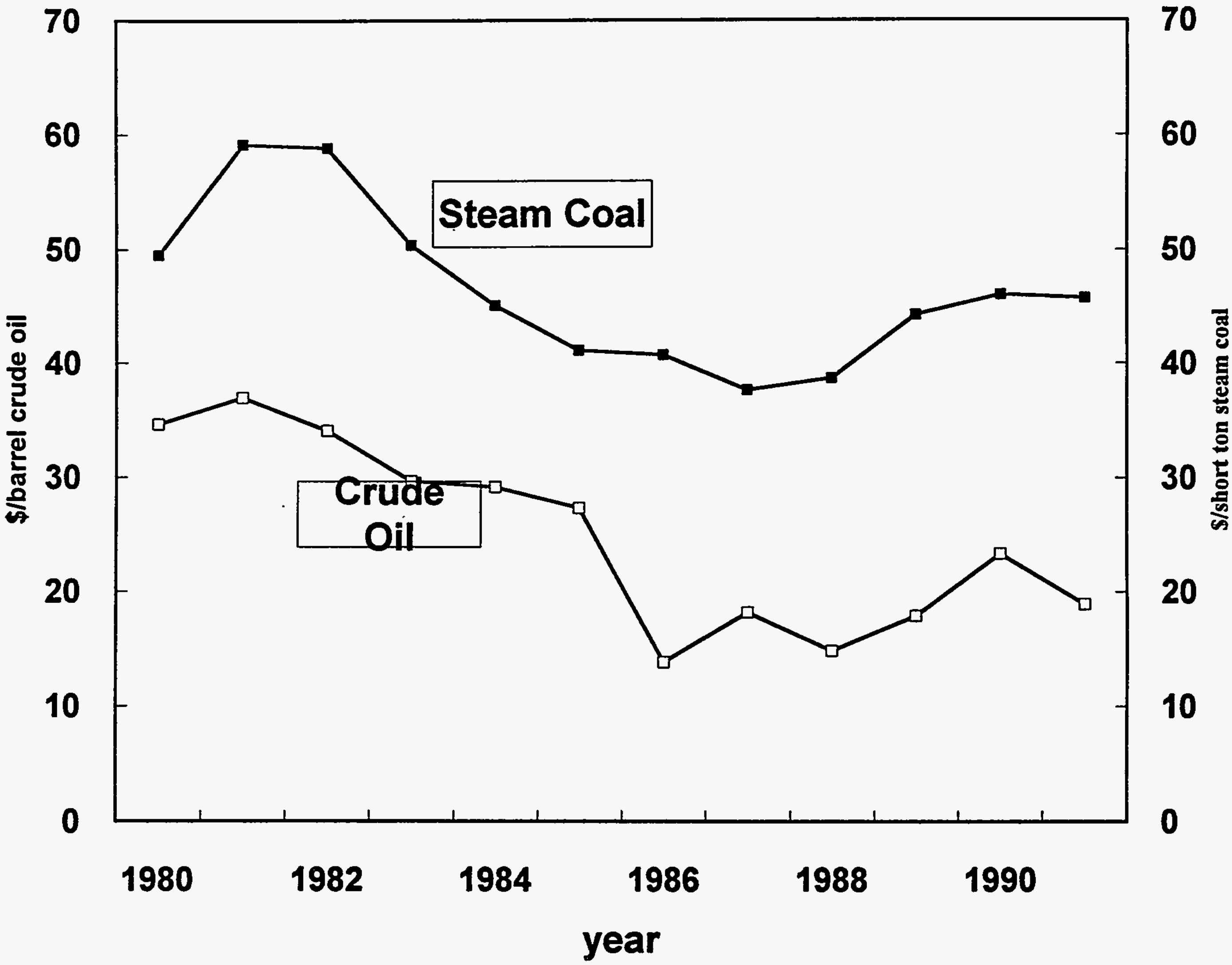
The costs of mining coal have been decreasing over the years with improvements in equipment and work practices. Coal mine productivity has risen significantly, and this trend is expected to continue with improvements in technology. There was widespread speculation at the end of the 1970s that coal prices would increase because of large projected increases in demand, but with the abundance and availability of a wide range of coals and gains in productivity and work practices, coal prices have decreased and are projected to increase at less than 1 percent per year in constant terms over the next two decades. Coal producers have consistently expanded supplies, and competition has caused coal prices to fall. Vigorous competition exists among the producers that can supply coal to Hawaii. In particular, competition between Indonesian and Australian producers has bid coal prices as low as U.S.$23 per ton f.o.b.t. (The term f.o.b.t. stands for "free on board and trimmed," or simply the price of coal on board the ship at the export port.)

Figure 82 compares the price fluctuations over the past decade of steam coal and oil imports to Japan—the largest importer in the world. When examined on a dollar per barrel vs. a dollar per short ton basis, the two curves coincide relatively closely. It would appear that coal and oil prices are influenced by similar market forces. As can be seen in the figure, both fuels reached a high price at about 1981-82 and reach a low point in 1986-87 corresponding to the crash and the "bottoming out" of oil prices in the respective years. The fluctuations in price do correspond to some degree, but, on further examination of the trends over the same period on an equivalent dollars-per-million-Btu ($/mmBtu) basis (as shown in Figure 83), the price of oil has fluctuated to a much greater degree than the prices paid for steam coal. Steam coal prices have hovered around the $2/mmBtu level, whereas oil prices have oscillated between almost $7/mmBtu to as low as around $2.50/mmBtu over the decade. While Japanese coal prices may not be exactly indicative of Hawaiian coal prices, Japan, as the leading importer, greatly influences the international price for seaborne trade of coal.

Figure 84 shows the price (in constant dollars) of both fuels decreasing over time with the curves corresponding relatively closely. Figure 85 shows that, on a cost per mmBtu basis, coal is much cheaper than oil, and significant oil price fluctuations are again evident on Figure 85.

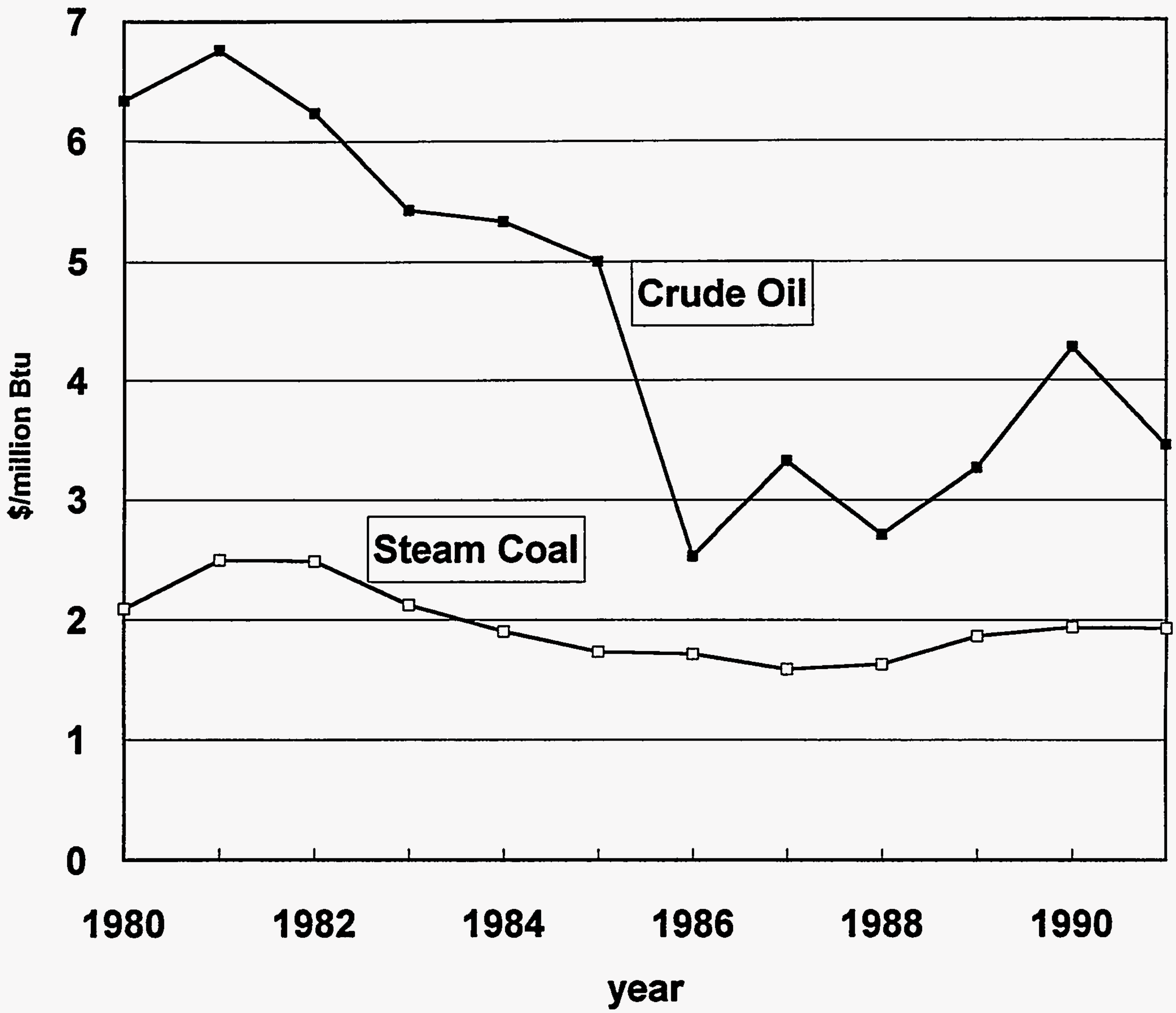
Figures 86 and 87 give the reader a general idea of the costs of possible coal suppliers to Hawaii. Figure 86 shows representative operating costs for possible coal suppliers. Operating costs include the direct costs of mining, handling and transporting coal. Figure 87 shows total costs including both capital and operating costs. In the table comparing operating costs between exporters, Australia and Indonesia have a clear cost advantage over the other suppliers, while U.S. and Canadian exporters are at a substantial disadvantage. The high cost of North American coals exported to the Asia-Pacific and Hawaii is primarily because of the more than 1,200 mile (2,000 kilometer) rail distance over which the coals must be transported. Transport costs represent a significant portion of the total delivered cost of

Figure 82. Steam Coal Import Prices to Japan vs. Crude Oil Import Prices, 1980-90



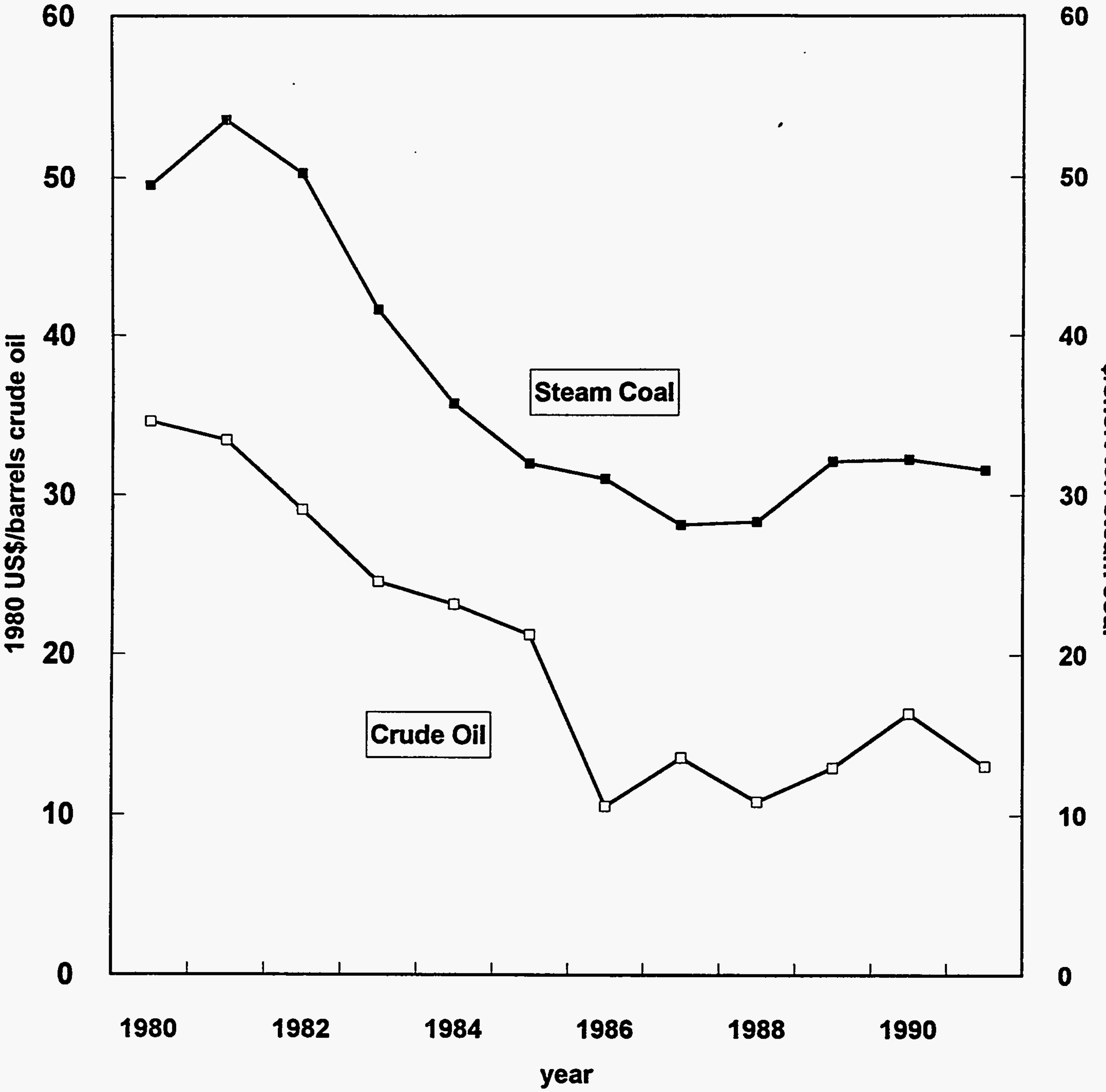
Source: Coal Information, 1992 and PAJ Annual Review, 1992

Figure 83. Steam Coal and Oil Import Prices to Japan per Million Btu, 1980-90



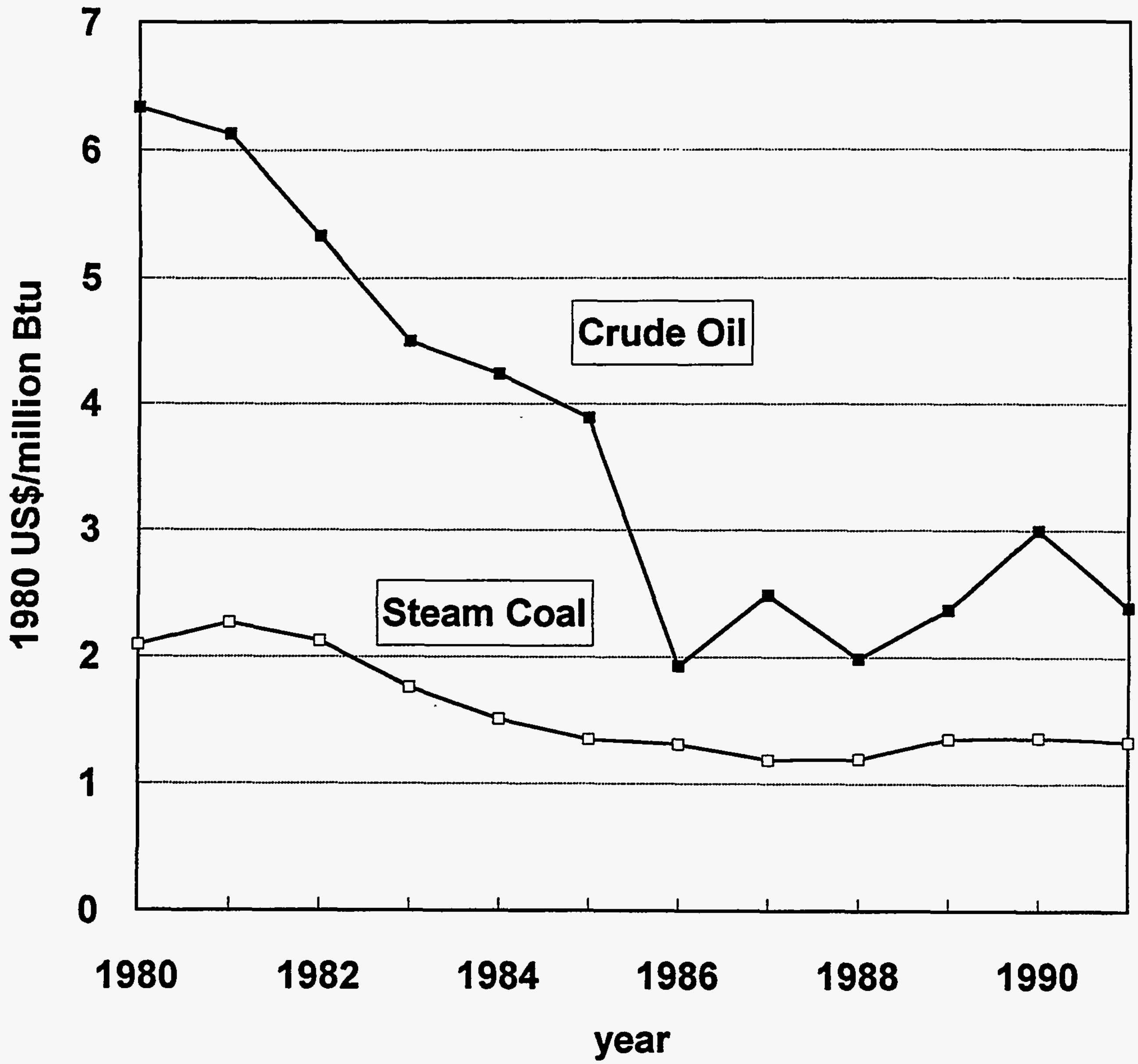
Source: Coal Information, 1992 and PAJ Annual Review, 1992

Figure 84. Steam Coal Import Prices to japan vs. Crude Oil Import Prices, 1980-90 (Constant 1980 US$)



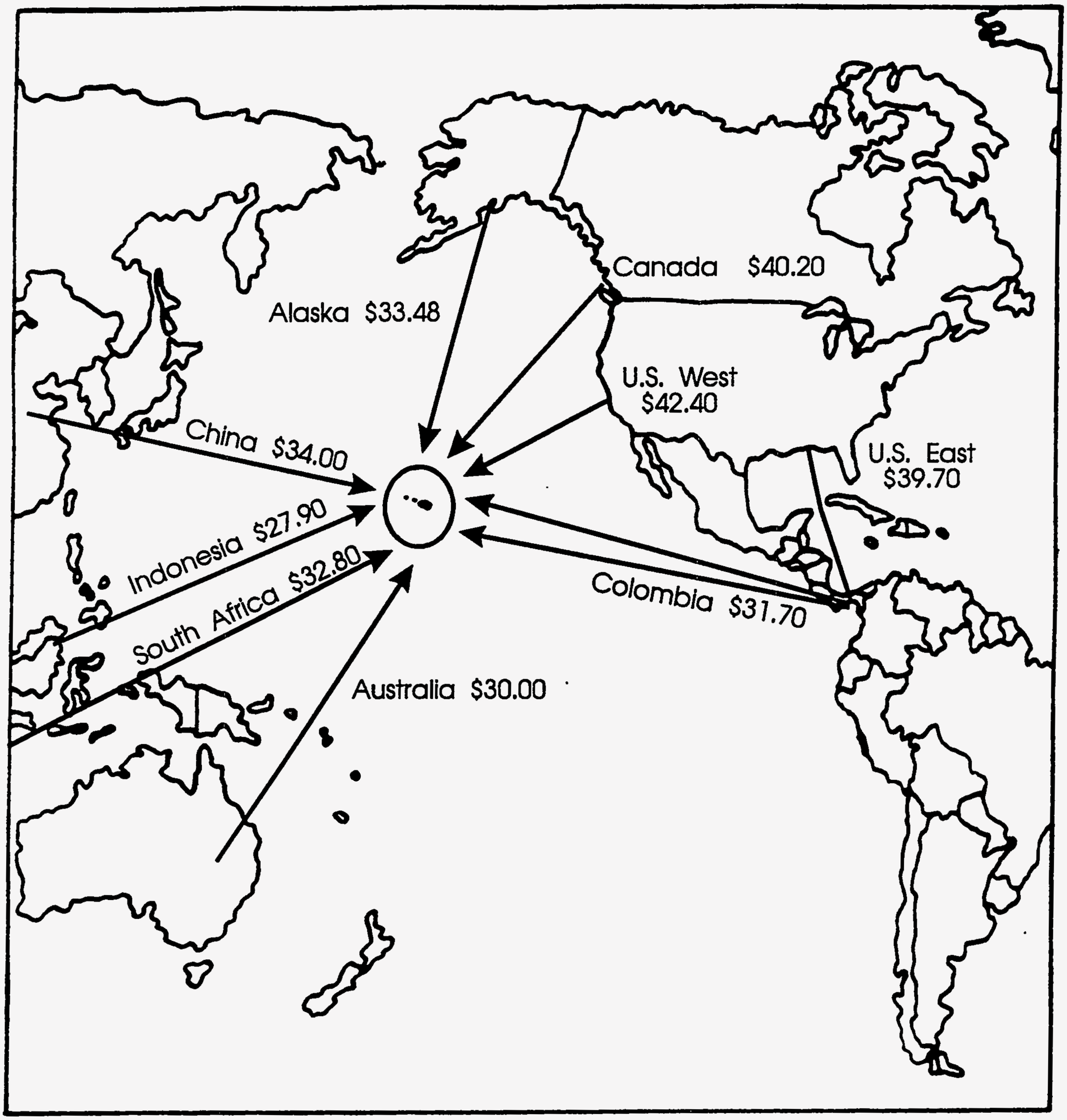
Source: Coal Information, 1992 and PAJ Annual Review, 1992

Fig 85. Steam Coal and Oil Import Prices to Japan per Million Btu, 1980-90 (Constant 1980 US$)



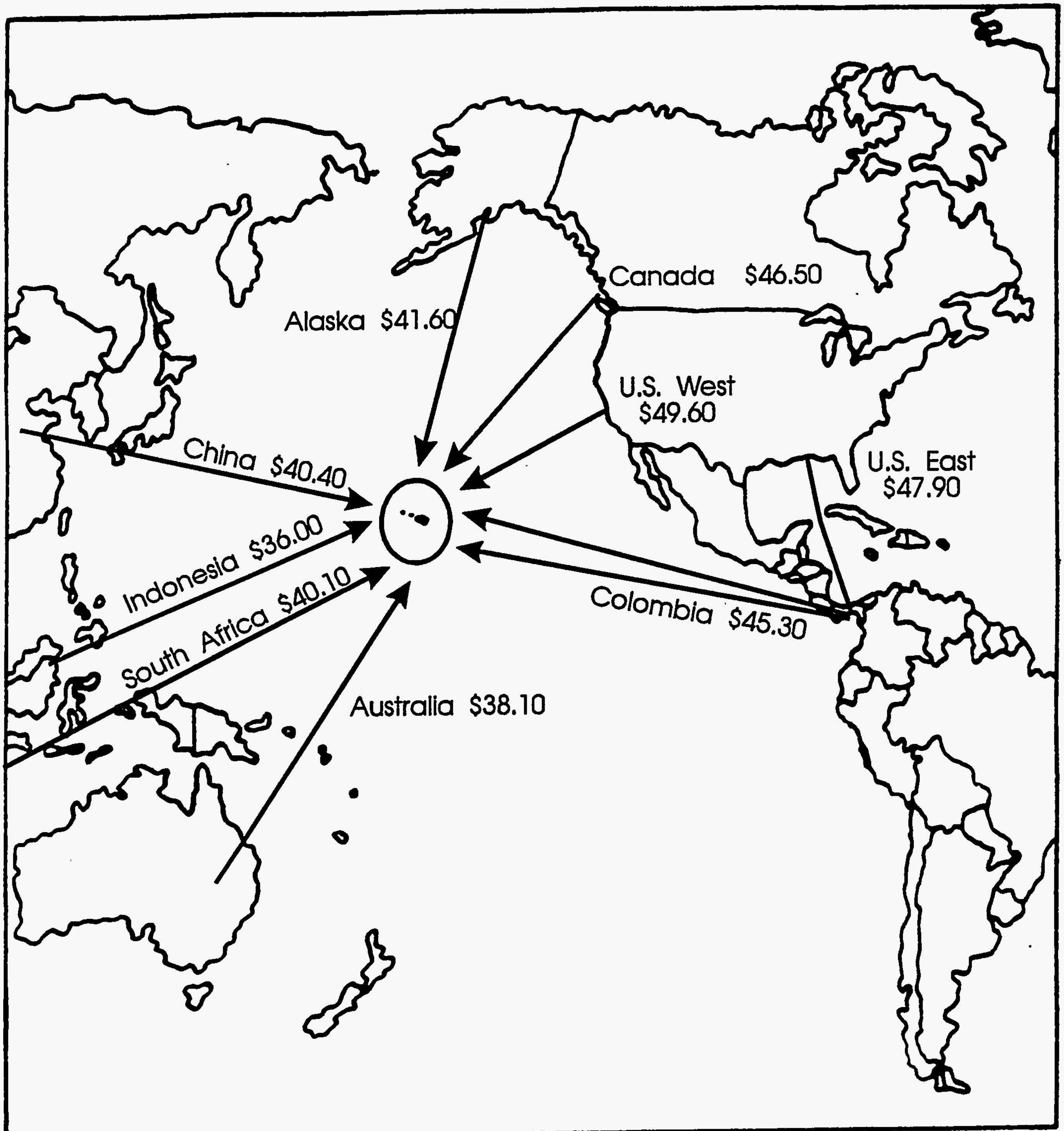
Source: Coal Information, 1992 and PAJ Annual Review, 1992

Figure 86. Representative Long-Term Operating Costs To Hawaii Coal Suppliers (1992 US$/short ton)



Source: EWC Coal Project, 1993

Figure 87. Representative Long-Term Total Costs To Hawaii Coal Suppliers (1992 US$/short ton)



Source: EWC Coal Project, 1993

coal. In the case of western U.S. coals, roughly half of the total cost of the coal involves transport costs. Australian and Indonesian mines not only have favorable mining conditions but the mines are typically close to ports. Indonesia's coal is 9-62 miles (15-100 km) from deep-water ports while mines in Australia are mostly less than 155 miles (250 km) from ports. Because they do not reflect capital charges, these operating costs represent the lowest price at which a coal producer would ship its coal.

Figure 87 shows the total costs including a capital charge of supplying coals to Hawaii. Basically the same trends exist with Indonesia and Australia having the lowest costs. Colombia's relative position changes the most dramatically because of the large amount of debt accrued in its mining projects. The capital charges added to Colombia's cost per ton are thus higher relative to the other producers.

Coal mines must cover at least their operating costs or they will shut down. Therefore, the representative operating costs in figure 86 are the lowest average prices that could occur in the marketplace for periods of a year or two. However, little investment will occur at the coal prices shown in Figure 86 because they do not include a return on capital investment. Figure 87 shows the long term total costs of coal, including both operating and capital costs. Figure 87 is indicative of the prices that would result in very active investments in expanding coal capacity. Prices are unlikely to remain at the levels in Figure 87 (the total cost table) over the long term because such prices would result in excess capacity and lower prices. For long term planning purposes, prices will most likely fall between the levels in Figures 86 and 87.

4. Coal Reserves and Production

World coal resources are greater than 5 trillion tons, and even the *proven reserves* that can be produced at present prices are about 1 trillion tons. Thus depletion is not an issue. In terms of energy content, world coal reserves account for about 85 percent of the total hydrocarbon reserves (coal, oil, and gas). Specific reserve data can only be relied upon as broad indicators, but they are useful in comparing the relative abundance of coal deposits between countries and in indicating the regions in which coal deposits can be presently found. Figure 88 shows the proven reserves of the ten countries having the largest coal reserves in the world. These ten countries represent 93 percent of the world's coal reserves. China, the Commonwealth of Independent States (CIS, the former Soviet Union), and the United States dominate, accounting for a combined 63 percent of total world coal reserves. The United States and particularly the CIS must transport coal very long distances by rail to Pacific exporting ports, which makes the coal less competitive to Hawaii consumers. China alone accounts for almost a quarter of total reserves, but almost all of its over 1 billion tons of production are consumed domestically to meet rapidly growing demand. India has a similar problem and must import a small quantity of coal. Germany and Poland are virtually ruled out as suppliers due to weak mining industries and the long transport distances to Pacific coal markets. The most probable coal suppliers to Hawaii in terms of cost and quality considerations would be Australia, Indonesia, South Africa, and the U.S. mainland.

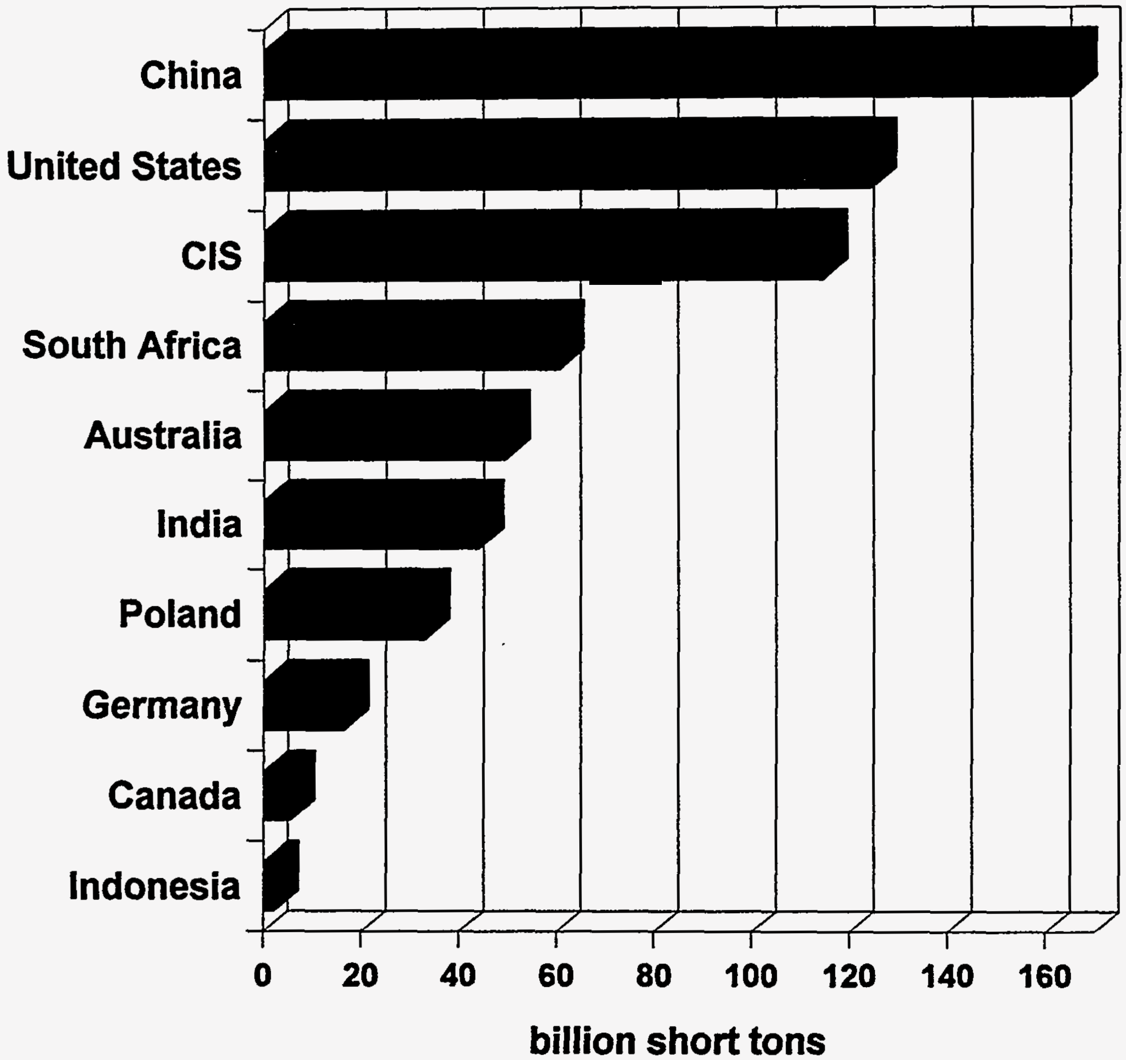
The 1992 coal production and exports of the seven most viable coal suppliers to Hawaii are listed in Table 42. China is the world's largest coal producer with production expected to increase by an additional 500 million tons by the year 2000, however as stated above, most of China's coal production is consumed within the country. China exports about 22 million tons per year, but the expansion of exports is expected to proceed slowly over the next two decades because of growing domestic consumption. The United States is the second largest producer and exporter in the world, but only 7.0 million tons (or 17 percent of total thermal coal exports) were sent to the Asia-Pacific region in 1992. Australia is the largest coal producer in the world, and 80 percent of exports go to the Asia-Pacific region. South African steam coal export tonnages are similar to those of Australia, but only 30 percent of total exports are sent to the Asia-Pacific. The majority is exported to Europe. Indonesia's exports are expanding rapidly with the start-up of new privately contracted mines on the island of Kalimantan. Exports are expected to increase to about 30 million tons by the year 2000.

Table 42. 1992 Coal Production and Exports of Potential Coal Suppliers to Hawaii,

(Million short tons)

	Total Coal		Steam Coal	Steam Coal %
	Production	Exports	Exports	of Total
Australia	207	139	64	46%
Canada	73	30	6	19%
China	1,201	22	18	80%
Columbia	26	13	13	100%
Indonesia	24	18	18	100%
United States	994	102	43	42%
South Africa	187	57	50	87%

Figure 88. Top Ten Coal Reserves, 1991



Source: BP Statistics, 1992 and EWC Coal Project, 1993

Also shown in Table 42 is the share of steam coal as a percentage of total exports for each country. All Colombian and Indonesian coals are exported as steam coal, while only 19 percent of Canadian coal is sold as steam coal. If coal fulfills the quality specifications to be considered coking coal, producers will attempt to sell their product as coking coal because this coal is able to command a premium of at least $8.00/ton higher than steam coal. Over half of the coal produced by the United States and Australia are currently marketed as coking coal. However, with the stagnation of the international steel market and the substitution of higher quality coking coals with lower quality coals in a process called pulverized coal injection (PCI), the share of steam coal as a percent of total exports will rise steadily over the next two decades for most exporters.

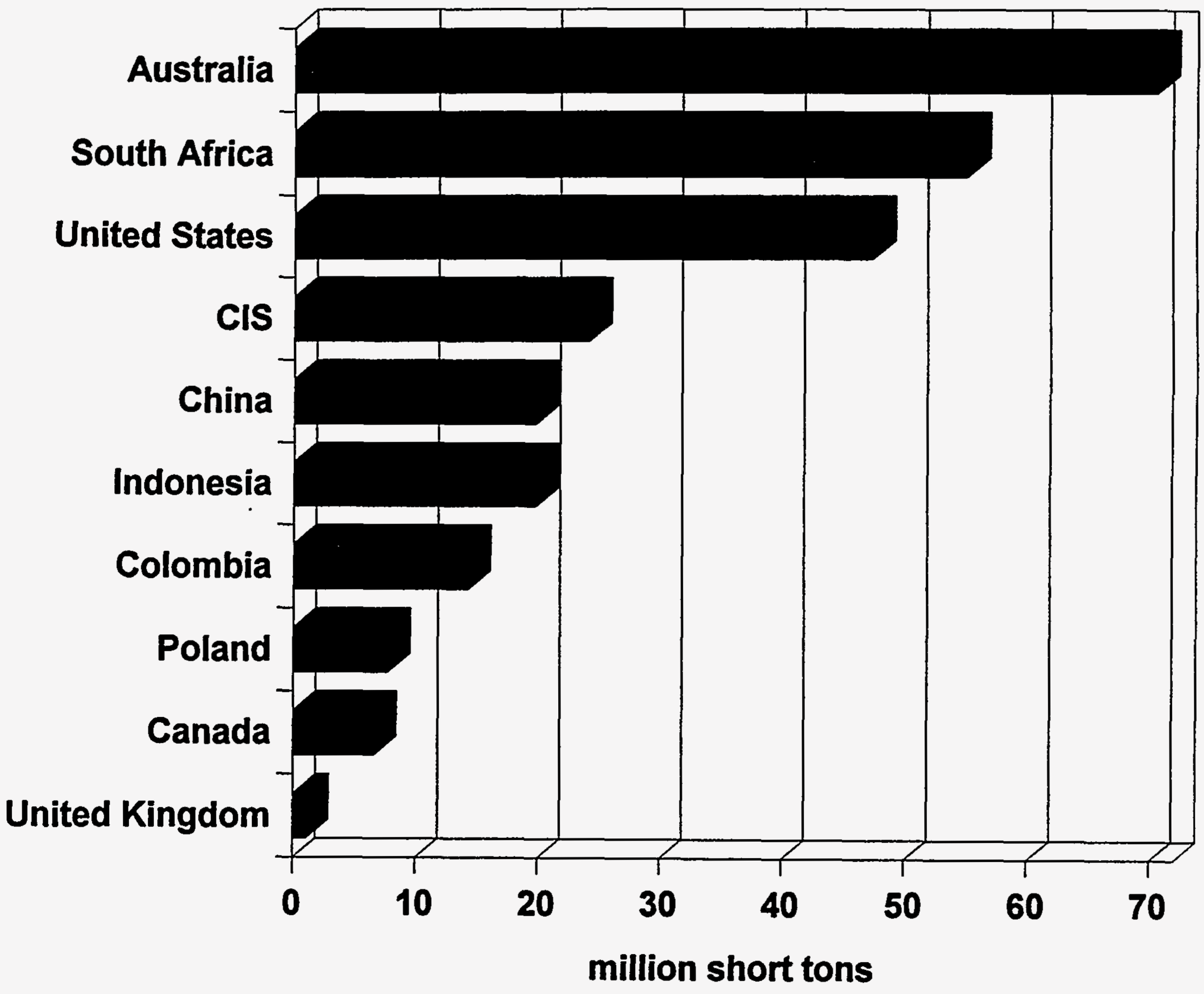
Figure 89 ranks the world's top ten steam coal exporters. Australia leads exporters followed by South Africa and the United States. As noted earlier a large percentage of South African exports are steam coal, which places the country above the United States in exports. CIS (the former Soviet Union) exports its coal mainly to central Europe.

5. Individual Suppliers

An overview of the individual supply situation of each major coal producer is given below. Individual suppliers within a country often have very different coal qualities and coal mining conditions, and the discussion below attempts to focus on those factors and data that apply to a majority of the suppliers in a country.

Australia. Australia is the largest exporter of coal to both the Asia-Pacific region and the world. Coal is also Australia's main export earner and, therefore the main focus of its government and industry is on promoting coal exports. Exports of steam coal were 64 million tons in 1992 and are projected to grow to nearly 90 million tons by the year 2000. During the 1980s, Australia made substantial progress in removing restrictive labor practices, and consequently is better positioned to maintain a competitive advantage in coal trade to the Asia-Pacific. The present cost structure and trends in the Australian and the emerging

Figure 89. Top Ten Steam Coal Exporters 1992



Source: ICR, 1993

Indonesian coal industries are such that coal exports from the United States are only marginally competitive in the Asia-Pacific region.

Almost all export mines are located within 120 miles (200 km) of deep-water ports in the states of Queensland and New South Wales. Reserves of anthracite and bituminous coal were listed at 50 billion tons in 1991, so depletion is not an issue.

Australian producers pay higher rail rates per ton per mile than other major competitors, which to some degree reduces the location advantage of deposits being near the coast. Australian coal rail networks are owned and operated by the New South Wales and Queensland state governments. In the event of significant price reductions or large losses in profits by producers, the state governments would most likely support their main export earner by reducing rail rates and other levies.

Australian coal exports have historically been the basis for both quality standards (typical coal qualities are shown in Table 41 above) and prices in Asian coal trade, and most coal importing utilities have designed their coal-fired plants to burn Australian coal. However, utilities are becoming more flexible in the qualities of coal that they will use because of the entry into the market of low energy content coals such as those found in Indonesia (also see Table 41).

Australia is a desirable coal supplier to Hawaii for many reasons ranging from its low delivered cost to Hawaii (estimated at about $38.00/ton in Figure 87), the high quality of its coal, the abundance of its coal resources, and its political stability. Australian producers have also stated in the past that if a premium was paid for higher qualities of coal, the quantities of the coal in demand could be significantly expanded. If a large demand for a coal of specific quality is demanded, Australian producers have more flexibility than their competitors to exploit the new markets.

Canada. As noted above, Canadian producers market most of their coal as coking coal. Only 6 million of steam coal were exported in 1992. Most of this coal was shipped to Japan which is purchasing most of the coal for diversification rather than economic purposes.

Canadian coal producers which export to the Asia-Pacific are located in British Columbia, and like those in the United States, they have to transport their coals over 600 miles (1,000 km) by rail to deep-water ports. This, together with high mining costs make Canadian coals mostly uneconomic to Hawaii consumers. Canada's coal exports are expected to decrease at least over the next decade.

China. Currently, coal accounts for one-third of the total rail shipments in China, and the present rail system for most main routes is operating at capacity. China's demand for coal is projected to grow to 1.7 billion tons by 2000 from 1.2 billion tons in 1992. As a result of insufficient investments in the transportation sector, the shortage of transport capacity is very serious. Export rail lines are receiving priority; however, periodic shortages in meeting export commitments may occur. The main coal producing areas lie in north-central China, long distances from the industrial and population centers to which the coal has to be transported.

About 80 percent of China's coal is located in north and northwest China. The main producing province is Shaanxi, which accounts for about one-quarter of China's total production. About 7 percent of China's coal is reportedly suitable for open-cut (surface) mining. Only about 18 percent of the coal is washed, and the coal that does get washed is usually mixed with unwashed coals at some point in China's complex transport system.

The inconsistent quality of China's coals, and uncertainties related to the amount of coal available for export at any point in time, make importing coals from China on a long term basis very risky. China's coal exports are projected to reach 39 million tons by the year 2000.

Colombia. The Cerrejon Norte mine located in the northeastern part of the country currently dominates production, but the Colombian government has plans to expand coal operations in six other coal producing areas. Mine capacity at Cerrejon is expected to be expanded from 17 million tons in 1992 to about 28 million tons in the late 1990s. Total Colombian coal exports, which are currently 13 million tons, could be expanded to 33 million tons by the year 2000. Although high capital costs cause Colombian coals to be less competitive, when compared with Australian or Indonesian coals (see Figure 87), the coal is relatively cheaper to import than U.S. mainland or Canadian coals since rail transport costs are low.

Indonesia. Indonesia has some of the lowest sulfur coals in the world, but a typical quality coal has a higher than average moisture content and a relatively low energy content, with some notable exceptions such as Kaltim Prima coal which was discussed earlier. Indonesia also has very low mining costs, and deposits are located close to deep-water ports.

Indonesia's large steam coal export potential was not recognized until the early 1980s. Rapid expansions in production are underway on the island of Kalimantan, and Indonesia's exports have quadrupled from 1990 levels to 18 million tons in 1992. Exports are expected to continue to expand to the year 2000, and then stabilize because of domestic demand, which has also been increasing sharply.

Most of Indonesia's production expansion originates from mines that are partly owned by foreign firms (mostly Australian). The foreign firms are under an agreement with the government to offer Indonesian mining companies controlling interest in the projects after a set period of time. The government has recently reversed its original policy, which allowed foreign firms the rights to develop coal deposits, but this policy change may be temporary. Indonesian firms may not have the capital or expertise to develop the mines without some form of foreign assistance.

The delivered cost of Indonesian coal to Hawaii is very low, which makes the coal very attractive as a blending coal or in some cases alone. The case of Kaltim Prima coal is an excellent example of the point stressed earlier concerning individual consumers dealing with individual mines. The average Indonesian coal may not be desirable to many consumers, but one mine within Indonesia does have excellent quality coal. The same could be true of Australian or even U.S. coal. An individual producer may be willing to offer above average quality coal or better contract terms than most coal producers within a specific country.

United States. The United States is the world's second largest producer of coal, and 1991 reserves are listed at 112 billion tons. As is the case with Australia, depletion is not a factor; however, changes in legislation relating to sulfur emissions from coal burning are likely to cause shortages of low sulfur coal in some central and eastern regions in the latter half of the 1990s. The United States produces about 990 million tons of coal each year with 60 percent coming from the east and 40 percent coming from the west. Thermal coal exports were 43 million tons in 1992 with only about 7 million tons being exported to the Asia-Pacific region. The fundamental problem with exports to the Pacific is the great distances of 900-1,200 miles (1,500-2,000 km) or more that the coal must travel by rail to deep-water ports. Even though the mining costs of some western deposits are among the lowest in the world ($5.00/ton), and the rail rates (less than $0.01 per ton per km) are also among the lowest in the world, the distance disadvantage has prevented western coals from capturing a significant share of the Asia-Pacific market. The delivered cost of the coal is estimated at $49.60/ton, which is uncompetitive with Australian and Indonesian coals (see Figure 87).

Imports to Hawaii from the mainland U.S. may also be hindered by higher sea transport rates because of the Jones Act, which forces coal commerce between U.S. states to take place on U.S. staffed and built vessels. Salaries and vessel freight rates are typically higher on U.S. ships, which causes inter-state ocean freight rates to be higher than those of most foreign shippers.

Since Hawaii is a PADD-V state, its coal market may seem to be somewhat linked with the other PADD-V states. As noted earlier, this is not the case. Nonetheless, it is worthwhile to provide a general picture of the PADD-V coal market. Table 43 presents coal production, consumption, and trade of the PADD-V states. In marked contrast to the situation with oil, California plays essentially no role in the coal market except as a

Table 43. PADD-V Coal Production, Consumption, and Trade

(thousand short tons)

		Production	Imports	Exports	Consumption
Alaska	1988	1,746	0	827	276
	1989	1,447	0	662	299
	1990	1,675	0	793	784
	1991	1,433	0	777	803
Arizona	1988	12,405	0	0	14,534
	1989	11,942	0	0	16,881
	1990	11,304	0	0	16,419
	1991	13,203	0	0	16,805
California	1988	54	17	1,100	2,210
	1989	117	48	2,130	2,552
	1990	61	2	2,127	2,900
	1991	51	9	2,875	2,816
Hawaii	1988	0	64	0	64
	1989	0	35	0	35
	1990	0	24	0	24
	1991	0	31	0	31
Nevada	1988	0	0	0	8,281
	1989	0	0	0	7,671
	1990	0	0	0	7,458
	1991	0	0	0	8,091
Oregon	1988	0	0	0	178
	1989	0	0	1	396
	1990	0	0	4	934
	1991	0	0	576	1,939
Washington	1988	5,173	3	261	5,933
	1989	5,016	11	146	5,847
	1990	5,001	31	82	5,138
	1991	5,148	27	202	5,457

Source: DOE, 1990, 1991, 1992

transshipment point for exports. Arizona is the main coal producing and consuming state. There is currently no coal trade, nor is trade likely to occur in the near future, between Hawaii and any other PADD-V state. This is mainly because of a relatively small reserve base over the states and coal quality constraints. Note that the export and import figures may be misleading in the table, as they refer only to imports at point of receipt and exports by port of origin. So, the trade activities of a landlocked state such as Arizona do not appear.

South Africa. South Africa exported 50 million tons of mostly steam coal in 1992, but 70 percent was shipped to Europe. As shown in Figure 87 South African coal is only about $3.00 less to Hawaii than coals shipped from Australia and Indonesia. Freight rates are slightly higher per ton/mile than those of the western U.S. coal producers, but coal must be transported over a much smaller distance to port. South Africa is well known for its low mine costs, which are attributed mainly to favorable geology, advanced mechanization, and good management.

In order for South Africa to expand coal exports significantly, however, new coal deposits must be developed a considerable distance from the current producing region, and the mining conditions in the new deposits are not comparable to those in existing deposits. Thus, it is expected that producers will be forced to charge higher prices in the future.

6. Conclusions

Hawaiian coal consumers have a wide variety of coals and coal producers from which to choose, and the optimum source and coal quality will vary significantly with the individual consumer's needs. Australia and Indonesia appear to be the most competitive supply sources to Hawaii, but in some situations, other coal sources or coal contract terms may better suit the needs of an individual consumer, especially if favorable terms can be worked out with specific mines.

FOSSIL FUEL IMPORTS

Although the long-term cost of coal is not expected to increase significantly, a premium is likely to be placed on both low sulfur and low ash coals as worldwide environmental awareness increases. Hawaiian users would most likely be forced to pay these premiums because of stringent environmental regulations and high public awareness.

III. Substitutability of Fuels

A. Fuel Substitution: What Is "Feasible?"

It is a risky matter even to speak about substitution horizons and future market penetration rates in fuels, because there are so many advocates of particular alternatives. Every advocate of a given alternative will typically insist that their favored technology is already "available," "feasible," and "economic." Apparently, the fact that usage of these technologies is not more widespread is a consequence of a sinister plot. At the risk of associating the present report with this plot, we will freely engage in generalizations in the following discussion. The reader should be aware that when we characterize a technology or fuel as "not fully competitive," "under development," or "not readily available," this does not mean that there are no examples of its use.

To take a single example, in automotive fuels, ethanol has been widely used in Brazil (although there have been significant problems associated with the Brazilian program), CNG (compressed natural gas) was widely deployed in New Zealand, and methanol has been used in high-performance race cars. Despite this, today nuclear-powered naval craft of various sorts still provide more transportation energy than ethanol, methanol, and CNG put together. We do not consider nuclear power to be a readily available alternative to transport fuels, even though it is in use today.

Figure 90 presents our outline list of petroleum products, their uses, and current substitutes. We list methanol, ethanol, LPG, and CNG as current substitutes for gasoline, but we note that none of these alternatives has achieved substantial market penetration rates. When we characterize a technology as "not readily available," this is not intended to reflect poorly on the technology, or to discourage its use. Our terminology is purely pragmatic, and is intended to reflect the degree to which a fuel substitution could be deployed on an "off-the-shelf" basis. Examples of substitutions that we would characterize as readily available would be solar-assisted residential water heating, the substitution of gas water heating for

Figure 90. Petroleum Products, Uses, and Current Substitutes

Temp. (F)	PRODUCT		USES		CURRENT SUBSTITUTES
0-50	LPG	==>	Mixed	<==	Gas, some coal
40-330	Gasoline	==>	Transport	<==	MeOH, EtOH, LPG, CNG
	Naphtha	==>	Petrochemicals	<==	?
290-520	Kero/jet	==>	Transport	<==	?
		==>	Rural Cooking	<==	Wood, LPG
		==>	Home Heating (Japan)	<==	Gas
370-675	Motor Diesel	==>	Transport	<==	?
	Heating Oil	==>	Home Heating (US)	<==	Gas, solar, wood
		==>	Industrial Heat	<==	Gas, coal
650-675+	Fuel Oil	==>	Industrial Heat	<==	Gas, coal
		==>	Electric Power	<==	Gas, coal, nuclear, hydro, geothermal, wind, biomass, etc.

electric water heating, or the selection of any number of coal-burning technologies to substitute for fuel oil in power generation. On the other hand, even a technology such as CNG, which has been fairly widely used, would require extensive study to deploy. (Should conversion kits be subsidized, or should the fuel itself be tax exempt? How large a tank should be used given tank costs, trunk space, and typical driving distances? How should fuelling stations be spaced? Should each canister fuelling station be a compressor center fed by pipeline, or should some of the locations have the canisters trucked in? Is reconversion to gasoline legal? Does Hawaii require a lower average pressure for safety reasons than New Zealand, given that trunk temperatures could potentially rise much higher? How will the service station personnel be trained in the new procedures, and will the community colleges need more funding to cover these additional services?) A policy maker could mandate that, for example, gas water heating be used in all new construction on Oahu, and with confidence expect that such a policy could be implemented without major technical hurdles being encountered, and without requiring additional policy decisions. A policy maker could not mandate a switch to methanol cars, CNG buses, or OTEC electricity with a similar degree of confidence, and these are exactly the distinctions that we wish to draw.

This document is of a preliminary nature. Not enough is known about the end-use distribution of fuel use in Hawaii to be definitive about substitution possibilities or vulnerabilities. Moreover, this document does not address the broad issue of conservation or other demand-side management (DSM) measures. There is little doubt that conservation and DSM measures in Hawaii could result in substantial savings of energy; based on experience elsewhere, it is likely that such measures are the cheapest ways of expanding energy supplies or lowering current levels of dependence.

1. Where the Oil Goes

As noted, only the most basic end-use information is available on the Hawaiian market, and many of the data sources contain contradictory information. Collection of comprehensive and reliable information is a long-term task that needs to be given high priority in the 1990s. Nonetheless, at least some background on the current situation can be gleaned from consideration of the 1992 base-year data from oil supplier and utility records and the pictures presented earlier on sectoral fuel use.

In the following, military use of oil is excluded. Defining "military demand" is itself a tricky matter, since military installation service stations contribute a significant quantity of fuel that is used for personal purposes by military personnel, dependents, and civilians employed on base. Here, the sales at military service stations (of both gasoline and diesel) are included in Hawaii demand as "non-military," while all other military consumption is excluded. Data on military fuel use is not always complete in any case, since the armed forces are able to procure fuel from outside the local market.

The excluded military demand is a significant factor in the total Hawaiian market, but fuel-use and fuel-switching decisions in the military are driven by very different sets of considerations than those driving state policies. Compatibility with other equipment and availability of fuel worldwide are overriding concerns in the military context. The military demands need to be accounted for, but they are not, in many cases, amenable to substitution policies; they are best considered as "exogenous" demands in the Hawaiian economy.

Table 44 shows the volumes of oil products (excluding LPG) in barrels/day delivered to various end-uses in Hawaii in 1992. The upper part of the table gives a more detailed view of the fuels and the end-uses; the lower part collapses the fuels into five generic categories and five basic sectors.

One of the most important features to note in this table is that more than one-third (37%) of Hawaii's oil demand is consumed by transport connections with the outside world—overseas air and overseas shipping. Out of non-military demand of about 116,500 barrels per day (b/d), jet fuel demand for overseas flights is nearly 32,000 b/d, and overseas shipping consumes almost 5,000 b/d of diesel and 7,000 b/d of fuel oil—a total of about 43,500 b/d of demand devoted to external commerce.

The volume of fuel devoted to external transport is important not only because it emphasizes Hawaii's reliance on oil to maintain links with the outside world, but also

Table 44. Hawaii: Estimated Non-Military Oil Use By Fuel and Sector, 1992*

(thousands of barrels/day)

	Aviation Gasoline	Motor Gasoline	Jet Fuel/ Kero	Diesel	Other Dist.	Fuel Oil	Other	TOTAL	% Share
Transport-Light Road	0	19,596	0	331	0	0	0	19,927	*17%*
Transport-Heavy Road	0	1,172	0	4,069	2	0	0	5,243	*4%*
Transport-Instate Shipping	0	15	0	763	0	0	0	779	*1%*
Transport-Overseas Ship.	0	0	0	4,899	0	7,030	0	11,930	*10%*
Transport-Instate Air	102	0	6,938	0	0	0	0	7,040	*6%*
Transport-Overseas Air	0	0	31,649	0	0	0	0	31,649	*27%*
Heavy Machinery/OTRVs	0	59	0	434	6	108	0	607	*1%*
Agriculture	6	75	0	504	179	1,355	0	2,120	*2%*
Commercial/Industrial	0	0	0	493	12	2,526	0	3,032	*3%*
Power Generation	0	0	0	4,149	0	29,068	0	33,217	*29%*
Other	0	0	0	0	0	5	989	994	*1%*
TOTAL	108	20,917	38,587	15,643	199	40,093	989	116,537	
% Shares	*0%*	*18%*	*33%*	*13%*	*0%*	*34%*	*1%*		

Summary Sectors:

	Gasolines/ Naphthas	Jet Fuel/ Kero	Diesel/ Distillate	Fuel Oil	Other	TOTAL	% Share
Road Transport	20,768		4,402	0		25,170	*22%*
Water Transport	15		5,663	7,030		12,708	*11%*
Air Transport	102	38,587	0			38,689	*33%*
Power Generation	0		4,149	29,068		33,217	*29%*
Other	140		1,629	3,995	989	6,753	*6%*
	21,026	38,587	15,842	40,093	989	116,537	*100%*
	18%	*33%*	*14%*	*34%*	*1%*	*100%*	

**estimated from Supplier Form 65-3, supplemented with utility information.*

because the nature of these linkages reaches far beyond the scope of state policy. A shipping line moving cargo between islands may be persuaded to convert to some alternative fuel; an international shipper will be extremely unlikely to make any changes unless identical fuelling facilities are available everywhere the ship is likely to call. Similarly, jet fuel characteristics and specifications are set by international accord, not by states; even if some alternative fuel were available for jets (which is only a remote possibility in the near future), there are unlikely to be many conversions without a concerted international effort. Thus, these externally linked fuels are to a large extent beyond the control of state policy regarding substitution; even the most aggressive fuel-switching policy would be unlikely to affect these volumes.

Figure 91 shows the situation graphically. All four of the main fuels are involved in transport. Fuel oil is the most important fuel in the power sector, although considerable quantities of diesel are also used. In the figure, fuel oil is the largest-volume fuel; with continued growth in air traffic, and the displacement of fuel oil in power generation by coal and other non-petroleum fuels, the relative volumes of fuel oil and jet fuel may switch over the next few years; some estimates of jet fuel consumption higher than those used here suggest that this changeover has already taken place, with actual jet demand 3-5,000 b/d higher than shown in the current figures.

Volumetric figures are useful for figuring flows or total values, but they give a misleading impression of how much energy is involved in an oil system. Gasoline has an energy content per barrel 20 percent lower than that of crude oil; fuel oil has an energy content 20 percent higher than crude. Some subtle but important shifts take place when the volumetric data of the previous table are transformed into barrels of oil equivalent/day (boe/d), as shown in Table 45. The energetic role of fuel oil becomes more pronounced, while the prominence of gasoline shrinks somewhat.

Placing these items into a common unit allows a broad-brush look at where Hawaii's oil goes. As Figure 92 shows, despite the wide array of uses of oil in modern economies, two sectors account for 94 percent of all Hawaiian non-military oil demand: transport (61

Table 45. Hawaii: Estimated Non-Military Oil Use By Fuel and Sector in Barrels of Oi . of Oil Equivalent per Days, 1992*

(barrels oil equivalent/day)

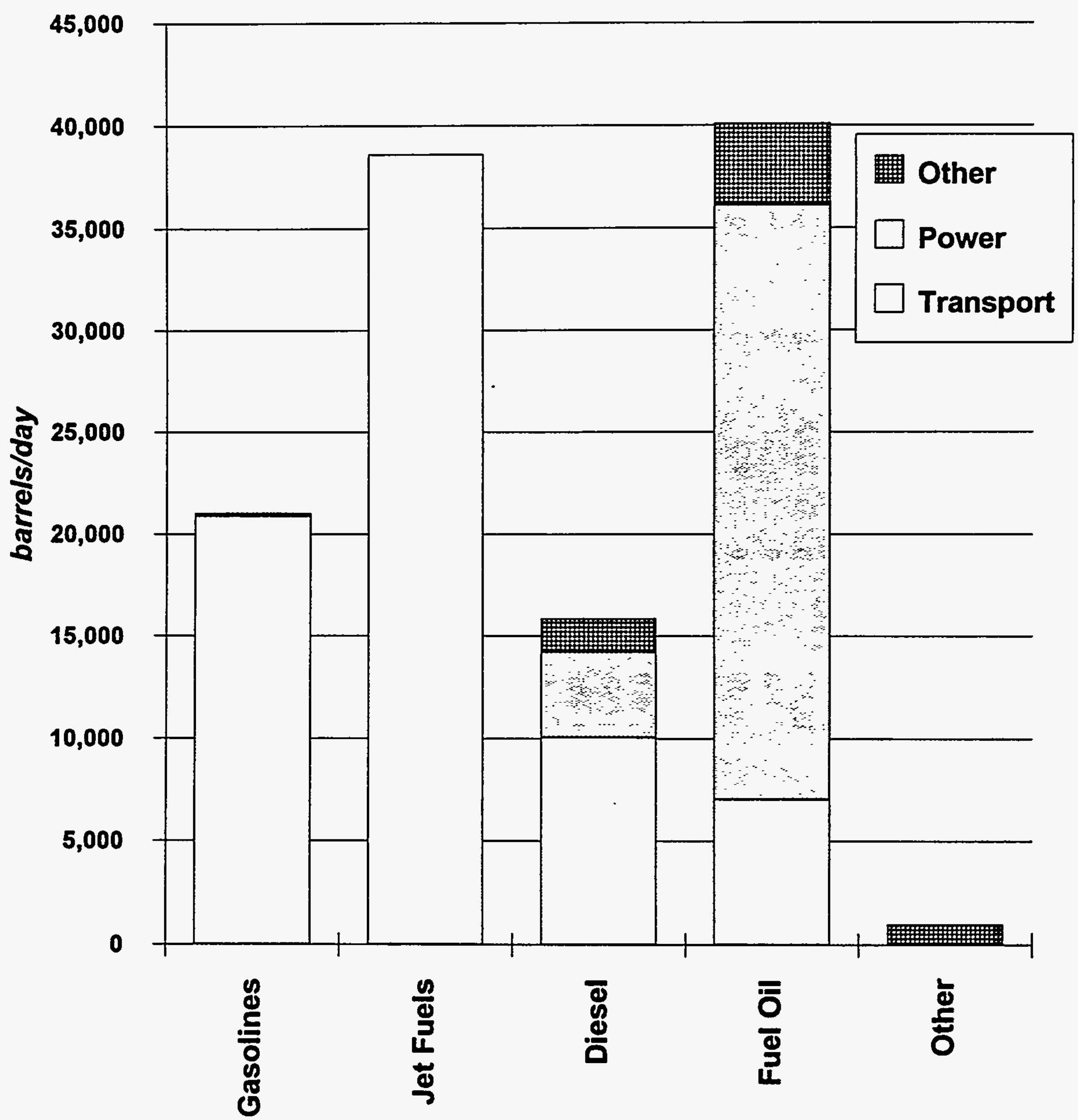
	Aviation Gasoline	Motor Gasoline	Jet Fuel/ Kero	Diesel	Other Dist.	Fuel Oil	Other	TOTAL	% Share
Transport-Light Road	0	15,939	0	328	0	0	0	16,267	*14%*
Transport-Heavy Road	0	953	0	4,033	2	0	0	4,988	*4%*
Transport-Instate Shipping	0	12	0	757	0	0	0	769	*1%*
Transport-Overseas Ship.	0	0	0	4,856	0	8,293	0	13,149	*11%*
Transport-Instate Air	83	0	6,596	0	0	0	0	6,679	*6%*
Transport-Overseas Air	0	0	30,089	0	0	0	0	30,089	*26%*
Heavy Machinery/OTRVs	0	48	0	430	6	127	0	612	*1%*
Agriculture	5	61	0	500	177	1,599	0	2,342	*2%*
Commercial/Industrial	0	0	0	489	12	2,980	0	3,481	*3%*
Power Generation	0	0	0	4,113	0	34,288	0	38,400	*33%*
Other	0	0	0	0	0	6	1,167	1,173	*1%*
TOTAL	88	17,014	36,685	15,505	198	47,293	1,167	117,949	
% Share	*0%*	*14%*	*31%*	*13%*	*0%*	*40%*	*1%*	#	

Summary Sectors:

	Gasolines/ Naphthas	Jet Fuel/ Kero	Diesel/ Distillate	Fuel Oil	Other	TOTAL	% Share
Road Transport	16,892		4,363	0		21,255	*18%*
Water Transport	12		5,613	8,293		13,918	*12%*
Air Transport	83	36,685	0			36,768	*31%*
Power Generation	0		4,113	34,288		38,400	*33%*
Other	114		1,614	4,712	1,167	7,608	*6%*
	17,102	36,685	15,703	47,293	1,167	117,949	*100%*
	14%	*31%*	*13%*	*40%*	*1%*	*100%*	

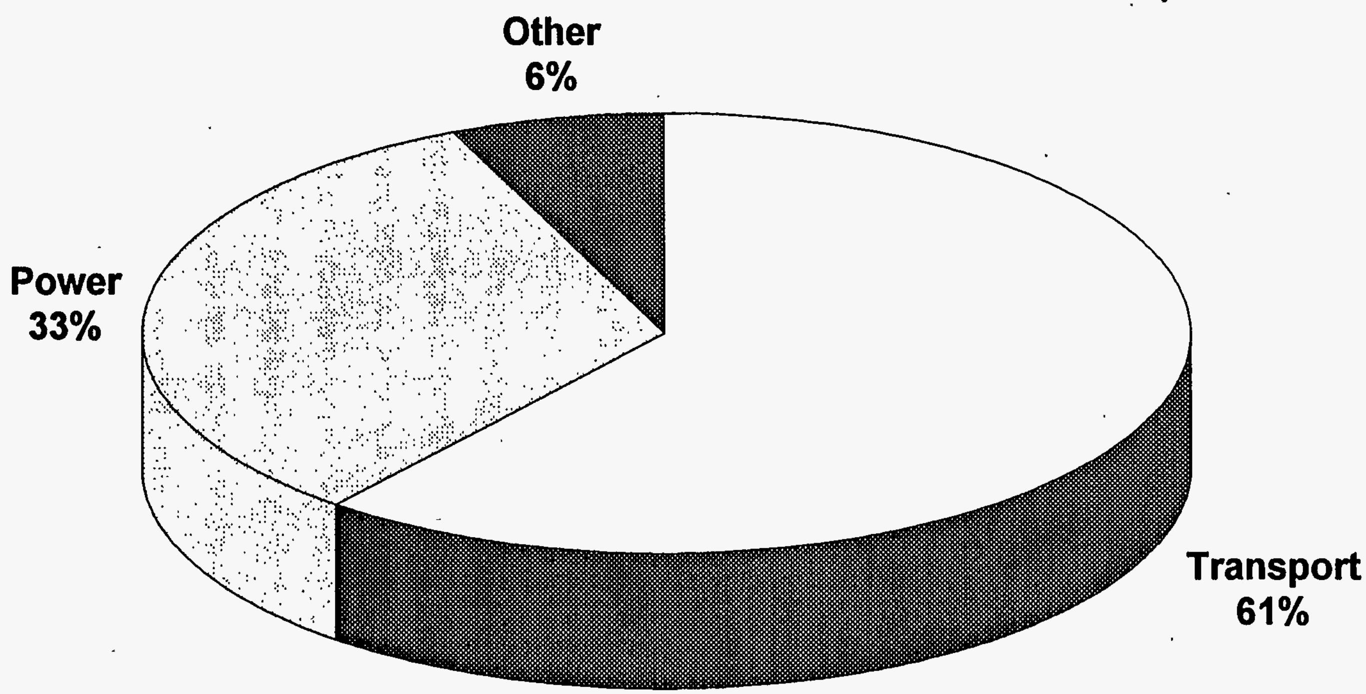
**estimated from Supplier Form 65-3, supplemented with utility information*

Figure 91. Non-Military Use of Oil in Hawaii By Sector and Fuel, 1992*



*Includes military service stations

Figure 92. Non-Military Use of Oil in Hawaii By Sector, 1992



In barrels oil equivalent (energy terms). Includes military service stations.

percent) and power generation (33 percent). Everything else, from agricultural machinery to asphalt paving, amounts to only 6 percent of the demand.

In terms of possibilities for switching away from oil, this is both good and bad news. The large amount of oil going toward power generation is one of the easier targets for fuel-switching; the economics may not be favorable in all circumstances, but there are a plethora of possible substitutes based on proven and widespread technologies. The bad news, of course, is that 60 percent of the demand is centered on the transport sector, the sector where there has historically been the least success in moving away from dependency on petroleum.

2. Substitutions between Fossil Fuels: Replacing Oil with Coal or Gas

In an era when the main focus of fuel substitution is on substituting *away from* fossil fuels, it must also be acknowledged that some of the most readily achievable types of fuel-switching involve the phasing in of another type of fossil fuel. There are often sound economic, political, and environmental reasons for doing so. Consider a situation where a new natural gas field is developed; the price of natural gas might become far more attractive, and coal or oil might then be supplanted in the power sector. If the coal and/or oil is imported, the substitution of natural gas may have an additional security bonus. In most cases, switching to natural gas also has certain environmental benefits. While switching away from oil or coal to natural gas is one of the most commonly considered modes of fossil fuel switching, it is also possible of course to switch *to* oil or coal; for example, if a natural gas field played out in a certain area, coal or oil might be used instead.

In principle, the fossil energy sources are interconvertible in most uses with sufficient application of engineering. In practice, there are serious limitations on the degree to which coal and gas can be substituted for oil products. Some of these are not purely technical limitations, but limitations of convenience and cleanliness; it is perfectly possible to return to coal-fired stoves, or coal-fired hot water heaters, but it is unlikely that such a move would find favor with either consumers or with environmental authorities.

2.1 Coal Substitution

SUBSTITUTABILITY

For practical purposes, in the Hawaiian context coal is limited to replacement of fuel oil and some industrial grades of diesel. In terms of end-use, this means that with current technologies, coal can find a logical home in power generation and in some process heat production. The scope for use outside the electric power sector is more limited in the Hawaiian situation than in many areas of the US, since Hawaii's high energy prices have always been a barrier to establishment of energy-intensive industries; the local requirements for process heat or steam appear to be rather modest.

With some effort, shipping can also be converted to coal burning; there was a flurry of interest in the revival of coal-powered ships after 1973 and 1979, and most marine engineers are confident that modern coal-burning ships could be made far more efficient and clean than their predecessors in the early 1900s. There is considerable doubt whether such conversion would be worthwhile in the Hawaiian context, and doubts about both the economics and environmental wisdom of such an approach, but it is the only area where coal could make inroads into the Hawaiian energy supply scene other than industrial-scale heat and power.

There are some obvious drawbacks to widespread coal utilization in Hawaii. The distribution infrastructure may limit use of coal to a few facilities where it can be offloaded and moved. Emissions controls are expensive and subject to economies of scale; therefore, coal is most likely to prove feasible at larger centralized plants. The scale arguments apply equally to handling facilities for storing, retrieving, and charging coal at the site.

2.2 Natural Gas Substitution

Gas can be used for industrial heating and power generation, and can typically achieve higher efficiencies than coal. Emissions from gas-fired facilities are normally much lower than those from coal plants, even without emissions controls. Although significant distribution infrastructure is required in the form of pipelines, the economies of scale at the consuming site are much less pronounced than for coal; while there are few high-efficiency coal furnaces, gas burners come in all sizes.

Because gas can be handled at a much smaller scale, gas can penetrate many markets where coal cannot be used. Coal competes with oil only directly, as power plant or process heat fuel. Gas can do this as well, but can also compete with oil power generation indirectly, by displacing electricity itself, thereby lowering the demand for oil. In many circumstances, it is more efficient to use gas directly in an appliance, rather than generating electricity to run a similar unit.

Table 46 shows a checklist of where coal and gas can compete with oil, either directly or indirectly. Many electric appliances have gas-powered equivalents, and large gas-based commercial HVAC systems are now available on a competitive basis in many areas. Gas has difficulty in driving most motors and cannot, of course, power electronic equipment. Although gas illumination is a thing of the past, by the time that electric power became widely available, high-efficiency mantles for gaslights had just been perfected; gas lighting is probably competitive with electricity, but is unlikely to make a return.

Most LNG tankers run on the "boil-off" of the gas from their cargos. There is nothing in principle to prevent the design of a high-efficiency gas-turbine ship; the economics of compressing or liquefying the gas, and the cruise distance are the limiting factors. There have been advanced designs for LNG-powered jet aircraft, but one of the reasons for relying on kerosene-based jet fuel is its low volatility; even the military has moved away from naphtha-type jet fuel as too explosive. LNG jets have their advocates, but it is very unlikely that any will be licensed for commercial use in the near future.

The one area in which gas could have a major impact on transport use of petroleum is in the use of compressed natural gas (CNG) in cars. A number of countries have had limited CNG programs in urban areas. New Zealand had a major push on CNG during the 1980s, and several percent of the automotive fleet were converted to gas. (When government conversion incentives and price inducements were eliminated, however, the trend reversed itself sharply.) Trucks and buses have also been converted to CNG, although such conversions are still more experimental than for passenger cars.

Table 46. End-Use Opportunities for Coal and Gas

Sector		Coal	Gas	Displacing	Comments
Residential	Lighting	No	Archaic	Elec.	Good efficiencies in mantle-type fixtures
	Electronics	No	No	Elec.	
	Air Conditioner	No	Some	Elec.	Not common, but commercially available
	Clothes Washer	No	Yes	Elec.	Very common in some mainland areas
	Clothes Dryer	No	Yes	Elec.	Very common in some mainland areas
	Water Heater	No	Yes	Elec.	Very common in some mainland areas
	Stove/Oven	No	Yes	Elec.	Very common in some mainland areas
Commercial	Lighting	No	Archaic	Elec.	Good efficiencies in mantle-type fixtures
	Electronics	No	No	Elec.	
	Refrigeration	No	Available	Elec.	Major expansion in commercial gas cooling underway in US
	Cooking	No	Yes	Elec.	Very common in both mainland and Hawaii markets
Industrial	Lighting	No	Archaic	Elec.	Good efficiencies in mantle-type fixtures
	Electronics	No	No	Elec.	
	Motors	No	Rare	Elec./Oil	Gas-impelled motors and turbines used for some specialties
	Process Heat	Yes	Yes	Elec./Oil	Many mature technologies widely available
	Power Generation	Yes	Yes	Elec./Oil	Many mature technologies widely available
Transport	Road	No	CNG/LPG	Oil	CNG limited in distance; not widespread.
	Waterborne	Archaic	Rare	Oil	LNG carriers run on gas. Designs for other ships available.
	Air	No	Experimental	Oil	LNG jets have been designed.

CNG has two main drawbacks: limited cruising radius, and slow refill. New Zealand solved the refill problem in a number of ways (including direct fill service stations, canister-exchange stations, and fill-overnight at-home services). Filling is still considered to be inconvenient compared to gasoline, and a tank of CNG will typically need to be refilled 2-4 times as often. Nonetheless, the Hawaiian islands are in principle well-suited to CNG, since maximum driving distances are limited in any case.

If Hawaii had natural gas reserves, then arguments for CNG would be compelling; prices are much the same as for gasoline, and sometimes lower. CNG in Hawaii, however, would have to be based on either SNG or LNG, both of which are expensive even before delivery to a station for compression. As we noted in the section earlier on natural gas sources, Hawaii consumers pay two to six times as much for SNG as the typical US West Coast consumer. For example, during the first ten months of 1992, Hawaii residential gas users paid around $18 per thousand cubic feet (mcf) of gas, whereas their California counterparts paid around $6/mcf. LNG is examined further in Task III (*Greenfield Options*) of this project; both the future prices of LNG as well as the minimum economic scale make establishment of an LNG industry in Hawaii a rather challenging proposition, but is not clear that LNG could not play a role here, and we will reserve judgment until the completion of the analysis.

Finally, LPG (propane and/or butane) can substitute for oil both directly and indirectly. LPG is somewhat more flexible than gas. It can drive most gas appliances with suitable modification and it can be used in power generation or process heating at high efficiency. LPG is compressible enough that it can be stored in cylinders at comparatively high densities, making it fairly attractive as an automotive fuel. The only drawback to LPG is its price. It is similar enough to oil that it tends to be priced somewhat like oil, although pricing formulas vary across time. International LPG prices are set in the Middle East, and are linked to crude prices. LPG-fuelled vehicles are somewhat less convenient than gasoline-powered vehicles, but have been successfully used in fleets in some areas (largely to lower pollution) for nearly 30 years. Since a large percentage of LPG is produced from oil fields and oil refineries, there are questions as to whether it can truly be called an alternative to oil. In fact, much of the interest in LPG as a gasoline substitute has come in response to the need for cleaner burning fuels in areas (such as the Los Angeles Basin) with severe air pollution problems.

3. Non-Fossil-Fuel Alternatives to Oil

Alternative energy sources will be intensively explored in other phases of the Hawaii Energy Strategy. Here, however, it is good to review the levels at which alternatives might provide substitutes for various oil products.

Wind and hydropower are aimed mainly at electricity production, as are geothermal, OTEC, and most bulk biomass projects. Wind and hydropower are also sources of mechanical work or pumping where required, and geothermal and bulk biomass can also provide process heat.

Photovoltaic cells and solar thermal power are aimed at electricity production, but the most promising and widespread use of solar energy is for residential and commercial heating, especially the heating of water. In this regard, solar, like gas, can provide some indirect competition to oil-generated electricity.

One of the most important potentials of biomass energy is in the production of alternative liquid fuels, such as ethanol and methanol. These can be used for "low-level" uses such as heating and power generation (though they are likely to be far too expensive), but their obvious application is in replacing petroleum transport fuels. Cars and heavy equipment can be run on alcohols without massive modifications; the technology is reliable, though it may still be far from optimized (after all, it is being run on equipment designed around gasoline). There is no reason that such principles cannot be extended to ships as well.

In many parts of the country, blends of various "oxygenates" (including methanol, ethanol, and the methyl and ethyl ethers of t-butane) on the order of 5-17 percent are now common, and in some areas are required by law for air-quality purposes. While this does not really constitute an alternative fuel (particularly in the case of MTBE and ETBE, where the bulk of the molecule is typically a refinery by-product), oxygenates can both extend the supply and improve the properties of gasoline. Alternative fuel vehicles (AFVs) may become more cost-effective as areas with severe air pollution problems mandate the use of alternative fuels. California has the nation's worst air pollution problem and is working to expand its fleet of alternative fuel vehicles, which in 1992 stood at around 4,100 vehicles. The California Energy Commission (CEC) expects the AFV fleet to include around 13,500 vehicles by 1995, then take off rapidly as more stringent air quality regulations come into force. Table 47 and Figure 93 present the CEC's forecast of AFVs in California; the fleet is expected to increase nearly twelvefold between 1995 and 1996, double again in the following year, then triple by the year 2000, reaching a total of over 937,000 vehicles. To put this into perspective, however, this is larger than Hawaii's entire fleet,[13] but represents only 4.2% of California's fleet.

The area where there is considerable doubt about the technical potential of the alcohols is in the area of aircraft fuels. Alcohols tend to absorb moisture from the atmosphere, and have the potential of seeding out ice crystals at high altitude, a tendency that could be disastrous. Many designers are confident that reliable and safe means of using alcohol in jet turbines can be found, but at present jet fuel is the one petroleum product for which there is no technically available substitute.

4. An Example Hierarchy of Fuel Substitution

In general, the easiest end-uses to substitute are power generation and process heat; the most difficult end-use is jet fuel. The other end-uses lie somewhere along the continuum between these two points.

[13]In 1992, 908,738 vehicles were registered in Hawaii, according to the State Department of Transportation, as cited in *The State of Hawaii Data Book 1992*.

Figure 93. Growth in the Alternative Fuel Vehicle Fleet in California, 1990-2000

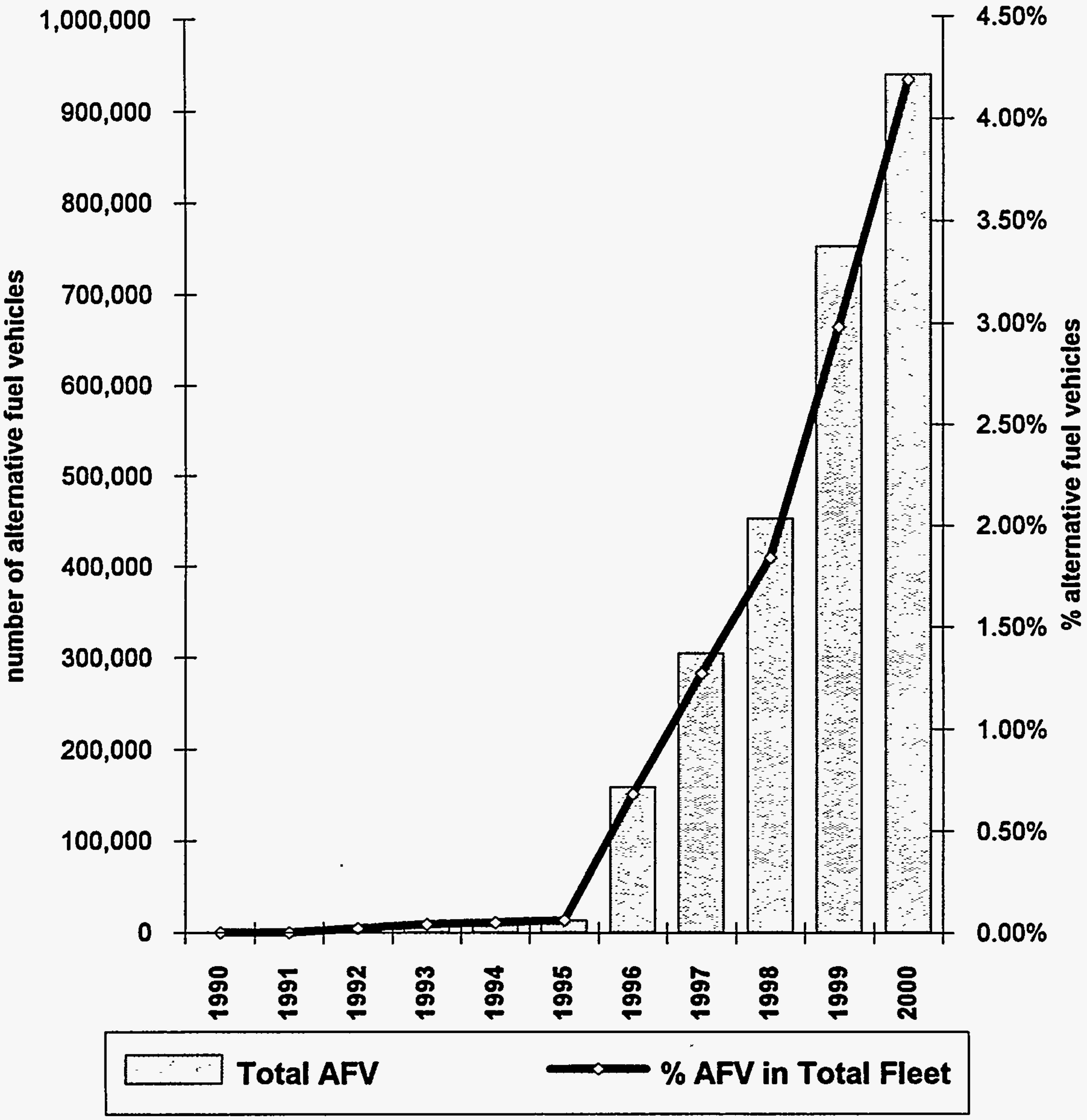


Table 47. Forecast of Alternative Fuel Vehicles in California, 1990-2000

Year	Total Number of Alternative Fuel Vehicles	Alternative Fuel Vehicle as a Percentage of Total Fleet
1990	0	0.00%
1991	0	0.00%
1992	4,095	0.02%
1993	8,451	0.04%
1994	10,951	0.05%
1995	13,451	0.06%
1996	159,356	0.68%
1997	305,000	1.27%
1998	452,500	1.84%
1999	750,000	2.98%
2000	937,288	4.19%

Note: Hawaii's total fleet is under 1 million vehicles
Source: California Energy Commission, "California Oxygenate Outlook," March 1993

Without making any claims to analytical rigor, Table 48 shows what effects the staged substitution of various end-uses would have on the savings of oil, and the composition of the demand barrel. These are arranged in increasing order of "difficulty."

The first stage would be the replacement of diesel and fuel oil in power generation and large-scale heating by any of a number of alternatives. This is selected as the first stage, since the substitution possibilities are wide and well-understood; the decision is a matter of economics. About 38,500 b/d of oil products could be cut from the system in this fashion.

The second stage would be to roll in about 10 percent of an alternative fuel (probably an oxygenate) as a blendstock in the existing gasoline pool. This would cut another 2,000 b/d from demand. The economics of this are more questionable in the Hawaiian situation, and there are still some unresolved technical matters (hygroscopic behavior, vapor pressure consequences in Hawaiian temperatures, etc.), but it would be a policy which would not be too difficult to implement; other areas have done it already for environmental reasons.

Stages 1 and 2 are fairly straightforward, and are unlikely to raise controversy as to their ordering. Stages 3, 4, and 5 are debatable as to their relative technical and economic difficulty. Our selected stage 3 is conversion of interisland shipping to some non-petroleum fuel. Although it might be argued that the technical parameters of this policy are more poorly understood than further conversion of road vehicles, it is a more manageable policy in that it affects only a small number of vessels, and new fuelling infrastructure needs to be provided only at a handful of sites. This measure saves less than 1,000 b/d of fuel.

Stage 4 is conversion of the automotive fleet to some alternative fuel (CNG, LPG, ethanol, methanol, etc.). This removes another 19,000 b/d from demand. Stage 5 follows up by additionally converting all heavy road vehicles to alternatives as well, dropping another 4,000 b/d from the system.

Stage 6 is, at this point, a technical unknown: conversion of interisland air travel to some unknown, perhaps nonexistent, alternative fuel. This would clip another 7,000 b/d from demand.

Table 48. Oil Substitution Scenarios for Hawaii

SUBSTITUTION FOR:	Overall Reduction	Remaining Demand						Cumulative % Reduction
		Gasoline	Jet Fuel	Diesel	Fuel Oil	Other	TOTAL	
0. 1992 Base Demand	0	21,050	38,689	15,577	41,501	989	117,806	0%
1. Power generation, process heat	38,473	21,050	38,689	11,440	7,165	989	79,333	33%
2. 10% gasoline blending	2,105	18,945	38,689	11,440	7,165	989	77,228	34%
3. Interisland shipping	734	18,945	38,689	10,706	7,143	989	76,472	35%
4. Conversion of all light road transport	19,254	14	38,689	10,383	7,143	989	57,218	51%
5. Heavy road transport	4,074	14	38,689	6,309	7,143	989	53,144	55%
6. Interisland air	7,041	14	31,648	6,309	7,143	989	46,103	61%

This is not intended as an action plan, but rather to make a point: even a very aggressive substitution campaign will leave Hawaii with a fairly large oil demand. At considerable expense (probably including replacement of much of the existing generating capacity), a third of Hawaiian oil demand might be cut. Ten percent blending saves only another percent of current demand. Substituting oil demand much beyond a third of current usage means going to much bolder and more speculative measures. Cutting demand in half requires replacing all existing road transport, oil power generation, plus interisland shipping. Cutting demand by more than half means going to technologies not yet defined. Moreover, some of the steps along the way have a very peculiar demand pattern, as Figure 94 shows.

The Figure gives the demand barrel in percentage terms. Merely moving to Stage 1 substitution pushes jet fuel's share of the barrel to almost half. Moving further along the path pushes jet fuel's share of the barrel up to a maximum of 73 percent (Stage 5). In the interim stages (1-3), fuel oil's share of the barrel is pushed to about 10 percent of the barrel—a technically feasible, but very expensive, level of heavy product output.

Hawaiian refineries are relatively flexible by world standards, but they are already close to their limits in terms of minimizing fuel oil output and maximizing jet fuel output. Some small adjustments could be made by altering the crude slate, but the patterns of demand shown in Figure 94 cannot be met by pulling in different crude oils: there are no crudes with this yield pattern, not even when supplemented by the cracking facilities of the Hawaiian refineries.

To show the nature of the problem that can arise, consider Figure 95. This chart shows the net surpluses of products that would develop along our hypothetical substitution path if refinery output stayed at 1992 volumes. Moving to Stage 1 pushes exports to high levels (about half of throughput); moving to Stage 4 or beyond means that all but a fraction of Hawaii's refinery output must be exported.

This is referred to as a "naive" analysis in that the output patterns are assumed to be fixed. In reality, if the Hawaiian refineries were forced to look to exports for the bulk of their marketing, very rapidly their output slates would be optimized to follow the external

Figure 94. Changes in Demand Barrel Along Hypothetical Substitution Path

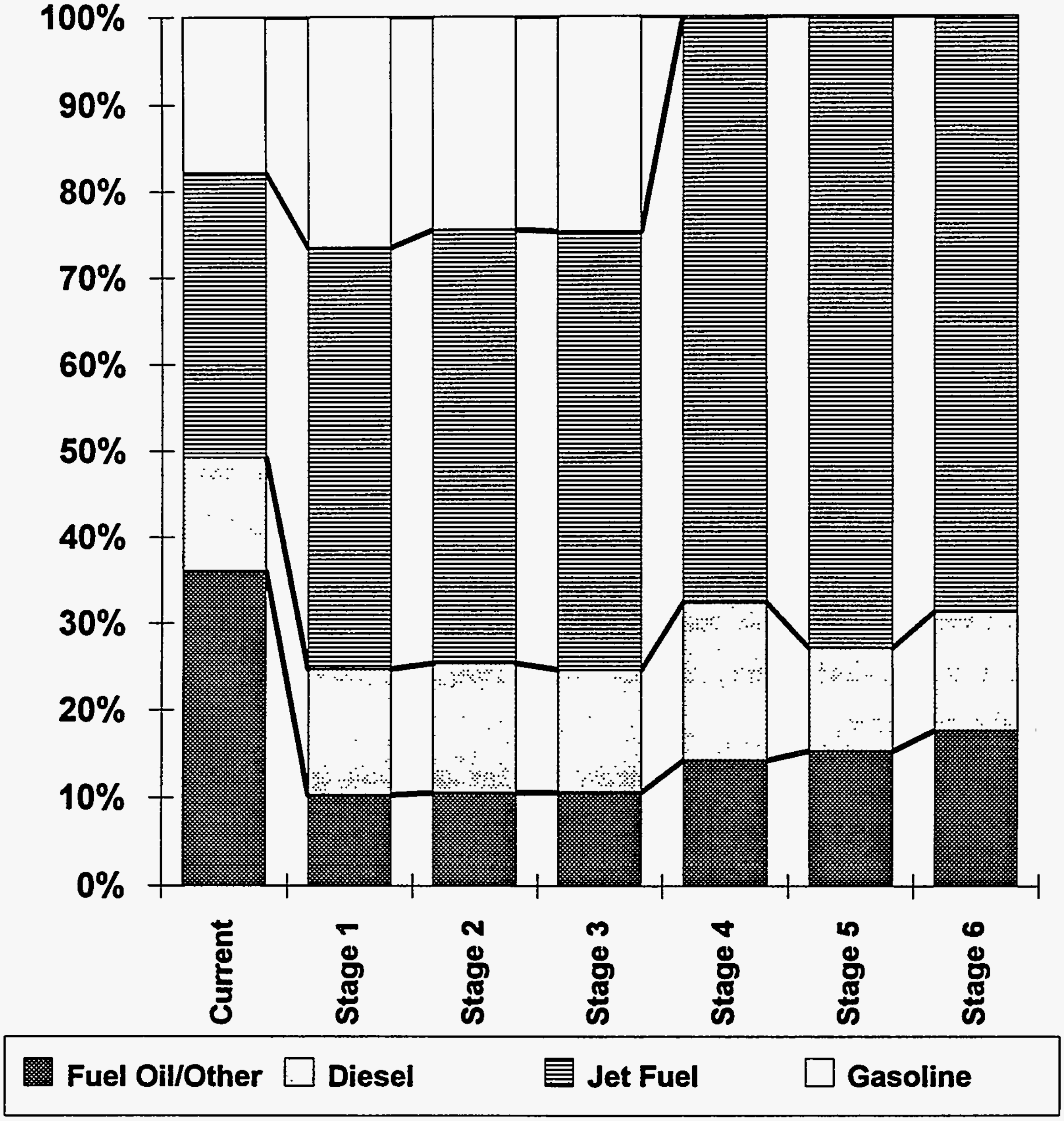
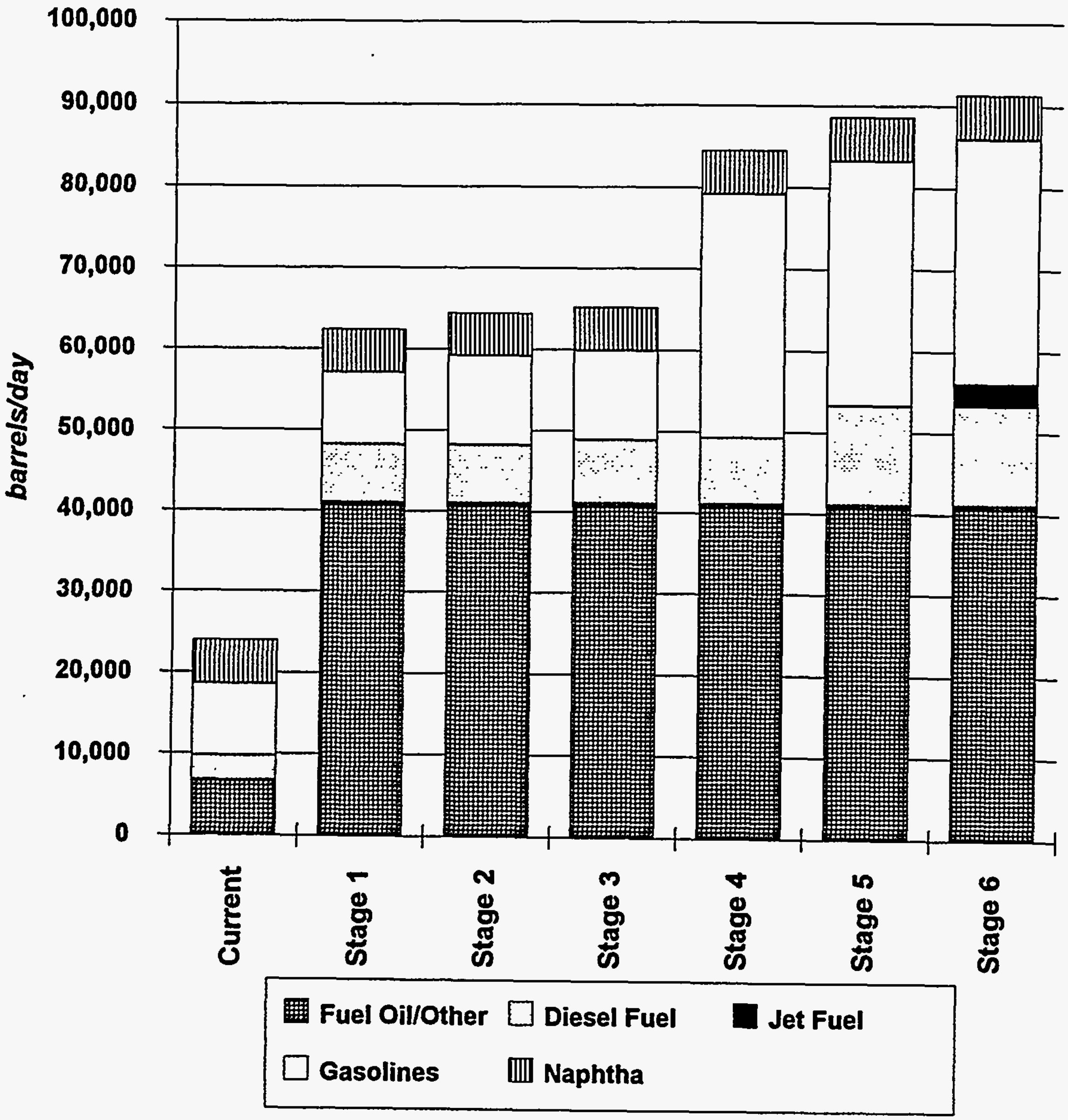


Figure 95. Naive Projections of Refinery Surpluses Along Hypothetical Substitution Path



market rather than the needs of the Hawaiian market; therefore, the current output patterns would be unlikely to hold.

The shipping of oil products is considerably more expensive than the shipping of crude. Hawaiian refiners are at a transport advantage in serving the Hawaiian market (competitors have to overcome a major transport hurdle to put product into the local market), but are at a comparable *disadvantage* with respect to most export markets. If the external market is strong enough—that is, if the market is short of refined products—then exporting from Hawaii might be enough to maintain the refining system for a time. The refining market is subject to recurring bouts of overcapacity, however, so a massive substitution away from oil would be threatening to the long-term viability of refining in Hawaii.

An assessment of the impacts of fuel substitution on the viability of Hawaiian refining cannot be made by comparing a handful of static numbers; only a refinery optimization model, with extensive assumptions about the course of prices on the external market, can give an idea of which substitution measures can readily be accommodated, and which measures would be threatening to the long-term stability of the industry. Such an analysis goes beyond the scope of this chapter and is examined, instead, in Task IV (*Scenario Development and Analysis*) of this project. Nonetheless, it is important for policy makers to be aware of the fact that substitution measures have consequences for the supply system, and ultimately for the pattern of import dependency.

IV. Energy Security: Possible Frameworks

A. What Is Energy Security?

"Energy security" is an elusive concept. It has meant different things at different times. John Bookout, III, a particularly vociferous critic of setting energy policy based on security issues, has called energy security "the argument of the scoundrel," and commented: "When I hear the words 'energy security,' I hear cash registers in the background." Indeed, virtually every proposed change to national energy policy—from a more aggressive nuclear program, to widespread use of solar water heating, to oil drilling in the Alaskan National Wildlife Refuge, pays lip service to energy security. Energy security is like motherhood in that it is hard to find any opponents; unlike motherhood, however, we are seldom sure of what we mean by the term.

In the early days of energy security, the focus was on *physical availability*—what the layman still thinks of as security. An effective energy security policy under this line of thinking is one that ensures that the required (read "desired") supplies of energy are available in the market despite disruptions elsewhere. A strategy to meet this type of energy security might include some holdings of strategic stockpiles, a switch to indigenous fuels and alternative energy forms, import-sharing strategies between cooperating countries, and a switch away from oil to other fossil fuels (which presumably are less prone to disruption). This type of energy security gave rise to Project Independence in the 1970s, an umbrella that happily sheltered advocates of the Strategic Petroleum Reserve, the Synthetic Fuels Corporation, the Solar Energy Research Institute, the Fast Breeder Reactor, Tokamak fusion, Arcosanti, and the Farallones Institute.

By the 1980s, energy security came to focus more on *price stability* in the local market. A number of Asian countries (notably Japan, South Korea, and Thailand) attempted to introduce price stabilization measures by adding on a flexible oil import tariff that made up the difference between the purchased price of oil and a higher, target price (with the tariff funds being contributed to a price-stabilization fund, and, in some cases, to stockpiling programs or the development of non-oil alternatives). The Asian consumers even attempted to open a consumer-producer dialogue on price stabilization; essentially, many of the Asian countries were suggesting that they would happily pay higher prices if they were guaranteed some level of stability in prices. Such measures did not win approval from the United States, where strategy has always been devoted to stabilizing the market against upward fluctuations in price, but taking full advantage of any downward movements. (The Japanese position, which has some degree of merit, has been that downward fluctuations in price are just as economically damaging as upward surges, since downward movements destroy the economics of oil-conservation and oil-substitution measures, and drive alternative-fuel producers out of the market.)

More recently, many analysts have begun using the term "energy security" to mean insulation from the adverse economic effects of energy supply and price fluctuations. Even with adequate supplies of energy at reasonable prices (as found in some Third World nations with price-controlled domestic sources of energy), the economic effects of recession elsewhere can have unfortunate consequences for the fortunes of exports of manufactured goods.

At the risk of introducing additional cumbersome terminology, we suggest that rather than referring to "energy security" here, we refer instead to *supply security* (physical availability), *price security* (stabilization of price fluctuations), and *economic security* (shielding from the consequences of energy price fluctuations elsewhere).

B. Supply Security

The oil price shocks of the 1970s greatly changed the psychology of the oil market, and to a considerable degree it also changed the psychology of the average person living in an oil-importing country. All over the world, governments established energy emergency preparedness plans, and plans to enhance oil supply security through enhanced domestic production, import source diversification, sharing agreements, and perhaps bilateral supply arrangements with other producing countries. There were summits and conferences and hearings and contingency plans and energy emergency preparedness exercises. To give an indication of how much this has changed, the California Energy Commission (CEC) was a leader in energy emergency planning and was greatly concerned with supply security. While both of these things continue to be true, the focus and level of emphasis has changed significantly. In their latest *1993 California Energy Shortage Contingency Plan* (Staff Report, March 1993), the CEC elucidates its philosophy as follows:

> The plan uses a free market approach with government intervention only to the extent necessary to protect the interests of public health, safety and welfare. Activation of the management and information system and the implementation of the specific programs described in this plan occur only when an energy shortage substantially disrupts California's economy and normal operation.
>
> During the early stages of a shortage, the primary role of state government is monitoring and information exchange, rather than direct intervention in industry efforts to restore services and satisfy customer requirements.

This contrasts markedly with the philosophies that were common around the world in the immediate post-oil shock periods. Most analysts today dismiss the issue of supply security. It is generally believed that energy, including oil, will be available if importers are willing to pay the price. The apparent physical shortages of 1973 and 1979 are now widely perceived as a result of mismanagement of the situation on the part of authorities. These contentions may overstate the case, but the recent Gulf operations made it clear that intelligent and calm management by state and federal authorities can avert the stockpiling and hoarding that are now generally perceived as the cause of local supply shortages during previous oil crises. In any case, the obvious remedies to supply security problems are stockpiling, conservation, and fuel-substitution measures. Aggressive conservation and fuel-substitution measures can cut substantial amounts from many segments of the petroleum barrel; only the jet fuel and international transport segments of the barrel remain relatively immune from such efforts. If physical availability is a major concern, then stockpiling of jet fuel would appear to be the only answer; this remains Hawaii's key vulnerability, and there are no ready answers to this problem.

Are non-oil sources secure? Supply security almost always stresses the matter of oil availability; it is usually taken for granted that any other required energy imports will be available. This is quite likely true with coal, where producible resources are always likely to exceed the demands of the export market; but experience shows that this may not be the case with natural gas, where shortages and surpluses have occurred on the mainland in the past two decades. In this regard, LNG—the likely import source of gas for Hawaii—deserves careful consideration. It is generally believed that LNG suppliers will be less likely to cut off supplies than oil suppliers; an LNG marketing scheme has a tremendous amount of capital and time invested in its market outlets, and there are no other ready customers. The risk of *inadvertent* disruption should not be neglected, however. The supplying plant might be destroyed or crippled by accident, war, or sabotage. A revolutionary government might interdict supplies without regard to economic consequences. Loss of a single cargo by accident at sea could leave the state dangerously short of supply. Hurricane damage to the receiving terminal could result in problems that would take far longer to repair (and have less interim options for landing cargos) than equivalent damage to oil-receiving terminals.

LNG trade may be less likely to be disrupted, but the consequences of disruption could be far more disastrous, especially when the minimum likely scale of LNG facilities is taken into account. To be economic, it is probable that an LNG facility in Hawaii would have to be of a size that would provide a significant fraction of total state energy demand. The obvious consequence is that a single accident along the supply chain could put a significant share of the state's total energy supply at risk. As the Director of the East-West Center's Program on Resources is fond of saying, "Buying oil is like dating; buying LNG is like a marriage." If Hawaii is to enter into a marriage with an LNG supplier, a great deal of research would be needed to find the proper spouse and the proper pre-nuptial agreements.

Generally speaking, most of the advocates of alternative fuels are looking toward local production of fuels such as methanol and ethanol. These quite clearly are more stable on the basis of supply security. In California, however, when there was a program to mandate large-scale conversion of the automobile fleet to methanol, the bulk of the supply was anticipated to come from imports. If alternative fuels are not locally produced, there are serious questions as to whether they are any more secure in supply terms than oil. Indeed, since the international ethanol and methanol markets are "thin" compared to oil, the risk of disruption may even be greater for such fuels. Alternative fuels should only be viewed as clear enhancements of supply security when they are produced within the state.

C. Price Security

Price security means an ability to cushion against upward price fluctuations. Once again, it is oil that is the focal point; gas and coal contracts are typically prone to less extremes in movement (though it is possible to write a supply contract for gas or coal that has all the disadvantages of the oil market in terms of price exposure). There are essentially three schemes for price stabilization: 1) Stockpiling of either crude, products, or both; 2) Price stabilization funds; and, 3) Futures trading.

The role of stockpiling at the international scale, such as the U.S. Strategic Petroleum Reserve (SPR) is fairly clear. Although initially justified on the basis of supply security, the SPR has only been used as a tool of price security; by dumping oil onto a tightening international market, it is possible to soften prices, and even reverse price trends. For smaller stockpilers, at the scale that might be seen in Hawaii, exactly how stockpiles would be deployed to cushion price increases presents some rather thorny issues. A Hawaiian stockpile would not be large enough to affect the course of the international market; the obvious hope would be to contain local prices. This would have to, in one form or another, involve some kind of direct or indirect price controls for the period of stock drawdown. What needs to be avoided at all cost is stockpiled oil entering the supply system at the cushioned cost and then being exported from the state to capture the difference between the external market price and the subsidized price. (An alternative, of course, would be to sell the stockpiled oil at market prices, reacquire new stocks when the market settles down, and contribute the resulting profits to taxpayers or those hurt by the oil price increases.) In any case, it is clear that the regulatory role of the state would have to be greatly extended in some fashion if a stockpile was to be of benefit to the people of Hawaii; without some controls, most of the benefits would be likely to seep out of the state.

Price stabilization has been attempted in many countries over the last two decades, and has now been generally abandoned. Price stabilization is much like Keynesian taxation; a target price needs to be selected. When prices are below the target, the prices are taxed up to the target; when prices are above the target, the funds collected from taxation are used to subsidize the prices back down to the target. Stabilization funds are simple and elegant in principle, but an administrative nightmare in practice. To begin with, only an omniscient being can pick a workable target price. Pick a price too high, and businesses and consumers in the domestic economy pay massively more for oil than their counterparts elsewhere (the reason that such controls were gradually abandoned in South Korea and Japan in the late 1980s). Pick a target price too low, and the government will have to engage in high levels of deficit spending to subsidize prices down to the target. Above all, such stabilization requires a regulatory apparatus of immense size and high levels of analytical skills, *and* full control over the market, including prices, imports, exports, and facility expansion. In short, it requires that oil companies be treated like public utilities, with guaranteed rates of return and highly interventionist regulation.

The third means of stabilization—the futures market—is used primarily by private companies to hedge against unexpected price changes, though there is no intrinsic reason why governments cannot buy and sell "paper barrels" as an alternative to holding stocks or regulating prices. Such a means of price stabilization might be cheaper than operation of a stockpiling system; this is certainly a matter that warrants further study. What a futures market cannot accomplish is the provision of physical supply; actual deliveries of "wet barrels" are subject to *force majeure*. Nonetheless, if price security is a prime consideration in state energy policy, the potentials of the futures market deserve close examination.

It should be noted that supply security and price security measures can often be in active conflict with one another. An important example is the encouragement of use of non-petroleum fuels by provision of a floor price plus a linkage to oil price increases. While such contracts may act to expand the supply of non-oil energy, and thereby help ensure supply security, they obviously expose the economy to continued fluctuations in oil prices that reverberate through the non-oil energy sources. Indeed, it is easy to imagine a situation where sufficient price security measures have been applied to stabilize local oil prices, but enough oil-linked contracts have been signed that it is coal, gas, and ethanol prices that are shooting up in line with movements in world market prices! (There are other ways, of course, of linking non-oil energy prices to oil that are less volatile, or not volatile at all; the AES Barbers Point coal plant contract is an example of a contract that takes the likely future price of oil into account, but does not follow the course of actual prices.)

D. Economic Security

Finally, there is the issue of economic security. This is an important issue for Hawaii, since oil-price shocks have typically been bad for the state economy. Unfortunately, it is not at all clear that there are any effective measures that can be taken to shield the Hawaii economy from the economic effects of price increases. Even if oil prices remain stable within the state, it is not clear that this is any great advantage beyond the obvious benefits to local consumers. The state does not have major, energy-intensive export industries that could benefit from competitive fuel-cost advantages. The main exposure that the economy seems to experience is from changes in tourism. Conventional wisdom has it that the tourists stay home during recessions and international disruptions, and those that do arrive are prone to spend less. It is unlikely that low energy prices will do much to lure in more tourists; would a tourist come to Hawaii in the midst of an oil price shock simply because we had cheap gasoline? Although we claim no expertise in this area, the contention that it is external factors that result in the decision to stay home seems reasonable. In this case, the only way to "shield" the Hawaiian economy from the economic effects of energy price increases may be to change the nature of the Hawaiian economy itself by moving away from such high levels of dependence on tourism—a policy which has often been advocated, but which goes far beyond the issue of energy policy.

In conclusion, comprehensive energy security may be unobtainable. In particular, economic energy security may be inconsistent with the basic nature of the Hawaiian economy. There may be trade-offs between some supply security and price security measures, although there is no intrinsic reason that the two cannot be made to work together. The differences between these two types of security measures needs to be made an explicit part of the energy planning process. Ideally, the deployment of non-oil fossil fuels or alternative energy sources should enhance both supply security and price stability. It is, unfortunately, possible to deploy alternatives that are both unstable and usuriously expensive as well, but such strategies are unlikely to find favor with the Hawaii Energy Strategy project teams and the state as a whole.

E. Conclusion: Is Oil Too Cheap?

Throughout this *Fossil Energy Review*, we have stated that oil is cheap, in both absolute and real terms. It is also an extremely convenient energy source. These attributes have fostered dependence, and dependence has fostered alarm. Since oil is so cheap, there are two ways to make alternatives cost-competitive: reduce the cost of the alternative (through technological breakthroughs or subsidization, for example) or raise the price of oil (through taxation, for example). At this point, many alternative energy proponents would raise the issue of externalities, setting forth different rationales and calculations to show us the "true" cost of oil. There is a significant constituency that is convinced that oil is already much more expensive than alternatives and renewables. We believe that many of the arguments for externalities pricing are valid, but for the sake of simple analytical rigor, we do not in the course of our research merely assume a higher oil price and announce, *Voilà!*, that alternatives and renewables are now cost-competitive. The price of oil is set internationally and will not rise to all consumers merely because externalities pricing is adopted in Hawaii, or the United States as a whole, or even the International Energy Agency (IEA) countries taken collectively. There is nothing to stop these political entities from paying more for oil—nothing, that is, outside of their citizenry. But their efforts to reduce oil consumption will not cause global oil prices to increase to their idea of the "true cost." It is far more likely that their efforts at conserving oil will exert *downward* pressure on international oil prices, making energy cheaper to other countries and possibly putting their own countries at a competitive disadvantage in the world economy.

Externalities include the environmental degradation and risk associated with exploration, development, transport, and consumption. The externalities may also include the costs of military force deployments, exercises, or combat operations in oil-bearing areas or strategic sea lanes of communication. The arguments for including some sort of externalities in the price of oil are very persuasive; many cite Garrett Hardin's famous "Tragedy of the Commons"[14] essay, which makes the case that a common good—a field for grazing cattle in Hardin's example—will soon be destroyed or completely consumed as individuals each pursue their own personal gain. No one assumes stewardship for the common resource, no one manages what should be a renewable resource for the public good, and thus it is destroyed.

Perhaps we are closer to acknowledging that the environment should be viewed as a public good, and that polluters will pollute if they reap a disproportional share of the benefits and pay little of the costs. But the arguments over even calculating—much less assessing payment for—exter nalities continue. Hardin's essay appeared in *Scientific American* in 1968, and it was used extensively in environmental studies classes during the 1970s and 1980s, yet his recommendations have not become the order of the day. "The Tragedy of the Commons" may be viewed as a classic; it is cited over and over again. Yet many people

[14]Garrett Hardin, "The Tragedy of the Commons," *Scientific American*, December 1968, pp. 1243-1248.

cite it incorrectly and do not do full justice to the broad implications of Hardin's message. Hardin notes that the commons can only survive under conditions of low population density, and that "As the human population has increased, the commons has had to be abandoned in one aspect after another" (Hardin, 1968, p. 1248). This sounds the rallying cry for those who believe that the government should simply pass more laws. Examine Hardin's essay more closely and consider the themes explored: "What Shall We Maximize?"; "Tragedy of Freedom in a Commons"; "Pollution"; "How to Legislate Temperance?"; "Freedom to Breed is Intolerable"; "Conscience is Self-Eliminating"; "Pathogenic Effects of Conscience"; "Mutual Coercion Mutually Agreed Upon"; and "Recognition of Necessity." A key conclusion is that individuals must sacrifice some degree of personal freedom; they must subsume their individual goals for the betterment of the collective. This is a key that most individuals overlook when they cite Garrett Hardin. At the heart of it, people do not want to give up their personal freedom, especially when they suspect that many—if not most—of their compatriots will not be giving up theirs. Americans generally want less regulation, not more; they want more freedom, not less; they want lower taxes and prices, not higher. They do not trust the government to solve their problems, and they do not want to entrust the government with more tax revenues unless they are convinced that those revenues will be spent wisely to deal with the problems of the day. And how many people can be convinced of such a thing?

Survey after survey shows that most Americans like to think of themselves as environmentalists or at least as environmentally sensitive. Let us accept for the moment the assertion that the majority of the population is environmentally oriented. Now consider the situation in which our country is mired: most families still own and drive automobiles, many of which are not economy cars, many of which are older-style "gas guzzlers." Many commute long distances and resist mass transit, carpooling, or other alternative transport modes because they are inconvenient, time-consuming, and perhaps dangerous in many metropolitan areas. Many have jobs in polluting industries. Most people live and work in electrified buildings, many of which require heating in the winter, cooling in the summer.

Thousands each day fly aboard jet planes. All rely on goods that are flown, shipped, or trucked. Few people recycle solid waste on a steady basis. Most are drawn to merchandise which is thoroughly and cunningly packaged. Most want a large selection of goods and services at low prices. In short, consumerism is way ahead of environmentalism, and not many people wish to acknowledge that in many ways, consumerism and environmentalism are fundamentally at odds with one another.

Debates over externalities pricing are widespread, while concrete action is rare. Many who cite Hardin's essay do so rather blithely, without going the additional step of expounding upon what must and can be done. Even the most devoted libertarian can agree that governments exist for a purpose, namely, to attend to matters such as national defense that are beyond the capability of the individual. All other functions may be viewed as extraneous at best, a huge waste of taxpayer's money or a violation of individual liberty at worst. If the environment is viewed as a public good, government's role and responsibilities expand enormously, since virtually all large-scale human activities have environmental impacts. Who ultimately decides on appropriate levels of payment for externalities? Who decides how and by whom payments should be made? Who collects the payments and oversees their disposition? The government does. Individual citizens happily assume that only businesses and industries would have to change their ways, but no one who pollutes or benefits from polluting behavior (for example, by receiving cheaper goods produced by a polluting company) should escape payment. Governments would then have a great deal more power over the activities of individuals, and individuals would pay more for goods and services without necessarily seeing *any* improvement in the environment. The simple truth is that no one wants to pay more, despite loud assertions to the contrary, and the sacrifice of many individual liberties is almost "un-American." Individuals do not want governments to mandate certain behaviors and outlaw others, and they do not trust governments to use tax revenues wisely. Consider the recent example of President Clinton's proposed Btu tax, a revenue-raiser that ostensibly had the added attraction of promoting conservation and efficiency, yet was attacked by one special interest group after another. Many people viewed the tax as inequitable, poorly-conceived, and insufficient to deal with our energy problems (which, of course, it was not intended to do anyway). On a larger scale, countries do not trust neighboring governments or international entities, therefore they do not sacrifice national sovereignty and pay to clean up the global environment.

That we do not pay the full price of pollution seems clear; it is also clear that some devotees of externalities pricing sometimes go too far in their assessments. For example, are we to believe that the full cost of military exercises, preparedness, and action in the Middle East should be factored into the price of oil? Many people would like to argue that oil is the only reason for the U.S. presence in the Middle East, so all costs associated with this presence should show up in the price of oil. Others argue—far more convincingly, in our opinion—that the development and maintenance of armed forces came about as a result of centuries of human aggression, individual upon individual, tribe upon tribe, society upon society. There are always land to grab, resources to steal, people to persecute, faith to argue about. If oil disappeared tomorrow, human nature would remain the same. The problem is, there are more of us now. We are reminded of a modern-day theorem: "The amount of intelligence on Earth is constant." The bad news is: the population is increasing.