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Hawaii Energy Strategy Project 2:
Fossil Energy Review

TASK IV

**SCENARIO DEVELOPMENT
AND ANALYSIS**

Prepared for

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

by

**The East-West Center
Program on Resources: Energy and Minerals**

December 1993

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Hawaii Energy Strategy Project 2: Fossil Energy Review

TASK IV SCENARIO DEVELOPMENT AND ANALYSIS

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Hawaii Energy Strategy Project 2, Fossil Energy Review

Task IV. Scenario Development and Analysis

Principal Investigator:
Nancy D. Yamaguchi

Co-Author:
David T. Isaak

Senior Editor:
Kennon Breazeale

Secretarial/Technical Support:
Sandra Dela Cruz
Suhaesih Rahmasari

December 1993

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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
mnt	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

I. Introduction

A. Overview of HES Project 2, Tasks I-III

The Hawaii Energy Strategy (HES) Program is a seven-project effort led by the State of Hawaii Department of Business, Economic Development & Tourism (DBEDT) to investigate a wide spectrum of Hawaii energy issues.¹ The East-West Center's Program on Resources: Energy and Minerals, has been assigned HES Project 2, *Fossil Energy Review*, which focuses on fossil energy use in Hawaii and the greater regional and global markets.

HES Project 2 has four parts: Task I (*World and Regional Fossil Energy Dynamics*) covers petroleum, natural gas, and coal in global and regional contexts, along with a discussion of energy and the environment. Task II (*Fossil Energy in Hawaii*) focuses more closely on fossil energy use in Hawaii: current utilization and trends, the structure of imports, possible future sources of supply, fuel substitutability, and energy security. Task III's emphasis is *Greenfield Options*; that is, fossil energy sources not yet used in Hawaii. This task is divided into two sections: first, an in-depth "Assessment of Coal Technology Options and Implications for the State of Hawaii," along with a spreadsheet analysis model, which was subcontracted to the Environmental Assessment and Information Sciences Division of Argonne National Laboratory; and second, a chapter on liquefied natural gas (LNG) in the Asia-Pacific market and the issues surrounding possible introduction of LNG into the Hawaii market

¹ For a complete description, see DBEDT's *Hawaii Energy Strategy Program Guide*, September 1992, revised March 1993.

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B. Focus and Purpose of HES Project 2, Task IV

Task IV is the final task of HES Project 2. The exact area of inquiry was left open-ended until the completion of Task II (*Fossil Energy in Hawaii*), and the Seminar on Fossil Energy in Hawaii, which was held at the East-West Center in May of 1993. Following this work, and internal review of Task I and Task II draft reports by DBEDT and the HES Technical Review Subcommittee of the Energy Policy Advisory Committee, discussions were held with DBEDT concerning possible directions for Task IV. DBEDT decided that Task IV should develop and analyze three scenarios of future petroleum use in Hawaii. These scenarios are discussed in greater detail in the body of this report, but are summarized as follows:

The first scenario is a Base Case, where the assumption is that oil will remain the "path of least resistance." In general, this implies a continuation of Hawaii's current demand pattern, where oil is used to meet most of Hawaii's energy requirements. This scenario, however, does take into account the types of diversification and conservation/efficiency improvements already in the system or firmly planned for the future, such as demand-side management (DSM) programs in the utility sector.

The second scenario is a Fuel Diversification scenario, which assumes that all new major electric generating capacity on Oahu is coal-fired (with the exception of certain near-term expansions of oil use, including repowering of existing units) and that 25 percent of gasoline consumption by the year 2010 will be replaced with alternative fuels and electric vehicles.

The third scenario was left to the discretion of the EWC team to design and analyze. After the initial analysis, however, it was decided to use this opportunity to test three additional scenarios: the first scenario, EWC-1, Fuel Diversification/Refinery Expansion, was designed to expand the analysis of Scenario 2, Fuel Diversification, by testing the economic attractiveness of expanding refinery capacity, given the fuel diversification demand patterns. A second scenario, EWC-2, Aggressive Substitution, was designed to investigate the impacts of an aggressive fuel substitution strategy, which

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essentially took the fuel diversification scenario several steps further by factoring in a rapid market penetration rate for alternative fuel vehicles (including buses). This scenario, unlike the first EWC scenario, required a separate demand forecast. The third scenario, EWC-3, Aggressive Substitution/Refinery Expansion, paralleled EWC-1 by investigating refinery expansion possibilities under the demand assumptions of the aggressive substitution scenario. Therefore, there are five scenarios analyzed, but only three different patterns of demand: base case, fuel diversification, and aggressive substitution. These will be referred to as Scenarios 1, 2, and 4. Scenario 3 takes the same demand pattern as Scenario 2, but factors in the possibility of refinery expansion. Scenario 5 adopts the same demand forecast as Scenario 4, but also adds the ability to expand refinery capacity.

Once the general direction of the main scenarios was set, the next step was to create forecasts of oil product demand and price that would be consistent with each scenario. In other words, each scenario had to be quantified so that the assumptions inherent in each were clear. Task IV involved a series of forecasting exercises: petroleum product demand, petroleum product prices, crude oil prices and availabilities by type, and crude and product transport costs, all for five-year intervals beginning in 1994 and extending to 2014. In order to fully analyze the implications of the three different future courses of demand, the EWC team developed a linear program (LP) model to simulate the crude purchase decision, refinery behavior, product trade, and relative costs. This LP model is named HAWMOD, the Hawaiian Refining Model and is described more fully in the sections following.

C. Integration of Data with Other HES Projects

One important priority at the outset of the forecasting exercises was to ensure some degree of consistency with other HES projects. Most notably, we coordinated our work with the HES Project 5, Transportation Energy Strategy, consultant team led by Parsons Brinckerhoff Quade & Douglas, along with their subcontractors, Acurex

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Environmental Corporation and the Hawaii Natural Energy Institute. HES Project 5 had produced in June of 1993 a draft volume dealing with transportation fuel consumption in Hawaii, which was based on Act 65 data. Their forecasts extrapolated to 2014 the observed trends from 1980 to 1990, as reported in Act 65 forms. As noted elsewhere in this report, however, the Act 65 data has not proven particularly reliable or complete. Additionally, extrapolation of trends from 1990 as a base year yielded forecasts of future demand which seemed too high, particularly given the downturn in demand from 1990 to the present time. In the demand forecasts presented in this volume, we adopt HES Project 5 forecasts of marine fuel consumption, but produce our own forecasts of gasoline and automotive diesel demand, as well as a revised forecast of jet fuel demand.

In the aggressive substitution scenarios, however, we adopt the gasoline and automotive diesel substitution scenarios developed by HES Project 5. Here, we take as given the HES Project 5-defined volumes of gasoline and diesel supplanted by alternative fuels, and subtract these from our base case demand forecast over the 1994-2014 time horizon. The LPG consumption forecasts are derived from Gasco's forecast.

On the electric power fuel side, we relied where possible on utility Integrated Resource Plan (IRP) projections for information on possible utility oil use in the future.² The utility oil use projections adopted in the demand forecast used here were produced using the ELFIN Model, which is owned and operated by the Environmental Defense Fund.³

All of these demand forecasts incorporate the reduction of petroleum demand accomplished by the use of biomass/cogeneration, the Oahu H-Power municipal solid waste plant, the AES Barbers Point coal plant, the Puna Geothermal Venture, windpower, and other renewables. In addition, demand is reduced by utility demand-side

² For readers interested in Hawaii's electric utility plans, integrated resource plans (IRPs) are available directly from the utilities.

³ Elfin Model V 1.98 3/7 SN0563, developed and owned by the Environmental Defense Fund. Scenario design and ELFIN Model runs were conducted by Carl Freedman.

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management (DSM) strategies. These types of supply-side resources are taken as a given, and they are noted here only with reference to their role in reducing oil demand; the variables of importance in this Task IV report are oil uses, and the forecasts developed and analyzed focus solely on oil. We emphasize this point at the outset because a great deal of public interest naturally focuses on alternative and renewable energy sources, demand-side management, and the electric utility IRPs. Large volumes of information on these topics will be available when HES Project 3, Renewable Energy Resource Assessment and Development Program, and HES Project 4, Demand-Side Management (DSM) Assessment, are completed. Also, as noted, the IRPs developed by the local utilities are public documents and are available for public review. This report, Task IV of HES Project 2, does not explicitly comment on, review, or summarize other reports on alternatives, renewables, or the power sector. The variables of concern in this task relate to oil.

The EWC forecasts developed for this project may be adopted in whole, in part, or not at all by other HES projects as they and DBEDT see fit. The EWC forecasts are not official State of Hawaii forecasts. The state, upon completion of the HES Program and the Integration exercises, may adopt official forecasts and scenarios, and these may differ significantly from the views presented herein. Forecasting is a difficult affair. As movie mogul Samuel Goldwyn advised: "Never prophesy, especially about the future." The HES Projects do not have the luxury of accepting this piece of advice, unfortunately, so our forecasts appear within. They are necessary operating assumptions, without which there can be no meaningful discussion of future directions and policy options. For the purposes of this analysis, the *absolute* numbers shown in the forecasts generally are not as important as the *relative* differences from scenario to scenario. These differences—with respect to refinery operations and production of petroleum products, oil imports and exports, optimal refinery expansion, and relative income—are discussed more fully in chapters IV and V of this report.

II. Methodology and HAWMOD Model Development

A. Petroleum Product Demand Forecasts and Future Scenarios

Three sets of petroleum product demand forecasts were developed for this project. All of these forecasts, as noted above, incorporate the reduction of petroleum demand accomplished through the use of biomass/cogeneration, the Oahu H-Power municipal solid waste plant, the AES Barbers Point coal plant, the Puna Geothermal Venture, windpower, and other renewables. In addition, demand is reduced by utility demand-side management (DSM) strategies.

The three petroleum demand forecasts have been used for analysis in the following five scenarios:

Scenario 1, Base Case. This scenario is based on Hawaii's current pattern of demand, where oil is used for approximately 92 percent of Hawaii's energy needs. The transportation energy demand forecast assumes a vehicle mix similar to today's. In the electric power sector, the Hawaiian Electric Company's (HECO) REP-35 plan alternative developed for the Integrated Resource Planning (IRP) effort, mandated by the Public Utilities Commission (PUC), is used as a basis for calculating future oil use in the power sector. This is not HECO's preferred plan. All new generation is oil-fired, consistent with past patterns, thus it serves as a base case. On the neighbor islands, oil also remains the key fuel in the power sector.

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The key assumptions in the HECO REP-35 IRP Plan Alternative are as follows:

<u>Year</u>	<u>Generation Unit Additions</u>
2000	82 MW Dual Train Combined Cycle (Phase I)
2005	82 MW Dual Train Combined Cycle (Phase II) 82 MW Dual Train Combined Cycle (Phase III)
2007	150 MW Repower Waiau Unit 3
2009	150 MW Repower Waiau Unit 4
2011	82 MW Simple Cycle Combustion Turbine
2012	120 MW Single Train Combined Cycle (Phases I and II)
Note: Plan includes 159 MW of DSM.	

Scenario 2, Fuel Diversification Plan. This plan looks at ways to diversify fuel use in Hawaii. Assumptions are as follows:

- In the ground transport sector, by the year 2010, conventional gasoline is displaced 10 percent by alcohol fuels/blends, 5 percent by propane, and 10 percent by electric vehicles. Electric vehicles will be recharged at off-peak hours, and therefore will not create any need for additional electrical generating capacity. No major changes are expected in the air and marine transport sectors.
- In the electrical power sector, the forecast uses HECO's preferred IRP plan, REP-1, as a basis for calculating future oil use. While this plan includes additional oil-fired power plants in the near term (two additional oil-fired units are added on Oahu, and two existing oil-fired units are repowered) most of its new generating capacity is provided by coal-fired power plants. This would triple the use of coal in the power sector by 2012. The plan is outlined below. The use of the HECO IRP plan in this scenario does not constitute an endorsement of the plan by the State of Hawaii; it is used as a basis for examining the impacts of the level of utility fuel diversification supported by Oahu's electric utility.

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<u>Year</u>	<u>Generation Unit Additions</u>
2000	82 MW Simple Cycle Combustion Turbine
2005	194 MW Fluidized Bed Combustion Coal
2008	150 MW Repower Waiau Unit 3
2009	150 MW Repower Waiau Unit 4
2012	194 Fluidized Bed Combustion Coal

Note: Plan includes 159 MW of DSM.

Scenarios 3, 4, and 5, East-West Center Scenarios. The following three scenarios were designed to supplement the base case and fuel diversification scenario analysis:

- **Scenario 3, Fuel Diversification/Refinery Expansion.** This scenario was developed to take Scenario 2 a step further by examining the possibility of adding refinery capacity, as deemed optimal in the HAWMOD linear program model runs. It is axiomatic that drastically changing Hawaii's patterns and levels of oil product demand will have an impact on the local refining industry. It is possible that fuel diversification (and aggressive substitution) strategies will reduce refinery profitability. HAWMOD is designed to investigate this issue. But an additional, vital question is, can restructuring or expanding the refineries improve future refinery economics, perhaps changing an unprofitable situation into a profitable one? In this scenario, new process vectors were added to HAWMOD that gave the model a choice of whether, and when, to build additional refinery capacity. Since the model operates in a cost-minimization/profit maximization mode, HAWMOD will choose only the most economically rational types of expansion; that is, the model will select only those types of construction projects that maximize profits. A variety of "construction" options were made available to HAWMOD in this scenario at an amortized capital charge rate per barrel processed (as detailed in Chapter IV, Scenario Results). The construction options

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included crude distillation capacity, vacuum distillation capacity, catalytic reforming, catalytic cracking, hydrocracking, visbreaking, and hydrogen manufacturing.

- **Scenario 4, Aggressive Substitution.** This scenario investigates the effects of more aggressive fuel substitution in the transport sector. The power sector fuel diversification plan in Scenario 2 was retained, but the forecast for Scenario 3 also adopts HES Project 5/Acurex Environmental's calculations of alternative fuel vehicle potential. Since this scenario was intended to assess the impacts of aggressive fuel substitution, it adopts the most aggressive levels quantified by HES Project 5, namely, that alternative-fuel vehicles are rapidly phased into the rental fleet and are retained fully year after year, that heavy-duty buses are also converted to alternative fuels, and that gasohol and diesohol begin to supplant traditional gasoline and diesel. The assumptions used in this scenario may set an upper bound for fuel substitution in Hawaii over the next twenty years.

- **Scenario 5, Aggressive Substitution/Refinery Expansion.** This scenario expands the analysis of Scenario 4, Aggressive Substitution, by the addition of model vectors allowing construction of new refinery capacity. The Scenario 4/Scenario 5 relationship therefore parallels the Scenario 2/Scenario 3 relationship. The refinery expansion options were identical to those delineated in Scenario 3, and are detailed further in Chapter IV, Scenario Analysis.

The Scenario 1, Base Case, petroleum product demand forecast appears in Table 1 and Figure 1. As noted, the forecast incorporates the marine fuel forecast developed by HES Project 5, and the utility fuel use implications of REP-35, the oil-based plan. These fuel use projections were produced using the ELFIN Model, which is owned and operated by the Environmental Defense Fund. The use of ground transport fuels was

Table 1. Hawaii Petroleum Product Demand: Scenario 1, Base Case, 1992-2014*(thousand barrels/day)*

	1992	1994	1999	2004	2009	2014	AAGR 1994-2014	AAGR 94-99	AAGR 99-04	AAGR 04-09	AAGR 09-14
LPG	4.22	4.37	4.88	5.32	5.78	6.20	1.77%	2.23%	1.65%	1.65%	1.43%
Naphtha	2.72	2.72	2.72	2.72	2.72	2.72					
Regular Mogas	15.96	16.66	18.55	19.63	21.02	22.38	1.49%	2.17%	1.38%	1.38%	1.26%
Premium Mogas	8.98	9.17	9.26	9.67	10.35	11.02	0.93%	0.20%	1.38%	1.38%	1.26%
Kerojet	48.00	49.65	53.02	56.33	60.32	64.21	1.29%	1.32%	1.38%	1.38%	1.26%
Diesel	5.09	5.25	5.61	5.96	6.38	6.79	1.29%	1.32%	1.38%	1.38%	1.26%
Industrial Diesel	11.53	11.92	12.75	13.72	14.48	15.54	1.33%	1.36%	1.08%	1.08%	1.43%
HSFO	7.03	7.14	8.04	9.36	10.62	12.05	2.65%	2.40%	2.56%	2.56%	2.56%
MSFO	7.54	7.34	7.39	7.41	7.41	7.41	0.05%	0.14%			
LSFO	30.91	36.03	37.17	37.60	38.21	39.65	0.48%	0.62%	0.32%	0.32%	0.74%
Other	2.20	2.20	2.20	2.20	2.20	2.20					
TOTAL	144.17	152.44	161.58	169.92	179.50	190.19	1.11%	1.17%	1.10%	1.10%	1.16%

Composition of Demand Barrel (% share)

	1992	1994	1999	2004	2009	2014	% change 1994-2014
LPG	2.9%	2.9%	3.0%	3.1%	3.2%	3.3%	41.90%
Naphtha	1.9%	1.8%	1.7%	1.6%	1.5%	1.4%	
Regular Mogas	11.1%	10.9%	11.5%	11.6%	11.7%	11.8%	34.36%
Premium Mogas	6.2%	6.0%	5.7%	5.7%	5.8%	5.8%	20.24%
Kerojet	33.3%	32.6%	32.8%	33.1%	33.6%	33.8%	29.35%
Diesel	3.5%	3.4%	3.5%	3.5%	3.6%	3.6%	29.35%
Industrial Diesel	8.0%	7.8%	7.9%	8.1%	8.1%	8.2%	30.36%
HSFO	4.9%	4.7%	5.0%	5.5%	5.9%	6.3%	68.88%
MSFO	5.2%	4.8%	4.6%	4.4%	4.1%	3.9%	0.96%
LSFO	21.4%	23.6%	23.0%	22.1%	21.3%	20.8%	10.04%
Other	1.5%	1.4%	1.4%	1.3%	1.2%	1.2%	
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	24.76%

*Developed by the East-West Center Program on Resources, HES Project 2. Marine fuels based on HES Project 5, Subtask 1.1.
Electric fuel use data prepared using the ELFIN Model, developed and owned by the Environmental Defense Fund: V. 1.98 3/7 SN05
Ground Transport fuels based on DBEDT's M-K Series forecast of population*

**Figure 1. Hawaii Petroleum Product Demand:
Scenario 1, Base Case, 1992-2014**

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linked to the state's M-K Series forecast of population. In this scenario, demand grows from a 1992 level of 144.2 thousand barrels per day (mb/d) to 169.9 mb/d in 2004 and 190.2 mb/d in the year 2014, an average growth rate of 1.11 percent per year across the period. Overall, this amounts to an increase of nearly 25 percent in oil demand.

The Scenario 2/Scenario 3 "Fuel Diversification" and "Fuel Diversification/Refinery Expansion" petroleum product demand forecast is provided in Table 2 and Figure 2. This forecast differs from the Base Case in two key ways: it incorporates the fuel use implications of REP-1's increased use of coal-fired generation (once again provided by the ELFIN Model), and it assumes a 25 percent reduction in gasoline use by the year 2010. Since 5 percent of the decline in gasoline use is achieved by increased use of propane, LPG consumption rises commensurately. In this scenario, demand grows from the 1992 level of 144 mb/d to 174.9 mb/d in 2004 and 171 mb/d in the year 2014, an average growth rate of 0.57 percent per year across the period. In total, this amounts to an increase of around 12.1 percent in oil demand during the next twenty years. Significantly, however, the final 5-year period from 2009 to 2014 shows a decline in oil demand of nearly 0.5 percent per year.

The Scenario 4/Scenario 5 "Aggressive Substitution" and "Aggressive Substitution/Refinery Expansion" demand forecast is presented in Table 3 and Figure 3. This forecast is based on the same utility fuel use projections as in the Fuel Diversification scenario, but it goes much further toward oil displacement by assuming aggressive purchasing and retention of alternatively fueled vehicles, a scenario quantified by Acurex Environmental Corporation as part of HES Project 5. The imputed fuel savings derived from Acurex's work appear as Table 4. The Acurex hierarchy focuses first on alternatively fueled rental fleets, then heavy duty buses, then gasohol, and finally diesohol. Under the most aggressive scenario, it should be possible to back nearly 11 mb/d of gasoline out of the market by 2014, as well as 3 mb/d of automotive diesel (the grade used by cars, trucks, and buses, as compared to industrial and marine diesels). In this scenario, demand growth is greatly moderated, with demand reaching around 160.7

**Figure 2. Hawaii Petroleum Product Demand:
Scenarios 2 and 3, Fuel Diversification, 1992-2014**

Table 2. Hawaii Petroleum Product Demand: Scenarios 2 and 3, Fuel Diversification, 1992-2014
(thousand barrels/day)

	1992	1994	1999	2004	2009	2014	AAGR 1994-2014	AAGR 94-99	AAGR 99-04	AAGR 04-09	AAGR 09-14
LPG	4.22	4.37	4.88	5.32	5.78	8.48	3.37%	2.23%	1.65%	1.65%	7.97%
Naphtha	2.72	2.72	2.72	2.72	2.72	2.72					
Regular Mogas	15.96	16.66	18.55	19.63	21.02	16.78	0.04%	2.17%	1.38%	1.38%	-4.40%
Premium Mogas	8.98	9.17	9.26	9.67	10.35	8.27	-0.52%	0.20%	1.38%	1.38%	-4.40%
Kerojet	48.00	49.65	53.02	56.33	60.32	64.21	1.29%	1.32%	1.38%	1.38%	1.26%
Diesel	5.09	5.25	5.61	5.96	6.38	6.79	1.29%	1.32%	1.38%	1.38%	1.26%
Industrial Diesel	11.53	11.92	12.78	13.84	14.53	15.57	1.34%	1.40%	0.97%	0.97%	1.40%
HSFO	7.03	7.14	8.04	9.36	10.62	12.05	2.65%	2.40%	2.56%	2.56%	2.56%
MSFO	7.54	7.34	7.39	7.41	7.41	7.41	0.05%	0.14%			
LSFO	30.91	36.03	37.17	37.60	33.55	26.47	-1.53%	0.62%	-2.26%	-2.26%	-4.63%
Other	2.20	2.20	2.20	2.20	2.20	2.20					
TOTAL	144.17	152.44	161.61	170.04	174.88	170.96	0.57%	1.17%	0.56%	0.56%	-0.45%

Composition of Demand Barrel (% share)

	1992	1994	1999	2004	2009	2014	% change 1994-2014
LPG	2.9%	2.9%	3.0%	3.1%	3.3%	5.0%	93.88%
Naphtha	1.9%	1.8%	1.7%	1.6%	1.6%	1.6%	
Regular Mogas	11.1%	10.9%	11.5%	11.5%	12.0%	9.8%	0.77%
Premium Mogas	6.2%	6.0%	5.7%	5.7%	5.9%	4.8%	-9.82%
Kerojet	33.3%	32.6%	32.8%	33.1%	34.5%	37.6%	29.35%
Diesel	3.5%	3.4%	3.5%	3.5%	3.6%	4.0%	29.35%
Industrial Diesel	8.0%	7.8%	7.9%	8.1%	8.3%	9.1%	30.61%
HSFO	4.9%	4.7%	5.0%	5.5%	6.1%	7.1%	68.88%
MSFO	5.2%	4.8%	4.6%	4.4%	4.2%	4.3%	0.96%
LSFO	21.4%	23.6%	23.0%	22.1%	19.2%	15.5%	-26.55%
Other	1.5%	1.4%	1.4%	1.3%	1.3%	1.3%	
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	12.14%

Developed by the East-West Center Program on Resources, HES Project 2. Marine fuels based on HES Project 5, Subtask 1.1.
Electric fuel use data prepared using the ELFIN Model, developed and owned by the Environmental Defense Fund: V. 1.98 3/7 SN0563
Ground Transport fuels based on DBEDT's M-K Series forecast of population

Table 3. Hawaii Petroleum Product Demand: Scenarios 4 and 5, Aggressive Substitution, 1992-2014
(thousand barrels/day)

	1992	1994	1999	2004	2009	2014	AAGR 1994-2014	AAGR 94-99	AAGR 99-04	AAGR 04-09	AAGR 09-14
LPG	4.22	4.37	4.88	5.32	5.78	6.20	1.77%	2.23%	1.65%	1.65%	1.43%
Naphtha	2.72	2.72	2.72	2.72	2.72	2.72					
Regular Mogas	15.96	16.66	16.34	15.13	15.28	15.07	-0.50%	-0.39%	0.20%	0.20%	-0.28%
Premium Mogas	8.98	9.17	8.16	7.45	7.53	7.42	-1.05%	-2.31%	0.20%	0.20%	-0.28%
Kerojet	48.00	49.65	53.02	56.33	60.32	64.21	1.29%	1.32%	1.38%	1.38%	1.26%
Diesel	5.09	5.25	3.35	3.35	3.54	3.75	-1.67%	-8.62%	1.14%	1.14%	1.17%
Industrial Diesel	11.53	11.92	12.78	13.84	14.53	15.57	1.34%	1.40%	0.97%	0.97%	1.40%
HSFO	7.03	7.14	8.04	9.36	10.62	12.05	2.65%	2.40%	2.56%	2.56%	2.56%
MSFO	7.54	7.34	7.39	7.41	7.41	7.41	0.05%	0.14%			
LSFO	30.91	36.03	37.17	37.60	33.55	26.47	-1.53%	0.62%	-2.26%	-2.26%	-4.63%
Other	2.20	2.20	2.20	2.20	2.20	2.20					
TOTAL	144.17	152.44	156.03	160.71	163.47	163.08	0.34%	0.47%	0.34%	0.34%	-0.05%

Composition of Demand Barrel (% share)

	1992	1994	1999	2004	2009	2014	% change 1994-2014
LPG	2.9%	2.9%	3.1%	3.3%	3.5%	3.8%	41.90%
Naphtha	1.9%	1.8%	1.7%	1.7%	1.7%	1.7%	
Regular Mogas	11.1%	10.9%	10.5%	9.4%	9.3%	9.2%	-9.55%
Premium Mogas	6.2%	6.0%	5.2%	4.6%	4.6%	4.6%	-19.05%
Kerojet	33.3%	32.6%	34.0%	35.0%	36.9%	39.4%	29.35%
Diesel	3.5%	3.4%	2.1%	2.1%	2.2%	2.3%	-28.56%
Industrial Diesel	8.0%	7.8%	8.2%	8.6%	8.9%	9.5%	30.61%
HSFO	4.9%	4.7%	5.1%	5.8%	6.5%	7.4%	68.88%
MSFO	5.2%	4.8%	4.7%	4.6%	4.5%	4.5%	0.96%
LSFO	21.4%	23.6%	23.8%	23.4%	20.5%	16.2%	-26.55%
Other	1.5%	1.4%	1.4%	1.4%	1.3%	1.3%	
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	6.98%

Based on EWC Base Case forecast adjusted by Acurex Environmental Corp. transport fuels substitution scenario
Electric fuel use data prepared using the ELFIN Model, developed and owned by the Environmental Defense Fund: V. 1.98 3/7 SN0563
Ground Transport fuels based on DBEDT's M-K Series forecast of population

**Figure 3. Hawaii Petroleum Product Demand:
Scenarios 4 and 5, Aggressive Substitution, 1992-2014**

Table 4. Imputed Fuels Savings from Acurex Substitution Analysis, 1996-2014

ACUREX CUMULATIVES:

	1996	1999	2004	2009	2014
Gasoline rental vehicles	11	140	1,437	2,070	2,981
HD buses	14	162	1,568	2,270	3,286
plus gasohol	1021	1,231	2,582	3,328	4,289
plus diesehol	1777	2,035	3,405	4,165	5,094

INCREMENTS:

	1996	1999	2004	2009	2014
Gasoline rental vehicles	11	140	1,437	2,070	2,981
HD buses	3	22	131	200	305
plus gasohol	1,007	1,069	1,014	1,058	1,003
plus diesehol	756	804	823	837	805

BARRELS/DAY:

	1996	1999	2004	2009	2014
Gasoline rental vehicles	0.0	0.4	3.9	5.7	8.2
HD buses	0.0	0.1	0.4	0.5	0.8
plus gasohol	2.8	2.9	2.8	2.9	2.7
plus diesehol	2.1	2.2	2.3	2.3	2.2

BARRELS/DAY TOTAL:

	1996	1999	2004	2009	2014
Gasoline	2.79	3.31	6.72	8.57	10.92
Diesel	2.08	2.26	2.61	2.84	3.04
TOTAL	4.87	5.58	9.33	11.41	13.96

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mb/d in 2004 and 163.1 mb/d in the year 2014, an average growth rate of just 0.34 percent per year from 1994 to 2014. In total, this amounts to an increase of just under 7 percent in oil demand during the next twenty years.

The three forecasts of demand are juxtaposed in Figure 4, where it can be seen that the aggressive substitution case (Scenarios 4 and 5) achieves a substantial flattening of demand growth, particularly relative to the base case. It is noteworthy, however, that even this rather radical scenario is not sufficient to reduce oil use in absolute terms.

The three approaches have varying implications for the overall structure of demand, as depicted in Figure 5. Since it is assumed that demand for jet fuel grows at the same rate under all scenarios, substituting away from fuel oil and/or ground transport fuels leads to a significant increase in jet fuel's share of the demand barrel. In 1992, jet fuel represented one-third of Hawaii's oil demand. In the fuel diversification scenario, jet fuel's share rises to 37.6 percent by the year 2014. In the aggressive substitution case, the share of jet fuel rises even more rapidly and reaches 39.4 percent by the year 2014. The possible implications of this change will become clearer in the section discussing refinery behavior.

B. Price Forecasts: Petroleum Products, Crude Oil, and Oil Shipping

There are many methods of forecasting crude oil and product prices, based on supply-demand regressions, energy-economy models, nonlinear programming, and various hybrid techniques. In the 1970s and early 1980s, many millions of dollars were spent in attempts to produce a reliable means of forecasting prices. Success was quite limited; in general, the best market-watchers have produced better predictions than the best models, and few companies or governments now rely on models for overall price forecasting.

One of the reasons that models fail so noticeably in this regard is that most are based on some assumption of equilibrium. Economic calculations, like thermodynamic equations, are well-developed for equilibrium conditions, but poorly understood in nonequilibrium states. The problem with the oil market, of course, is that it is seldom

**Figure 4. Hawaii Petroleum Product Demand:
Comparison of Scenarios, 1994-2014**

**Figure 5. Jet Fuel's Share of Hawaii Demand
Barrel Under Three Scenarios, 1992-2014**

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anywhere near economic equilibrium. Political events, government policies, crude oversupply, and the sheer length of time that it takes the world's capital stock to respond to price changes, all conspire to keep the market from settling down.

Although there is still some interest in modeling of oil prices, especially in the academic world, most of those with a practical need to forecast oil prices rely more on judgmental methods than on explicit calculations. Many oil companies either rely on the opinions of "experts" (without inquiring as to the methods of forecasting used), or assemble opinion surveys. This latter approach, often dignified by the name of "Delphi forecasting," is the approach used by many public bodies, including the California Energy Commission (CEC).⁴ The CEC's survey has the twin virtues of covering around two dozen experts from government, academia, industry, consulting groups, and the financial community, and of being published. The CEC crude oil forecast of delivered crude prices has therefore been adopted for this analysis; it differs only slightly from the Middle East crude price forecast used internally at the East-West Center, and from the published projections of various U.S. oil companies (though the latter seldom extend very far into the future).

The CEC product price forecasts,⁵ on the other hand, are less valuable for the present effort. They do not cover the full range of products needed for this analysis; they are oriented strictly to the internal California market, which has differing specifications and onshore costs from the Asia-Pacific market or Hawaii; and the predictions are on wholesale, rather than refinery gate, prices.

Forecasting product prices given the price of crude might seem to be a straightforward matter. After all, the price of crude oil is the single most important determinant of product prices. And, indeed, regressions on the prices of products, such as gasoline, against the price

⁴ California State Energy Commission, "Results of the California Energy Commission Delphi VI Survey of Oil Price Forecasts," *1991 Fuels Report*. Sacramento, California, December 1991. Adjusted to 1993 dollars for HES Project 2 (see appendix).

⁵ California Energy Commission, "SB 1214 Fuel Price Forecasts," Senate Bill 1214 Workshop, April 29, 1993, Sacramento, California.

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of crude oil, invariably yield regressions with very high r^2 (correlation coefficient) values, often in excess of 90 percent. As a simple illustration, consider the pattern shown in Figure 6: the solid line traces the course of kerojet prices from 1979 to 1992, while the dashed line represents a model prediction of kerojet prices based solely on the price of crude. The simple equation:

$$\text{Kerojet Price} = 1.1445 * (\text{Crude Price}) + \$4.6728$$

actually produces a fairly good fit with observed historical data. The adjusted r^2 is 0.88, meaning in general that 88 percent of the kerojet price can be explained by the crude price. Including additional variables (for example, to account for jet fuel price spikes caused by events such as the Gulf War) can produce successively better fits.

Unfortunately, as a generation of price forecasters can testify, there is also an extremely high component of autocorrelation in the result; that is, the observations are not independent. (This fact is common sense; this week's gasoline price tends to be heavily influenced by, or at least correlated with, last week's price.) Attempts to untangle the matter by using Generalized Least Squares or Cochrane-Orcutt iteration still leave much to be desired. Even if a best linear unbiased estimator (*blue*) is determined, examination of the residuals will show errors that, while small relative to the crude price, are huge in terms of refinery profitability or loss, or in terms of trade potentials.

A second approach to product-price forecasting is to work with engineering economics through an iterative (nonlinear) programming methodology. A model of global trade and refining is constructed based on engineering vectors and marine distances. The price of the "swing crude" (the crude meeting the last increment of demand) is set. The LP is solved, and the resulting shadow prices are put into price/demand equations; the resulting demands are fed back to the LP, and the process

Figure 6. Kerojet Prices Predicted From Crude, 1979-1992

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continues to cycle until equilibrium is established. This approach has considerable academic appeal, and has been used with some success (although when it goes awry, it often does so in spectacular fashion). Its drawbacks are the sheer size and complexity of the LP model required (by its nature, it can only be done on a global basis), and the reliance on the price/demand equations. Since these econometric values play just as much role in determining the equilibrium position of prices as the whole engineering LP, the results are extremely sensitive to the accuracy of these equations. Although demand prediction given price is a somewhat better-established art than price prediction itself, the model results are never better than the demand equations, and the LP process in fact can act to amplify inaccuracies in the demand equations.

Yet another alternative is to work with product-crude differentials. These are used routinely, in a qualitative way, in the industry. Gasoline, jet fuel, and diesel are typically well above the crude price; fuel oil and bunker fuel are typically below the crude price; and naphtha has fluctuated wildly, falling as low as the price of fuel oil in some periods, and rising toward the price of gasoline in some others.

There are some generalizations that can be made about crude-product differentials. For example, high crude prices tend to widen differentials, pushing up the price of transport fuels, and pushing down the price of fuel oil. Many exceptions can be found, however, to such a generalization at various points in time. Other factors, such as international crises, strikes, the availability of refining capacity, or accidents in the downstream oil sector, can all act to distort the underlying relationship. A regression of Singapore gasoline-crude differentials against crude prices for the period 1986-92, for example, yields an r^2 of only 17 percent, and the Durbin-Watson test shows that even the differentials are highly autocorrelated. As Figure 7 shows, gasoline-crude differentials fluctuate across a wide range, from a low of \$3.67/b (at the onset of the 1986 oil price collapse), to a high of \$15.10/b (during the Iraqi invasion of Kuwait). The average for the period, of \$7.88/b, is a poor guide to the future. Differentials are a useful way of discussing the emerging pressures in the refined product market, but they are difficult to

**Figure 7. Gasoline-Crude Price Differentials, 1986-92
(Singapore Market)**

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use in forecasting. Typically, they are used judgmentally rather than in modelling; for example, forecasters may pick what they consider to be a "base" value for the differential in the current market (adjusting, of course, for any present distortions), and then, based on a host of considerations, make a guess as to the prevailing differential ten years hence. This differential, added to the crude price, then becomes the product price forecast. The main difficulty in this method is, rather surprisingly, not in estimating the changes in the differential, which can be based on very good—if qualitative—understandings of trends in the market, but rather in finding a good base value for the differential. In effect, the forecaster must decide what the differential "ought" to be in today's market.

Singapore Prices and Gross Product Worth (GPW) Shares

At the East-West Center, we have used all three approaches—regression, nonlinear programming, and differential forecasting—to project product prices. At present, we use what is, in essence, a variation of differential forecasting which we find to be somewhat more stable than differentials. This technique is called the "GPW share" approach, GPW standing for Gross Product Worth. Prices and differentials may vary widely, but each product's share of the total value of a barrel of output varies across a narrower range. Forecasting shares does not eliminate the highly judgmental aspect of forecasting differentials, but it has the virtue of being more stable and of forcing the analyst to consider all products simultaneously—which is essential in an industry where products are jointly produced.

What is meant by a GPW share? The product value is the yield of each product times its price: If the yield of gasoline is 10 percent, and the price of gasoline is \$25/b, then the Product Value is $\$25/b \times 0.10 = \$2.50/b$. The GPW is the sum of all of the Product Values. If the GPW in this case is \$20/b, then gasoline's GPW share = $\$2.50 / \$20 = 12.5$ percent. Note that gasoline's GPW share of 12.5 percent is higher than its

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volume yield of 10 percent; this results because gasoline's price is higher than some of the other products.

Of course, refineries vary widely in their output of products; and crudes vary widely in their yields even in a single refinery. For comparison purposes, such as the refining margins shown in the Task I report, standard yields and standard crudes are typically adopted. The largest export crude, Arab Light, is frequently used as a crude standard; and a hydroskimming refinery (distillation, reforming, and hydrotreating for sulfur removal) is normally used as a refining basis.

The main purpose of such standard calculations is not to analyze the profitability of a given refinery, nor to project the output of the refining sector. Instead, the standard yields of a standard crude can allow the calculation of a GPW and a gross refining margin (defined as GPW - crude costs). This gives an index of how much a crude costs relative to the intrinsic value of its product content. Hydroskimming is typically used as a basis, since it is the simplest refinery configuration that can produce a modern product slate. In any case, it should be kept in mind that GPWs and margins are just indicators; the precise yields used do not really matter, so long as the same yield pattern is always used in the calculations.

Table 5 shows the GPW share of premium motor gasoline (97 RON leaded, which is similar to prices for unleaded regular) in the Singapore market for the period 1986-92, alongside the spot price of "marker crude" (Dubai + \$0.80/b). According to these figures, the gasoline share of GPW averages 9.8 percent of the hydroskimming barrel, with a standard deviation of only 1.0 percent. This means that more than two-thirds of the time, we would expect gasoline's GPW share to be between 8.8 percent and 10.8 percent of the value of output from a barrel of crude. Compare the GPW-share mean-standardized statistics with the similar statistics for crude oil prices: 10.4 percent standard deviation (22.6 percent for crude), 0.1 percent variance (86.6 percent for crude), a range of 45.2 percent (138.5 percent for crude). Thus, while crude prices fluctuated over a range equal to nearly 140 percent of the mean, the GPW share for gasoline was

**Table 5. Premium Gasoline Prices As Share of Gross Product Worth, 1986-92
(Singapore Market)**

	Crude Price (\$/b)	Mogas Share (% of GPW)		Crude Price (\$/b)	Mogas Share (% of GPW)	Statistics	
						Crude	Mogas
86 Jan	\$24.47	8.1%	90 Jan	\$18.25	9.3%	Mean	\$16.97 9.8%
Feb	\$15.51	8.0%	Feb	\$17.60	10.2%	Standard Err.	\$0.42 0.1%
Mar	\$12.37	7.9%	Mar	\$16.60	10.5%	Median	\$16.58 9.7%
Apr	\$11.30	9.2%	Apr	\$15.10	10.6%	Standard Dev	\$3.83 1.0%
May	\$12.20	11.8%	May	\$15.40	10.5%	Variance	\$14.71 0.0%
Jun	\$11.20	11.9%	Jun	\$14.05	11.5%	Range	\$23.50 4.4%
Jul	\$8.85	12.3%	Jul	\$16.10	11.5%	Minimum	\$8.85 7.9%
Aug	\$12.95	11.7%	Aug	\$25.80	10.8%	Maximum	\$32.35 12.3%
Sep	\$13.55	10.7%	Sep	\$31.10	10.8%	Mean + 1 sd	\$20.81 10.8%
Oct	\$13.95	10.6%	Oct	\$32.35	8.8%	Mean - 1 sd	\$13.14 8.8%
Nov	\$14.35	10.7%	Nov	\$28.75	8.6%	Mean-Standardized Statistics	
Dec	\$15.70	10.0%	Dec	\$24.05	8.9%		
87 Jan	\$18.00	9.3%	91 Jan	\$20.20	8.2%	Crude	Mogas
Feb	\$17.50	9.9%	Feb	\$15.25	8.0%	Standard Err.	2.5% 1.1%
Mar	\$17.70	10.1%	Mar	\$15.65	10.2%	Standard Dev	22.6% 10.4%
Apr	\$17.75	9.9%	Apr	\$16.15	11.1%	Variance	86.6% 0.1%
May	\$17.85	9.5%	May	\$16.70	11.2%	Range	138.5% 45.2%
Jun	\$18.05	9.4%	Jun	\$16.20	11.1%	Minimum	52.1% 81.2%
Jul	\$18.55	8.8%	Jul	\$17.05	10.9%	Maximum	190.6% 126.3%
Aug	\$18.10	8.4%	Aug	\$17.45	10.6%	Mean + 1 sd	122.6% 110.4%
Sep	\$17.80	8.7%	Sep	\$18.60	10.3%	Mean - 1 sd	77.4% 89.6%
Oct	\$17.85	8.7%	Oct	\$19.75	9.5%	Histogram	
Nov	\$17.40	8.9%	Nov	\$19.25	9.4%	Bin	Frequency
Dec	\$16.30	9.2%	Dec	\$16.10	10.1%	7.0%	4
88 Jan	\$16.20	9.0%	92 Jan	\$16.00	10.6%	8.0%	16
Feb	\$15.85	9.0%	Feb	\$16.55	10.8%	9.0%	29
Mar	\$14.20	9.3%	Mar	\$16.60	10.4%	10.0%	26
Apr	\$15.75	9.3%	Apr	\$17.50	9.9%	11.0%	8
May	\$15.65	9.5%	May	\$18.40	10.3%	12.0%	1
Jun	\$14.60	9.8%	Jun	\$19.80	10.5%	13.0%	0
Jul	\$13.85	9.7%	Jul	\$19.30	10.3%		
Aug	\$13.95	9.7%	Aug	\$18.60	10.1%		
Sep	\$12.35	10.0%	Sep	\$19.10	9.8%		
Oct	\$11.10	10.6%	Oct	\$19.05	9.5%		
Nov	\$11.40	9.8%	Nov	\$17.95	9.5%		
Dec	\$13.30	9.1%	Dec	\$17.80	9.6%		
89 Jan	\$15.25	8.7%					
Feb	\$15.40	9.5%					
Mar	\$16.75	9.9%					
Apr	\$17.70	9.4%					
May	\$16.45	9.4%					
Jun	\$16.20	10.1%					
Jul	\$16.30	9.2%					
Aug	\$15.80	8.8%					
Sep	\$16.40	8.7%					
Oct	\$16.95	8.1%					
Nov	\$16.95	7.9%					
Dec	\$17.90	7.9%					

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restricted to a range of only 45 percent of its mean value. The distribution of observations of GPW shares for gasoline, while not perfectly gaussian, still give a surprisingly good approximation of a normal curve, as Figure 8 shows.

Tables 6-9 and Figures 9-12 give an overview of the equivalent behavior of the GPW shares of naphtha, jet fuel, diesel, and high-sulfur fuel oil. In all cases, the standardized range is between 41 percent and 49 percent (as opposed to 140 percent for crude oil), and the percentage standard deviation is between 7 percent and 10 percent (as opposed to crude at more than 22 percent). These numbers show more central tendency and more normal distributions than crude prices.

Table 10 summarizes these results, and shows the GPW shares at one standard deviation from the mean, and at their maximum and minimum values. In addition, the assumed hydroskimming yields are given (although it should be kept in mind that the fundamentals of the method would not be altered if a different yield pattern had been assumed). The GPW total is less than 100 percent because about 1.3 percent of the product worth is in the form of refinery gas, propane, butane, and other minor products not shown. The hydroskimming yields total only 96.3 percent of the crude input not only because of the yields of minor products, but also because of fuel use in the refinery. (Totals for the other columns are not conceptually meaningful.)

Two fundamental assumptions must be made to apply the GPW share method to price projections. First, a crude price is needed; in the following we have applied the CEC Delphi forecast, updated to 1993 dollars. Second, a gross refinery margin (margin before accounting for operating costs or capital charges) must be assumed. For the Singapore market, we have assumed strong hydroskimming margins of \$1.36/b in 1994, dropping only slightly to \$1.26/b by the end of the forecast period; this is in line with the vigorous regional growth in oil demand discussed in earlier chapters. Since the gross refining margin is the GPW minus the crude costs, these two assumptions allow us to impute the GPW from $GPW = \text{Crude Cost} + \text{Gross Refining Margin}$.

**Figure 8. Histogram: Premium Leaded Gasoline Share of GPW,
1986-92 (Singapore Market)**

**Figure 6. Naphtha Prices As Share of Gross Product Worth, 1986-92
(Singapore Market)**

			Crude		Naphtha		
			Price		Share		
			(\$/b)		(% of GPW)		
86	Jan	\$24.47	10.0%	90	Jan	\$18.25	10.1%
	Feb	\$15.51	9.2%		Feb	\$17.60	11.0%
	Mar	\$12.37	7.9%		Mar	\$16.60	11.4%
	Apr	\$11.30	9.8%		Apr	\$15.10	11.1%
	May	\$12.20	13.4%		May	\$15.40	10.5%
	Jun	\$11.20	12.8%		Jun	\$14.05	10.8%
	Jul	\$8.85	12.0%		Jul	\$16.10	10.5%
	Aug	\$12.95	12.4%		Aug	\$25.80	11.6%
	Sep	\$13.55	11.5%		Sep	\$31.10	12.2%
	Oct	\$13.95	11.5%		Oct	\$32.35	11.4%
	Nov	\$14.35	11.6%		Nov	\$28.75	10.9%
	Dec	\$15.70	10.8%		Dec	\$24.05	11.2%
87	Jan	\$18.00	10.6%	91	Jan	\$20.20	11.0%
	Feb	\$17.50	11.2%		Feb	\$15.25	10.4%
	Mar	\$17.70	11.7%		Mar	\$15.65	13.0%
	Apr	\$17.75	11.9%		Apr	\$16.15	13.1%
	May	\$17.85	11.5%		May	\$16.70	13.0%
	Jun	\$18.05	11.4%		Jun	\$16.20	12.6%
	Jul	\$18.55	10.8%		Jul	\$17.05	12.4%
	Aug	\$18.10	9.9%		Aug	\$17.45	12.6%
	Sep	\$17.80	10.0%		Sep	\$18.60	12.9%
	Oct	\$17.85	10.9%		Oct	\$19.75	12.3%
	Nov	\$17.40	10.9%		Nov	\$19.25	12.2%
	Dec	\$16.30	10.8%		Dec	\$16.10	12.4%
88	Jan	\$16.20	10.8%	92	Jan	\$16.00	12.8%
	Feb	\$15.85	11.3%		Feb	\$16.55	13.3%
	Mar	\$14.20	11.9%		Mar	\$16.60	12.7%
	Apr	\$15.75	12.5%		Apr	\$17.50	11.9%
	May	\$15.65	12.6%		May	\$18.40	11.6%
	Jun	\$14.60	12.6%		Jun	\$19.80	11.2%
	Jul	\$13.85	12.3%		Jul	\$19.30	11.1%
	Aug	\$13.95	12.2%		Aug	\$18.60	11.0%
	Sep	\$12.35	11.0%		Sep	\$19.10	10.0%
	Oct	\$11.10	11.5%		Oct	\$19.05	9.4%
	Nov	\$11.40	11.0%		Nov	\$17.95	10.1%
	Dec	\$13.30	10.3%		Dec	\$17.80	10.5%
89	Jan	\$15.25	10.0%				
	Feb	\$15.40	11.0%				
	Mar	\$16.75	11.9%				
	Apr	\$17.70	11.4%				
	May	\$16.45	11.3%				
	Jun	\$16.20	11.2%				
	Jul	\$16.30	10.8%				
	Aug	\$15.80	10.2%				
	Sep	\$16.40	10.1%				
	Oct	\$16.95	9.4%				
	Nov	\$16.95	9.2%				
	Dec	\$17.90	9.4%				

Statistics		
	Crude	Naphtha
Mean	\$16.97	11.3%
Standard Err.	\$0.42	0.1%
Median	\$16.58	11.2%
Standard Dev.	\$3.83	1.1%
Variance	\$14.71	0.0%
Range	\$23.50	5.5%
Minimum	\$8.85	7.9%
Maximum	\$32.35	13.4%
Mean + 1 sd	\$20.81	12.4%
Mean - 1 sd	\$13.14	10.2%

Mean-Standardized Statistics		
	Crude	Naphtha
Standard Err.	2.5%	1.1%
Standard Dev.	22.6%	9.7%
Variance	86.6%	0.1%
Range	138.5%	48.6%
Minimum	52.1%	70.5%
Maximum	190.6%	119.0%
Mean + 1 sd	122.6%	109.7%
Mean - 1 sd	77.4%	90.3%

Histogram		
Bin	Frequency	
7.0%	1	
8.0%	0	
9.0%	9	
10.0%	23	
11.0%	29	
12.0%	18	
13.0%	4	
14.0%	0	

**Figure 9. Histogram: Naphtha Share of GPW, 1986-92
(Singapore Market)**

Table 7. Kerojet Prices As Share of Gross Product Worth, 1986-92
(Singapore Market)

			Crude		Kerojet		
			Price	Share			
			(\$/b)	(% of GPW)			
86	Jan	\$24.47	24.4%	90	Jan	\$18.25	24.1%
	Feb	\$15.51	27.4%		Feb	\$17.60	23.5%
	Mar	\$12.37	27.9%		Mar	\$16.60	23.0%
	Apr	\$11.30	24.8%		Apr	\$15.10	23.0%
	May	\$12.20	22.3%		May	\$15.40	23.8%
	Jun	\$11.20	23.4%		Jun	\$14.05	25.8%
	Jul	\$8.85	22.2%		Jul	\$16.10	24.6%
	Aug	\$12.95	21.4%		Aug	\$25.80	23.8%
	Sep	\$13.55	23.3%		Sep	\$31.10	26.3%
	Oct	\$13.95	24.3%		Oct	\$32.35	31.5%
	Nov	\$14.35	25.4%		Nov	\$28.75	26.9%
	Dec	\$15.70	25.8%		Dec	\$24.05	23.4%
87	Jan	\$18.00	22.0%	91	Jan	\$20.20	23.1%
	Feb	\$17.50	22.0%		Feb	\$15.25	28.1%
	Mar	\$17.70	21.8%		Mar	\$15.65	25.0%
	Apr	\$17.75	19.9%		Apr	\$16.15	23.3%
	May	\$17.85	20.3%		May	\$16.70	23.6%
	Jun	\$18.05	20.1%		Jun	\$16.20	23.8%
	Jul	\$18.55	20.7%		Jul	\$17.05	23.7%
	Aug	\$18.10	22.4%		Aug	\$17.45	24.7%
	Sep	\$17.80	23.2%		Sep	\$18.60	25.5%
	Oct	\$17.85	23.3%		Oct	\$19.75	25.1%
	Nov	\$17.40	24.1%		Nov	\$19.25	25.5%
	Dec	\$16.30	26.2%		Dec	\$16.10	25.9%
88	Jan	\$16.20	26.7%	92	Jan	\$16.00	25.6%
	Feb	\$15.85	25.2%		Feb	\$16.55	24.9%
	Mar	\$14.20	24.3%		Mar	\$16.60	24.0%
	Apr	\$15.75	22.8%		Apr	\$17.50	23.9%
	May	\$15.65	22.0%		May	\$18.40	24.0%
	Jun	\$14.60	22.3%		Jun	\$19.80	24.4%
	Jul	\$13.85	24.8%		Jul	\$19.30	24.8%
	Aug	\$13.95	23.3%		Aug	\$18.60	24.2%
	Sep	\$12.35	23.3%		Sep	\$19.10	24.0%
	Oct	\$11.10	24.2%		Oct	\$19.05	24.2%
	Nov	\$11.40	25.9%		Nov	\$17.95	24.7%
	Dec	\$13.30	28.4%		Dec	\$17.80	25.0%
89	Jan	\$15.25	27.4%				
	Feb	\$15.40	24.7%				
	Mar	\$16.75	23.4%				
	Apr	\$17.70	21.9%				
	May	\$16.45	21.6%				
	Jun	\$16.20	21.9%				
	Jul	\$16.30	23.1%				
	Aug	\$15.80	25.1%				
	Sep	\$16.40	25.6%				
	Oct	\$16.95	26.4%				
	Nov	\$16.95	26.0%				
	Dec	\$17.90	25.0%				

Statistics		
	Crude	Kerojet
Mean	\$16.97	24.2%
Standard Err.	\$0.42	0.2%
Median	\$16.58	24.1%
Standard Dev.	\$3.83	2.0%
Variance	\$14.71	0.0%
Range	\$23.50	11.7%
Minimum	\$8.85	19.9%
Maximum	\$32.35	31.5%
Mean + 1 sd	\$20.81	26.2%
Mean - 1 sd	\$13.14	22.3%

Mean-Standardized Statistics		
	Crude	Kerojet
Standard Err.	2.5%	0.9%
Standard Dev.	22.6%	8.1%
Variance	86.6%	0.2%
Range	138.5%	48.1%
Minimum	52.1%	82.0%
Maximum	190.6%	130.1%
Mean + 1 sd	122.6%	108.1%
Mean - 1 sd	77.4%	91.9%

Histogram		
Bin	Frequency	
19.0%	1	
20.0%	3	
21.0%	5	
22.0%	9	
23.0%	20	
24.0%	22	
25.0%	13	
26.0%	5	
27.0%	3	
28.0%	2	
29.0%	0	
30.0%	0	
31.0%	1	
32.0%	0	

**Figure 10. Histogram: Kerojet Share of GPW, 1986-92
(Singapore Market)**

Table 8. Diesel Prices As Share of Gross Product Worth, 1986-92
(Singapore Market)

			Crude		Diesel		Statistics						
			Price	Share				Crude	Diesel				
			(\$/b)	(% of GPW)									
86	Jan	\$24.47	19.3%	90	Jan	\$18.25	21.5%	Mean	\$16.97	20.8%			
	Feb	\$15.51	20.1%		Feb	\$17.60	20.8%	Standard Err.	\$0.42	0.2%			
	Mar	\$12.37	19.0%		Mar	\$16.60	20.6%	Median	\$16.58	20.8%			
	Apr	\$11.30	21.3%		Apr	\$15.10	21.4%	Standard Dev.	\$3.83	1.6%			
	May	\$12.20	20.5%		May	\$15.40	21.4%	Variance	\$14.71	0.0%			
	Jun	\$11.20	20.8%		Jun	\$14.05	22.8%	Range	\$23.50	9.2%			
	Jul	\$8.85	18.1%		Jul	\$16.10	21.4%	Minimum	\$8.85	17.0%			
	Aug	\$12.95	17.9%		Aug	\$25.80	20.1%	Maximum	\$32.35	26.2%			
	Sep	\$13.55	17.0%		Sep	\$31.10	20.4%	Mean + 1 sd	\$20.81	22.4%			
	Oct	\$13.95	18.1%		Oct	\$32.35	20.2%	Mean - 1 sd	\$13.14	19.3%			
	Nov	\$14.35	19.3%		Nov	\$28.75	21.4%	Mean-Standardized Statistics					
	Dec	\$15.70	18.8%		Dec	\$24.05	21.1%		Crude	Diesel			
87	Jan	\$18.00	18.6%	91	Jan	\$20.20	20.7%	Standard Err.	2.5%	0.8%			
	Feb	\$17.50	20.4%		Feb	\$15.25	26.2%	Standard Dev.	22.6%	7.5%			
	Mar	\$17.70	20.1%		Mar	\$15.65	23.7%	Variance	86.6%	0.1%			
	Apr	\$17.75	18.6%		Apr	\$16.15	21.7%	Range	138.5%	44.3%			
	May	\$17.85	18.4%		May	\$16.70	21.3%	Minimum	52.1%	81.4%			
	Jun	\$18.05	18.6%		Jun	\$16.20	21.5%	Maximum	190.6%	125.7%			
	Jul	\$18.55	18.2%		Jul	\$17.05	21.6%	Mean + 1 sd	122.6%	107.5%			
	Aug	\$18.10	18.4%		Aug	\$17.45	22.4%	Mean - 1 sd	77.4%	92.5%			
	Sep	\$17.80	20.2%		Sep	\$18.60	23.1%	Histogram					
	Oct	\$17.85	19.9%		Oct	\$19.75	22.8%		Bin	Frequency			
	Nov	\$17.40	19.7%		Nov	\$19.25	23.2%	17.0%	1				
	Dec	\$16.30	20.0%		Dec	\$16.10	23.6%	18.0%	9				
88	Jan	\$16.20	20.2%	92	Jan	\$16.00	23.4%	19.0%	10				
	Feb	\$15.85	20.9%		Feb	\$16.55	22.8%	20.0%	25				
	Mar	\$14.20	21.6%		Mar	\$16.60	21.9%	21.0%	21				
	Apr	\$15.75	21.2%		Apr	\$17.50	22.1%	22.0%	10				
	May	\$15.65	20.2%		May	\$18.40	22.2%	23.0%	6				
	Jun	\$14.60	20.1%		Jun	\$19.80	22.3%	24.0%	0				
	Jul	\$13.85	19.5%		Jul	\$19.30	21.9%	25.0%	0				
	Aug	\$13.95	19.7%		Aug	\$18.60	21.2%	26.0%	1				
	Sep	\$12.35	20.2%		Sep	\$19.10	21.1%	27.0%	0				
	Oct	\$11.10	20.0%		Oct	\$19.05	21.6%						
	Nov	\$11.40	20.2%		Nov	\$17.95	22.4%						
	Dec	\$13.30	20.4%		Dec	\$17.80	22.7%						
89	Jan	\$15.25	22.8%										
	Feb	\$15.40	23.0%										
	Mar	\$16.75	21.6%										
	Apr	\$17.70	19.7%										
	May	\$16.45	20.0%										
	Jun	\$16.20	20.1%										
	Jul	\$16.30	20.4%										
	Aug	\$15.80	20.6%										
	Sep	\$16.40	21.0%										
	Oct	\$16.95	21.0%										
	Nov	\$16.95	21.6%										
	Dec	\$17.90	21.9%										

**Figure 11. Histogram: Diesel Share of GPW, 1986-92
(Singapore Market)**

**Table 9. High-Sulfur Fuel Oil Prices As Share of Gross Product Worth, 1986-92
(Singapore Market)**

			Crude		HSFO						
			Price	Share							
			(\$/b)	(% of GPW)							
86	Jan	\$24.47	36.8%	90	Jan	\$18.25	33.6%	Statistics			
	Feb	\$15.51	34.0%		Feb	\$17.60	33.2%	Crude		HSFO	
	Mar	\$12.37	35.7%		Mar	\$16.60	33.2%	Mean	\$16.97	32.6%	
	Apr	\$11.30	33.5%		Apr	\$15.10	32.5%	Standard Err.	\$0.42	0.3%	
	May	\$12.20	30.7%		May	\$15.40	32.5%	Median	\$16.58	32.5%	
	Jun	\$11.20	29.9%		Jun	\$14.05	27.9%	Standard Dev.	\$3.83	3.1%	
	Jul	\$8.85	34.0%		Jul	\$16.10	30.7%	Variance	\$14.71	0.1%	
	Aug	\$12.95	35.2%		Aug	\$25.80	32.4%	Range	\$23.50	13.6%	
	Sep	\$13.55	36.0%		Sep	\$31.10	29.1%	Minimum	\$8.85	26.3%	
	Oct	\$13.95	34.1%		Oct	\$32.35	26.9%	Maximum	\$32.35	39.9%	
	Nov	\$14.35	31.8%		Nov	\$28.75	30.9%	Mean + 1 sd	\$20.81	35.7%	
	Dec	\$15.70	33.2%		Dec	\$24.05	34.0%	Mean - 1 sd	\$13.14	29.5%	
87	Jan	\$18.00	38.0%	91	Jan	\$20.20	35.6%	Mean-Standardized Statistics			
	Feb	\$17.50	35.1%		Feb	\$15.25	26.3%	Crude		HSFO	
	Mar	\$17.70	34.9%		Mar	\$15.65	27.0%	Standard Err.	2.5%	1.0%	
	Apr	\$17.75	38.2%		Apr	\$16.15	29.6%	Standard Dev.	22.6%	9.6%	
	May	\$17.85	38.7%		May	\$16.70	29.7%	Variance	86.6%	0.3%	
	Jun	\$18.05	38.9%		Jun	\$16.20	29.7%	Range	138.5%	41.9%	
	Jul	\$18.55	39.9%		Jul	\$17.05	30.2%	Minimum	52.1%	80.7%	
	Aug	\$18.10	39.2%		Aug	\$17.45	28.5%	Maximum	190.6%	122.6%	
	Sep	\$17.80	36.5%		Sep	\$18.60	27.1%	Mean + 1 sd	122.6%	109.6%	
	Oct	\$17.85	35.7%		Oct	\$19.75	29.1%	Mean - 1 sd	77.4%	90.4%	
	Nov	\$17.40	34.9%		Nov	\$19.25	28.5%				
	Dec	\$16.30	32.5%		Dec	\$16.10	26.9%				
88	Jan	\$16.20	31.9%	92	Jan	\$16.00	26.5%	Histogram			
	Feb	\$15.85	32.3%		Feb	\$16.55	27.1%	Bin	Frequency		
	Mar	\$14.20	31.6%		Mar	\$16.60	29.8%	27%	4		
	Apr	\$15.75	32.9%		Apr	\$17.50	30.9%	28%	2		
	May	\$15.65	34.2%		May	\$18.40	30.5%	29%	8		
	Jun	\$14.60	33.9%		Jun	\$19.80	30.2%	30%	11		
	Jul	\$13.85	32.5%		Jul	\$19.30	30.6%	31%	6		
	Aug	\$13.95	33.7%		Aug	\$18.60	32.2%	32%	9		
	Sep	\$12.35	34.0%		Sep	\$19.10	33.7%	33%	17		
	Oct	\$11.10	32.4%		Oct	\$19.05	33.8%	34%	5		
	Nov	\$11.40	31.7%		Nov	\$17.95	31.9%	35%	8		
	Dec	\$13.30	30.6%		Dec	\$17.80	31.0%	36%	4		
89	Jan	\$15.25	29.8%						37%	0	
	Feb	\$15.40	30.5%						38%	4	
	Mar	\$16.75	31.8%						39%	2	
	Apr	\$17.70	36.1%						40%	0	
	May	\$16.45	36.1%								
	Jun	\$16.20	35.2%								
	Jul	\$16.30	35.1%								
	Aug	\$15.80	34.0%								
	Sep	\$16.40	33.3%								
	Oct	\$16.95	33.7%								
	Nov	\$16.95	33.9%								
	Dec	\$17.90	34.4%								

**Figure 12. Histogram: Fuel Oil Share of GPW, 1986-92
(Singapore Market)**

Table 10. Gross Product Worth (GPW) Shares, 1986-92
(Singapore Market)

	Low (% GPW)	-1 sd (% GPW)	Mean (% GPW)	+1 sd (% GPW)	High (% GPW)	Hydro- skimming Yields
Naphtha	7.9%	10.2%	11.3%	12.4%	13.4%	10.9%
Gasoline	7.9%	8.8%	9.8%	10.8%	12.3%	7.1%
Kerojet	19.9%	22.3%	24.2%	26.2%	31.5%	18.0%
Diesel	17.0%	19.3%	20.8%	22.4%	26.2%	16.5%
Fuel Oil	26.3%	29.5%	32.6%	35.7%	39.9%	43.8%
TOTAL			98.7%			96.3%

Note: Detailed statistics by product appear on preceding tables.

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The final step is to do iterative estimation of prices, carefully tracking what each assumption does to the GPW shares. Price adjustments are done by beginning with the historic GPW share means, and then moving these from their means based on emerging trends. (Or, if the future is expected to mimic the past, then simply by applying the GPW shares to calculate the prices.)

In our forecast, there are three key market trends assumed:

- 1) A steady strengthening of naphtha; a narrowing of the gap between naphtha and gasoline prices from present levels of \$7-8/ barrel to \$4.15/b by the end of the forecast period.
- 2) A decrease in the value of high-sulfur fuel oil relative to crude. Fuel oil still maintains a high GPW share, since it constitutes the bulk of hydroskimming output, but steadily becomes cheaper relative to crude oil.
- 3) A steady narrowing of the gaps between gasoline, jet fuel, and diesel, as all segments of the transport fuel barrel approach parity owing to high middle distillate demand in Asia.

The forecast selected for the Singapore market, based on the GPW approach and the principles listed above, is shown in Table 11. As discussed in greater detail in Task I of HES Project 2, Singapore prices are used as a pricing basis throughout the region, and are important price indicators for global market watchers as well. Singapore is regarded as the only truly free market in the Asia-Pacific region, and is one of the only places where petroleum product spot prices are regularly reported. The vast majority of Asia-Pacific countries have some sort of government involvement in oil product pricing. Some directly set the prices of petroleum fuels, some cross-subsidize certain fuels at the expense of others. Singapore prices are the only accepted market prices in the region, and Singapore is also the only major export-led refining entrepot, refining the majority of its oil for export rather than domestic use.

**Table 11. Projected Singapore Product Prices, 1994-2014
(1993 US \$ per barrel)**

OIL PRODUCT PRICE FORECAST, 1994			
Crude Price:	\$20.62	(% GPW)	Diff.
<i>Price Inputs:</i>			
Naphtha	\$23.80	11.8%	\$3.18
Gasoline	\$30.21	9.8%	\$9.59
Kerojet	\$29.56	24.2%	\$8.94
Diesel	\$27.74	20.8%	\$7.12
Fuel Oil	\$16.10	32.1%	(\$4.52)
Gross Margin:	\$1.36		
Gross Prod. Worth:	\$21.98		

OIL PRODUCT PRICE FORECAST, 2009			
Crude Price:	\$30.49	(% GPW)	Diff.
<i>Price Inputs:</i>			
Naphtha	\$37.15	12.8%	\$6.66
Gasoline	\$41.60	9.3%	\$11.11
Kerojet	\$41.50	23.5%	\$11.01
Diesel	\$41.40	21.5%	\$10.91
Fuel Oil	\$22.90	31.6%	(\$7.59)
Gross Margin:	\$1.26		
Gross Prod. Worth:	\$31.75		

OIL PRODUCT PRICE FORECAST, 1999			
Crude Price:	\$23.80	(% GPW)	Diff.
<i>Price Inputs:</i>			
Naphtha	\$27.50	11.9%	\$3.70
Gasoline	\$34.50	9.8%	\$10.70
Kerojet	\$34.10	24.5%	\$10.30
Diesel	\$33.50	22.0%	\$9.70
Fuel Oil	\$17.50	30.5%	(\$6.30)
Gross Margin:	\$1.29		
Gross Prod. Worth:	\$25.09		

OIL PRODUCT PRICE FORECAST, 2014			
Crude Price:	\$33.43	(% GPW)	Diff.
<i>Price Inputs:</i>			
Naphtha	\$41.05	12.9%	\$7.62
Gasoline	\$45.20	9.3%	\$11.77
Kerojet	\$45.05	23.4%	\$11.62
Diesel	\$44.90	21.4%	\$11.47
Fuel Oil	\$25.20	31.8%	(\$8.23)
Gross Margin:	\$1.26		
Gross Prod. Worth:	\$34.69		

OIL PRODUCT PRICE FORECAST, 2004			
Crude Price:	\$27.28	(% GPW)	Diff.
<i>Price Inputs:</i>			
Naphtha	\$33.50	12.8%	\$6.22
Gasoline	\$38.20	9.5%	\$10.92
Kerojet	\$37.95	23.9%	\$10.67
Diesel	\$37.60	21.7%	\$10.32
Fuel Oil	\$20.10	30.8%	(\$7.18)
Gross Margin:	\$1.28		
Gross Prod. Worth:	\$28.56		

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For some products, California harbor prices are needed for this analysis. In future years, actual prices within California will deviate considerably from the external market prices, as a result of special gasoline and diesel reformulation measures. California's product exports, however, are not likely to be of these new grades, since they are likely to be scarce in the California market, as well as being unnecessarily reformulated in most other markets. Thus, the prices used in the present study should not be used as estimators of prices in the Californian domestic market, but rather as guideline prices for Californian exports of external-market-quality fuels.

U.S. West Coast prices show a tight correlation with Singapore prices (to be expected, since small differences in price alter trade patterns across the Pacific). Product-to-product regressions were used to predict California harbor (Los Angeles) prices from their Singapore counterparts. These regressions are shown in an appendix to this report.

Finally, price projections are needed for LPG, premium and regular unleaded gasoline, and the medium-sulfur (2 percent) and low-sulfur (0.5 percent) fuel oil grades used in Hawaii. LPG is taken at 90 percent of the price of crude c.i.f. Southeast Asia (which reflects the trend in LPG contracts in many producing countries). A differential of \$2.00/b between premium (92 R+M/2) and regular (87 R+M/2) grades of gasoline is assumed, reflecting the ready availability of octane in the Asia-Pacific market in the absence of aromatics controls.

The matter of fuel oil prices is somewhat more complex. The LSFO-HSFO differential between 1979 and mid-1993 averaged \$2.42/b, but ranged from -\$4.39/b to \$17.84/b. This differential is prone to wide swings, particularly in the Asia-Pacific market. Japanese LSFO purchasing patterns, which are highly responsive to Japanese temperature and Japanese rainfall levels, can have dramatic effects on the market. This can clearly be seen in Figure 13, which shows past LSFO-HSFO differentials, along with our forecast to 2014.

**Figure 13. Historic and Projected Price Differential,
LSFO-HSFO, 1979-2014**

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Our forecast is based on the assumption that desulfurization of residual fuel oil—as opposed to the refining of low-sulfur crudes—will become the incremental source of LSFO in the region, and that the majority of the consumption in the region will move to low-sulfur specifications by early in the next decade. This is reflected in a move to a differential of \$4.80/b—the estimated cost of full amortization and operating of residuum desulfurizing units to strip sulfur from high-sulfur fuel oils. The cost of moving HSFO to an MSFO standard of 2 percent sulfur, such as is used outside Oahu, is estimated at only a third of the cost (about \$1.60/b).

Prices for Crude Oils

The final elements that need to be added to the oil price projections are price forecasts for various crude oils. The model uses 18 crude types to represent the array of crudes available to the refiner; some are quite similar, while others are dramatically different, both in price and quality.

The main determinant of crude prices is the value of the products contained in the crude oil. In addition, there are a host of other factors, such as geographical location, crude viscosity, bilateral agreements, package and barter deals, and credit terms, that can all affect the basic crude price. The method followed here has been to calculate the hydroskimming value of each crude for each future year in the Singapore market. This is also calculated for the 1992 base year. In 1992, the differentials between the hydroskimming values of the crudes and Arab Light are compared to the differentials between the market prices of the crudes and Arab Light, and an adjustment factor is calculated from the two kinds of differentials. This adjustment factor, L , is held constant in the future, and the prices of crudes are projected to be:

$$P_C = P_A + H_C - L$$

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where P_A is the price of Arab Light, H_C is the difference in hydroskimming values, and L is the adjustment factor for location and other variables. The results of this exercise are shown in Table 12.

Freight Rates for Crude and Products

The final component of the price forecasts is a forecast of the cost of shipping. Hawaii's geographic isolation and the small size of the market places it at a transport disadvantage relative to most other Asia-Pacific and U.S. West Coast destinations, and oil transport costs are generally higher on a per-barrel basis.

To produce a forecast of future shipping rates, historical freight rates were surveyed, and an assessment was made of the future demand for oil tanker ton-mileage as it impacted future freight markets.⁶ A preliminary freight rate forecast was developed to cover U.S. West Coast and Singapore voyages to and from Honolulu. Clean products (light and middle distillates) were assumed to be carried in 30,000 deadweight ton (dwt) clean tankers, while crude oil and dirty products (fuel oil and asphalt) were assumed to be shipped in 80,000-100,000 dwt tankers.⁷ Crude oil deliveries to Barbers Point refineries could come from a variety of sources: Alaska, Canada, Washington, Latin America, the Middle East, Africa, Australia, Southeast Asia, and China. These sources were forecast to coincide with the crude slate made available to the HAWMOD model.

The preliminary forecast was sent to a regional shipping company, Teekay Shipping (Canada), for their comments. The forecast, as revised based on Teekay's recommendations, is presented in Table 13.

The main purpose of the forecast was to generate freight rates in dollars-per-barrel terms. For example, the forecast indicates a per-barrel shipping cost of \$1.47 for

⁶ See David Isaak and Nancy Yamaguchi, "Changing Geography of Oil Shipments," *Seatrade Review*, September 1993, pp. 77-79.

⁷ The deadweight tonnage (dwt) of a ship is equal to the weight of the ship's cargo, fuel, and stores. In a large tanker, roughly 90-95% of the dwt is cargo.

Table 12. Crude Price Forecast for 1994-2014, Based on Hydroskimming Yield and 1992 Location Differentials

	Arab Light	Omani	Gipps-land	Seria Light	Cham-pion	Daqing	Arun	Cinta	Duri
1994	\$20.62	\$21.37	\$23.59	\$23.38	\$21.74	\$22.39	\$23.41	\$22.14	\$19.63
1999	\$23.80	\$24.74	\$27.29	\$27.54	\$25.95	\$25.56	\$27.63	\$24.88	\$22.68
2004	\$27.28	\$28.36	\$31.25	\$31.60	\$29.83	\$29.35	\$32.06	\$28.42	\$26.40
2009	\$30.49	\$31.66	\$34.49	\$34.99	\$33.20	\$32.43	\$35.53	\$31.25	\$29.42
2014	\$33.43	\$34.72	\$37.50	\$38.20	\$36.27	\$35.13	\$39.02	\$33.68	\$32.03

	Minas	Tapis	Oriente	Boscan	Bonny Light	Maya	Alaska N Slope	Cook Inlet	Attaka
1994	\$22.61	\$24.14	\$20.84	\$14.55	\$23.33	\$16.28	\$20.84	\$22.90	\$23.86
1999	\$25.90	\$28.44	\$23.81	\$16.47	\$27.03	\$18.97	\$23.85	\$26.69	\$27.91
2004	\$29.60	\$32.55	\$27.13	\$19.16	\$30.86	\$22.19	\$27.22	\$30.71	\$31.88
2009	\$32.64	\$36.01	\$30.25	\$21.95	\$34.02	\$25.23	\$30.40	\$34.00	\$35.17
2014	\$35.35	\$39.31	\$33.06	\$24.31	\$36.97	\$27.96	\$33.26	\$37.06	\$38.34

Note: Arab Light price based on California Energy Commission Delphi Survey corrected to 1993 dollars

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gasoline moving between Hawaii and Los Angeles in 1994. This cost is forecast to rise to over \$3 per barrel in the year 2014. Part of the increase is attributable to the fact that prices are reported in 1993 constant dollars, while part is explained by a regional increase in demand for shipping (consistent with the growth in demand described in Task II of HES Project 2).

The "WS rate" indicated in the table is a shipping rate index, the "World Scale." World Scale, or WS, rates are used worldwide as a basis for negotiating ship charter rates. Subscribers to the World Scale service receive a volume of "World Scale 100 Rates" covering almost every conceivable voyage. Briefly, the WS 100 rate is an index of the cost of shipping, in dollars per ton, for a standard-sized ship on a set voyage. Each voyage has a specific WS 100 rate; say, for example, a voyage from Port A to Honolulu was assessed a published WS 100 rate of \$5.00 per ton, while a voyage from Port B to Honolulu had a WS 100 rate of \$10.00 per ton. Cargo brokers and ship brokers negotiate the WS rate that the market will actually bear, which can be considerably higher or considerably lower than the WS 100 rate. For a small ship chartered during a period of strong market demand, the WS rate agreed upon might be WS 200; that is, 200 percent of the WS 100 rate. The voyage rate from Port A to Honolulu would therefore be \$10 per ton, and the rate from Port B to Honolulu would be \$20 per ton.

The methodology used in the freight rate forecast took into account first the published WS 100 rates (in dollars per ton) for the voyages listed in Table 13 (Los Angeles, Singapore, Alaska, Indonesia, and so forth, to Hawaii), then forecast future WS rates, then converted units of dollars-per-ton into dollars-per-barrel to arrive at forecast freight rates per barrel by type of oil, source/destination, and year.

Table 13. Forecast Freight Rates for Voyages to Barbers Point, 1993-2014

(Worldscale Rates and constant 1993 US Dollars per barrel)

CLEAN PRODUCTS: 30,000 DWT

Los Angeles Market linked to Honolulu				
		Gasoline	Kero/Jet	Diesel
Year	WS rate	LA \$/b	LA \$/b	LA \$/b
1993	164.5	\$1.41	\$1.54	\$1.65
1994	167.5	\$1.47	\$1.61	\$1.73
1999	178	\$1.82	\$1.99	\$2.13
2004	186	\$2.20	\$2.41	\$2.58
2009	189	\$2.59	\$2.84	\$3.04
2014	192	\$3.05	\$3.34	\$3.58

CLEAN PRODUCTS: 30,000 DWT

Singapore Market linked to Honolulu			
	Gasoline	Kero/Jet	Diesel
WS rate	S'pore \$/b	S'pore \$/b	S'pore \$/b
158.7	\$1.80	\$1.97	\$2.12
162.7	\$1.90	\$2.08	\$2.23
172	\$2.33	\$2.55	\$2.74
178	\$2.80	\$3.06	\$3.29
181	\$3.30	\$3.61	\$3.87
185	\$3.91	\$4.28	\$4.59

DIRTY PRODUCTS: 80-100,000 DWT

Los Angeles/Honolulu		Singapore/Honolulu	
	Fuel Oil		Fuel Oil
WS rate	LA \$/b	WS rate	S'pore \$/b
82	\$0.90	74	\$1.07
84	\$0.94	76	\$1.14
91	\$1.19	85	\$1.47
95	\$1.44	88	\$1.77
99	\$1.74	93	\$2.17
102	\$2.07	97	\$2.62

CRUDE: 90-100,000 DWT

Forecast Shipping Rates for Crude Imports to Barber's Point

\$/bbl

Year	Seattle	Alaska	Vancouver	Ecuador	Venezuela	Low Arabian	High Gulf	Singapore	Malaysia	(Ardjuna) Indonesia	(Dalian) China	Melbourne	Dampier	Forcados Nigeria
1993	0.66	1.12	0.92	1.17	1.92	1.72	1.75	1.18	1.02	1.18	1.00	1.12	1.16	2.32
1994	0.68	1.15	0.95	1.23	1.98	1.99	2.03	1.36	1.16	1.35	1.15	1.15	1.26	2.57
1999	0.79	1.34	1.10	1.43	2.29	2.31	2.35	1.57	1.35	1.56	1.33	1.40	1.54	2.98
2004	0.92	1.55	1.28	1.66	2.66	2.97	3.02	1.82	1.56	1.81	1.54	1.63	1.79	3.46
2009	1.06	1.80	1.48	1.92	3.08	3.45	3.51	2.11	1.81	2.10	1.78	1.89	2.07	4.01
2014	1.23	2.08	1.72	2.22	3.57	4.00	4.06	2.45	2.10	2.43	2.07	2.19	2.40	4.64

Note: WS rate default is WS100. Venezuela rate is for 60,000 dwt ship via Panama Canal

III. HAWMOD Model Structure

A. Types of Models

The model employed to analyze the Hawaii oil industry is a simplified refinery linear program (LP). Refinery LPs are a widespread and generally accepted tool in the U.S. oil industry. They are, however, used at two very distinct levels of resolution: operations models and planning models.

A refinery operations model is a highly detailed model of the refinery used for making specific blending, processing, or purchasing decisions. It is typically run on a weekly or even daily basis. Such a model will normally reflect every major constraint in the refinery, including the maximum flow rates of delivery pipes and the size of storage tanks. Operations models are designed to optimize the refinery "as is," without making alterations to the processing capabilities. Operations models are huge; models consisting of 3,000 equations and 40,000 variables are common, and many models exceed this size by a significant margin.

Planning models are more generic; they usually cover more than one refinery, and may cover entire states, countries, or regions. Curiously, despite their increased scope, they are typically much smaller than the operations models for single LPs. There are a number of reasons for this. First, since they are typically used for analyzing groups of refineries, the specific constraints and quirks of given hardware in particular refineries tend to cancel out. Second, planning models are often run to analyze the future, and most of the minor hardware constraints having to do with piping, tankage, or utilities can be changed across time if the economics warrant; allowing minor constraints to become binding on the whole system can give a distorted view of the possibilities. Third, planning models are normally run to simulate long periods, such as a year, as opposed to the week-by-week or day-by-day simulations common for operations models; over the period of a year, many constraining features of the system are not binding.

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Finally, planning models are normally used to answer different kinds of questions than operations models. An operations model is normally a company-oriented, profit-maximizing model that answers questions about the best crudes to purchase and the best ways to process and blend them. A planning model does not always have this kind of profit orientation; planning models are more often centered on matters of meeting demand at minimum cost, or on the effect of future market changes on output and trade.

Planning models typically range in size from about 150 to 1,000 equations, and involve 300 to 3,000 variables, though some—such as planning models like the U.S. Department of Energy's (USDOE) *OTM* (Oil Trade Model), that attempt to cover the globe on a multiregion basis—can be larger. Some of the highly integrated regional models, such as Chem System's monitoring model for Western Europe, achieve valuable results with as few as 100 equations.

The model developed for use in this analysis is a 323-equation, 944-variable model, which treats the Hawaiian refining sector as a single, integrated refinery. There are certain drawbacks to modeling the system as a single, integrated operation, the foremost of which is "overoptimization." Overoptimization is LP jargon for the problem that occurs when a real bottleneck—sometimes physical, sometimes corporate, sometimes political—is not explicitly represented in the model. For example, if one refiner has a surplus of a certain feedstock, while another has a identical shortage of the same feedstock, an integrated model will not capture the mismatch; the feedstock will be treated as if it is available in the same refinery where it is needed. If the refineries are well-connected, this may be a reasonable approximation, since the feed will probably be purchased by the deficit refiner. The Hawaiian refineries are quite well-situated for inter-refinery transfers of products; they are adjacent, and interconnected by pipeline. Nonetheless, corporate strategies or temporary events in the market may prevent such a transfer even if the refineries are well-connected. Thus, a single-refinery model still runs some risk of projecting a system that is somewhat more flexible and responsive than reality.

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Running counter to the risk of overoptimization are the advantages of considering the refining sector as a single unit. The single-sector approach reflects the state's public-policy concerns more accurately: The state formulates policy with regard to the oil sector, not with regard to the individual players. The single-unit approach cuts the model size down by more than half, thus making scenario analysis easier to perform and more readily interpretable. Most important, however, the single-refinery approach aggregates both the inputs (important for preserving the confidential nature of some of the data) and the results. This prevents undue analysis of the position of the two refiners, and also limits the kinds of company-specific financial information that would have to be gathered to run the model as a two-refinery system.

In practice, we have seldom found overoptimization to be a significant problem for analysis on an annual basis. Generally speaking, if the cost of trading intermediates between refineries is not too high, the products will move most of the time, if not in every daily instance. Some of the differences we have found between reality and the results of planning models are wrongly attributed to overoptimization, when in fact they are the result of modeling the system annually rather than daily.

Annual models work with annual average prices and annual average demands. Both demand and prices fluctuate throughout the year. Moreover, prices do not fluctuate in a perfectly coordinated fashion. A given crude oil, for example, may be "overpriced" relative to its yields one week, and "underpriced" the next. A crude that a given refiner would not normally purchase may be available as a single distress cargo on attractive terms. Changes in external product markets may temporarily turn a net importer of a given product into a net exporter (or vice-versa). In addition, movements of crude and products via corporate channels may offer a given refiner special opportunities, or face them with special obligations.

A considerable amount of the refiner's income in a turbulent market may actually be derived from making single transactions that would not be economically sensible if facing annual average prices. Annual averages, however, are only seen retrospectively,

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or, in the case of planning models, prospectively. Planning models are therefore not expected to reproduce trade patterns, refinery production, or crude imports with perfect accuracy. Indeed, the highly detailed operations models will not reproduce actuality accurately if they are run against annual prices, since getting a better deal than the annual average is one of the major driving forces in crude and product trading. The test of a model is whether it seems to reflect the major pressures in the system, and whether it reproduces reality with an acceptable degree of accuracy.

B. Refinery Linear Program (LP) Models, Shadow Prices and Gradients

As noted, HAWMOD is a refinery linear program, or LP, model which simulates refinery activity and calculates product prices. A few definitions are in order:

What LPs are: LP modeling offers a method of finding the most economical, "optimal" pathway to a user-defined set of goals within the bounds of user-defined constraints (such as demand, price of inputs, opportunity cost of trade, petroleum product specifications, restrictions on refinery construction/expansion, and so forth.)

The Components of an LP

1) A set of n variables $x_1, x_2, x_3, \dots, x_n$. These variables represent the "activities" in a refining system (such as crude purchase, crude distillation, coking, and so forth).

2) A function $F(x_1, x_2, x_3, \dots, x_n)$ of the variables. F is linear and can be written in the form:

$$F(x_1, x_2, x_3, \dots, x_n) = c_1x_1, c_2x_2, c_3x_3, \dots, c_nx_n$$

where the c_i are constants. F is called the *objective function*.

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3) A set of m linear (in)equalities relating the n variables. These are the *constraints* in the LP problem. The i th constraint may be written as:

$$a_{i1}x_1 + a_{i2}x_2 + \dots + a_{in}x_n \leq b_i$$

Each a_{ij} and b_i is constant. The inequality may also be $\geq$, or $=$. The b_i are the *right hand side (RHS)* of the constraint.

4) A requirement that each x_i be positive.

The LP Problem

Given the above definitions, the LP problem is:

Maximize $F(x)$ (the objective function)

Subject to

$a_{i1}x_1 + a_{i2}x_2 + \dots + a_{in}x_n \leq b_i$ for $i=1\dots m$ and

$x_j \geq 0$ for $j=1\dots n$.

The LP Solver

The revised simplex algorithm is most commonly used (the simplex algorithm was first developed by Dantzig in the 1940s). This algorithm finds the least-cost/highest-profit solution by cycling through all feasible solution sets until objective function F is either maximized or minimized, depending on how the problem was set up.

Shadow Prices and Gradients

Each constraint has an associated shadow price p_i , which shows the marginal cost or value of the constraint. The shadow price $p_i = dF/db_i$; that is, the change in the objective function that results from a change of one unit in the RHS of the constraint (all other constraints being unchanged). Shadow prices are extremely useful for analysts: if the analyst has set the proper coefficients—which should be real engineering

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coefficients—then the shadow price on a row really is the best approximation of the true price/value within the system. This is the best marginal price, and the modeler can easily test the sensitivity to change by relaxing the constraint bit by bit to see what happens to the price curve.

C. The Hawaii Model, HAWMOD

The Hawaii LP refining model allows the processing of 18 different crude types. Although these are by no means the only crudes available to Hawaiian refiners, they can act as proxies for the full array of crudes that could be purchased.

The processing vectors are obtained from public sources or industry contacts. None of the processing vectors were obtained from the two refiners; this is an "arms-length" model that does not contain proprietary or strategic information.

For those readers requiring a review of refinery technology and terminology, a complete discussion is provided in the Task I report (*World and Regional Fossil Energy Dynamics*) of this project.

Each crude is cut into 10 straight-run cuts as shown in Table 14. For ease of modeling, each crude type available to the model, denoted in Table 12, was assigned a four-letter code. In the sample shown in Table 14, Arab Light is abbreviated ARLT, Omani crude is OMAN, Gippsland is GIPP, Seria Light Export Blend is SLEB, and Champion is CHMP. In addition to the main cuts—FG (fuel gas), LPG (liquefied petroleum gas), LNP (light naphtha), HNP (heavy naphtha), KER (straight-run kerosene), DSL (straight-run diesel), and RES (atmospheric residuum)—there are also three "swing cuts" (swing naphtha, or SNP, swing kerosene, or SKR, and swing diesel, or SDL). These are included to represent cutpoint flexibility, and may later be blended upward or downward into the adjacent output stream. For example, SKR may be blended upward into the KER stream, or downward into the DSL stream. With the exception of FG and LPG, all of these streams remain segregated according to the crude from which they are derived, in order to retain their quality considerations.

Table 14. EXAMPLE OF DISTILLATION CUTS					
TABLE PRIMARY DISTILLATION					
	DIST.ARLT	DIST.OMAN	DIST.GIPP	DIST.SLEB	DIST.CHMP
FG	0.008	0.000	0.015	0.008	0.005
LPG	0.025	0.000	0.045	0.023	0.014
LNP.ARLT	0.068				
HNP.ARLT	0.082				
SNP.ARLT	0.041				
KER.ARLT	0.128				
SKR.ARLT	0.051				
DSL.ARLT	0.152				
SDL.ARLT	0.019				
RES.ARLT	0.427				
LNP.OMAN		0.098			
HNP.OMAN		0.089			
SNP.OMAN		0.043			
KER.OMAN		0.133			
SKR.OMAN		0.056			
DSL.OMAN		0.166			
SDL.OMAN		0.019			
RES.OMAN		0.403			
LNP.GIPP			0.105		
HNP.GIPP			0.086		
SNP.GIPP			0.043		
KER.GIPP			0.132		
SKR.GIPP			0.054		
DSL.GIPP			0.161		
SDL.GIPP			0.027		
RES.GIPP			0.331		
LNP.SLEB				0.091	
HNP.SLEB				0.107	
SNP.SLEB				0.050	
KER.SLEB				0.175	
SKR.SLEB				0.083	
DSL.SLEB				0.242	
SDL.SLEB				0.015	
RES.SLEB				0.206	
LNP.CHMP					0.005
HNP.CHMP					0.040
SNP.CHMP					0.032
KER.CHMP					0.162
SKR.CHMP					0.104
DSL.CHMP					0.311
SDL.CHMP					0.036
RES.CHMP					0.290
END TABLE					

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The atmospheric residua may be charged to vacuum distillation, and the resulting VGO (vacuum gasoil) and VBT (vacuum bottoms) are also tracked by crude source.

Options are then made available for hydrotreating and hydrorefining for the removal of sulfur. The vectors are provided to carry this process down through the level of vacuum gasoil (to allow analysis of possible future additions), but these capacities are set to zero, since current desulfurization capacities installed only cover light intermediates.

Heavy naphtha streams are grouped by "reformability" into three categories. Catalytic reforming vectors are included for these groupings at two levels of reforming severity (95 and 100 RON clear). Reforming vectors are also available for heavy FCC (from fluid catalytic crackers, or FCC units) naphtha and heavy hydrocracker naphtha.

VGOs are grouped into low-sulfur and medium-sulfur categories to be charged to hydrocracking. High-sulfur VGOs are excluded from the option of being fed to hydrocracking. Four hydrocracking vectors are available, limited to middle-distillate maximizing modes (diesel and jet operation); naphtha maximization is not included in the model, since it is not expected that Hawaiian hydrocrackers would ever run in such a mode.

Atmospheric residua and vacuum bottoms are grouped by sulfur content as feed to the visbreaking unit. Five vectors are available for this unit.

The FCC accepts the same feed groupings as the hydrocracker; once again, very high-sulfur VGOs are excluded from unit feeds. (A hydrorefined feedstock is allowed to model future expansion, but cannot provide feedstock with the current refinery configuration.) Four vectors are provided for the FCC unit.

Alkylation, polymerization, and bitumen units are modeled explicitly, as is hydrogen manufacturing via steam reforming of gases, LPG, or naphtha. In addition, vectors to allow construction of new refining facilities are included in the model, although these are bounded at a zero level in most scenarios.

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All units have specific demands for electricity, water pumping, heat, and (where appropriate) hydrogen. Some, of course, may be net donors of hydrogen or heat. Fuel and hydrogen balances are explicitly modeled. The cogeneration plant at the Hawaiian Independent Refinery, Inc. (HIRI), however, is not treated explicitly; it is treated as an additional demand for fuel and a reduction in the cost of provided electricity. This is done to avoid the detailed modeling of company-specific details and transactions.

Explicit blending of 10 products is modeled. LPG is blended from five feeds, *ad libitum*. Naphtha is blended from 44 possible intermediates, also *ad libitum*. Two grades of gasoline (regular unleaded and premium unleaded) are blended to octane and RVP specifications from 51 intermediates. Jet fuel is blended to sulfur and smoke point specifications from 20 intermediates. Two grades of diesel (high-speed and industrial) are blended to cetane, sulfur, and viscosity specifications from 46 intermediates. Three grades of fuel oil (HSFO, MSFO, and LSFO) are blended to sulfur and viscosity specifications from 114 intermediates.

The LP structure is one of cost minimization, and it is driven by Hawaiian domestic demands. The demands may be met by importing crude and refining it, or by importing finished products. In addition, the model may export products produced in the Hawaiian refineries. The export of products may be thought of as a "negative cost" in the process of cost minimization.

A key assumption is that Hawaii is a price-taker with respect to the external market; that is, no import or export actions by the Hawaiian refiners have a noticeable impact on regional prices. This means that the Hawaiian refiners face a two-way transport barrier with respect to trade. Imports of products are at the external market price plus transport and handling; but exports of products are worth only the external market price *minus* transport and handling. This is a confusing point that deserves elaboration.

If the external market price for a product is \$20/b, and transport/handling charges from the market to Hawaii are \$2/b, then the cost to deliver the product to the Hawaiian

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market is \$22/b. If, on the other hand, a Hawaiian refiner is surplus in the same product, he cannot sell it in the external market for \$22/b. Assuming that the external market is not desperate for additional supplies, the refiner will only be able to sell it at the prevailing market rate of \$20/b. It will still cost the refiner \$2/b to get it to the external market to sell it at \$20/b; thus, the net to the refiner on the sale is only \$18/b. In this case, there is a \$4/b differential between the cost of the product as an import, and its value as an export.

Of course, the refiner may not have to move the product back to the main external market center to sell it. There may be closer markets, somewhere between the main export market and the refiner's location. In such a case, the transport losses may be reduced; if a market is found where the refiner has a transport advantage, there may even be an export premium. Such opportunities are limited for the Hawaiian refiner, however, because of location. The only area in which Hawaiian refiners have a major export advantage over the main refining centers is in the Pacific islands, which provide only a very limited market. Under the circumstances, the only responsible assumption to make is that the transport barrier is two-way on the average.

The transport barrier works to the refiner's advantage for sales in the Hawaiian domestic market, of course. The "opportunity cost" of providing another barrel per day of product is the external market cost plus the transport and handling. Thus, the products produced in Hawaii can be sold at prices above the external market. The transport barrier is the main reason that Hawaiian refiners can survive in competition with larger refiners elsewhere, despite the economies of scale and lower land, operating, labor, and fuel costs elsewhere. Hawaii is not a good location for an export refinery (unless Californian refiners begin to close down because of environmental problems), but it is a competitive location for supplies into the Hawaiian market.

The purpose of the model is to analyze the effects that future prices and demand changes will have on the Hawaii oil balance, and to assess the effects that these changes will have on the viability of the refining industry. This needs to be accomplished,

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however, without requiring detailed financial information from the companies. The solution adopted here is to assess refinery profitability on the basis of relative changes in income. The income for each year is given by:

$$I = \sum [R_i * (P_i + T_i)] - \sum [C_j * (P_j + T_j)] - B$$

where

R_i = Refinery Production of the i th fuel

P_i = External market price of the i th fuel

T_i = Transport and handling cost for the i th fuel

C_j = Import volume of the j th crude

P_j = FOB price of the j th crude

T_j = Transport and handling cost for the j th crude

B = Annual amortized cost for new facilities (relevant only in scenarios where facility expansion occurs).

This index can readily be calculated for each scenario from the input price and cost data in combination with the output from the LP model. Rather than determining an absolute level of profitability, then, this index can be compared between the resulting scenarios and the base case.

D. Model Calibration Results

One difficulty in calibrating such a model for Hawaii is that, as noted in the Task II report, there is considerable uncertainty about Hawaii's current oil balance. It is generally supposed that the Act 65 data at least captures the trade components of the oil balance, but some industry sources have suggested that there may even be errors in those values. This once again underlines the importance of developing a more systematic and accurate means of obtaining energy data in the state.

An additional problem in relying on Act 65 data as presently gathered is that it is lacking in resolution for this kind of modeling exercise. The data reported gives gasoline

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information, but not gasoline grade (premium, regular, etc.); it does not differentiate between types of diesel oils; and it does not break down fuel oils but sulfur levels. Thus, the numbers that we have used as "reported" oil balances consist of Act 65 data with considerable adjustments based on other data sources and on interviews with energy industry sources in the state. In some cases, the numbers reported by different sources have varied widely. For example, official reports of jet fuel consumption range as low as 38,000 b/d, compared to the figure of 48,000 b/d that appears to match the actual production and import volumes.

In some cases, a process of elimination had to be applied. To balance fuel oil, for example, aggregate consumption figures were broken down by grade, by separating out bunkers (high-sulfur), and neighbor island use (medium sulfur). The rest of the material, burned for electricity generation on Oahu, is assumed to be low-sulfur material. Interviews with the refiners suggested that all of the reported exports in 1992 were of high-sulfur material, and all of the imports were of the lower-sulfur grades. This is consistent with USDOE data on fuel oil trade, presented in the Task II report. Allocating imports and exports allows production levels by grade to be inferred. Any such allocation process, of course, assumes that no net stock changes occurred in the year. In principle, this should be verifiable from the Act 65 reports, since stock changes are reported on the form. In practice, this number is not provided by all of the companies.

Crude slates for the year were obtained directly from the refiners. Some volumes of crudes not included in the model were processed in 1992; in such cases, proxy crudes were selected. The simulated slate is shown in Table 15.

Initial calibration exercises showed a primary problem in the model centered around exports of high-grade diesel; these were well in excess of actual. A basic problem here is one of grade; cetane specifications for motor diesels in Asia are typically well above U.S. specifications. This was solved by not allowing export of high-grade diesel to the Asian market at U.S. specifications. Some structural errors in model programming

Table 15. HAWMOD Model Crude Slate for 1992

CRUDE TYPE ORIGIN thousand b/d		
Daqing	China	2.6
Boscan	Venezuela	0.4
Maya	Mexico	0.0
Oriente	Ecuador	1.9
Total Latin America		
Alaska North Slope	Alaska	58.7
Cook Inlet	Alaska	0.5
Total Alaska		
Arab Light	Saudi Arabia	0.0
Omani Export	Oman	0.5
Total Mideast		
Arun Condensate	Indonesia	0.0
Attaka	Indonesia	14.6
Champion	Brunei	1.0
Cinta/Intan	Indonesia	6.3
Duri	Indonesia	14.5
Gippsland	Australia	1.2
Minas	Indonesia	23.0
Seria Light	Brunei	0.4
Tapis	Malaysia	9.3
Total SE Asia/Pacific		
Bonny Light	Nigeria	0.0
Cracker Feed	na	4.8
TOTAL CRUDE		
		139.7

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that resulted in feed bottlenecks also became obvious during calibration, and were rectified.

The results of the calibration exercise for 1992 are shown in Table 16.

The most noticeable difference between the model results and the base data is that both imports and exports are higher in the base data. This is normal, since the model will never decide both to import and to export the same fuel in a single time period.

The model results are very close to the reported values for LPG, naphtha, gasoline, jet fuel, and diesel/gas oils. The main divergences are at the bottom of the barrel in the fuel oils. The model shows no trade in fuel oil; the reported figures show 5.5 mb/d of exports and 5.2 mb/d of imports for the year. Of course, as the Aggregated Net Reports section of Table 16 suggests, the numbers reported from Act 65 (which reports only "Fuel Oil" as opposed to the grades used here), the reported net imports of the state were very close to the zero basis estimated by the model. The separation into grades causes the apparent difficulties. Nonetheless, information from the refiners does insist that only high-sulfur grades of fuel oil are typically exported from the islands.

Careful reexamination of the bottoms processing units in the model shows that, based on the current crude slate and demand levels by grade, the Hawaii refiners *could* balance the fuel oil in the way the model suggests. The fact that this does not occur in practice is apparently a consequence of timing during the year, coupled with different corporate economics; the companies operating in the state have different fuel-oil contract commitments and different external sales and supply channels.

Furthermore, the present external market does not provide the kind of sharp differentiation between fuel oil grades that we expect to emerge during the late 1990s. Although the average LSFO-HSFO differential for 1992 was \$2.02/b, this number masks a wide variation on a monthly basis, from a high of \$5.06/b to a low of -\$0.38/b. The differential was below \$1.35/b for 6 months of the year, below \$1.00/b for 4 months of the year, and below \$0.50/b for 3 months of the year. The year-average prices were used

Table 16. Calibration Exercise: 1992 Balances, Reported and Simulated

(thousand b/d)	1992 - Reported				1992 - Model Results			
	Production	Imports	Exports	Demand	Production	Imports	Exports	Demand
LPG	3.9	0.3		4.2	4.1	0.1		4.2
Naphtha	5.9		2.7	3.2	6.1		3.0	3.2
Gasoline*	30.2	0.1	5.4	24.9	30.1		5.2	24.9
Jet Fuel	34.3	14.2	0.5	48.0	33.7	14.3		48.0
Diesel	5.1			5.1	5.1			5.1
Ind Gasoil	13.2	1.0	2.7	11.5	13.7		2.2	11.5
HS Fueloil	12.5		5.5	7.0	7.0			7.0
MS Fueloil	4.5	2.9		7.4	7.4			7.4
LS Fueloil	28.5	2.4		30.9	30.9			30.9
Asphalt/Other	3.3		1.1	2.2	2.2			2.2
TOTAL	141.5	20.9	17.9	144.4	140.3	14.4	10.3	144.4

(thousand b/d)	1992 - Results Less Reports				1992 - Aggregated Net Reports			
	Production	Imports	Exports	Demand	Production	Imports	Demand	
LPG	0.2	(0.2)			LPG	3.9	0.3	4.2
Naphtha	0.2		0.2		Naphtha	5.9	(2.7)	3.2
Gasoline*	(0.2)	(0.1)	(0.3)		Gasoline*	30.2	(5.3)	24.9
Jet Fuel	(0.7)	0.2	(0.5)		Jet Fuel	34.3	13.6	48.0
Diesel					Gasoil	18.3	(1.7)	16.6
Ind Gasoil	0.5	(1.0)	(0.5)		Fuel Oil	45.5	(0.2)	45.3
HS Fueloil	(5.5)		(5.5)		Other	3.3	(1.1)	2.2
MS Fueloil	2.9	(2.9)						
LS Fueloil	2.4	(2.4)						
Asphalt/Other	(1.1)		(1.1)					
TOTAL	(1.2)	(6.4)	(7.6)	(0.1)	TOTAL	141.5	2.9	144.4

*includes aviation gasoline

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in providing inputs for the model, but by changing the differentials, it is possible to dramatically change the relative economics of dealing with different grades of fuel oil. This problem should lessen greatly in future years as the LSFO-HSFO differential widens and becomes more stable.

The model reflects the net fuel oil situation accurately (a situation of balance in the Hawaii market), and in terms of grades produces an output slate well within the capabilities of the model. Although at the present, one refiner may choose to bring in one grade of fuel oil from the external market, while another may be exporting a different grade, in the future, the economics of producing and moving the differing grades should become more sharply defined (for example, as production, storage, and transport costs rise), and sales between the refiners should take on a more prominent role. Thus, the model appears to reflect the dynamics of this market in a way that should be adequate for this analysis; it is doubtful that a better base-year calibration can be obtained without explicitly modeling the individual oil companies and their contract commitments. Furthermore, while this latter course might provide a better match to the base-year data, there are good arguments against pursuing such a course. First, of course, is the issue of confidentiality and proprietary data, which would make it difficult to make such an adaptation to the model. Second, the base-year data themselves are of questionable validity; while they are the best estimates available, attempting a detailed match to such numbers is a questionable exercise. Finally, even if all needed data were available and reliable, running the scenarios of future years would require rather heroic assumptions about future corporate structures and awarding of supply contracts. Estimating prices for future years is a risky business at best; it is even more difficult to envision a methodology that would allow prediction of the company that would win the HECO fuel-oil supply contract in 2014.

IV. Scenario Results

A. Scenario 1, Base Case Balances

Table 17 shows the 1992 calibration run, along with the Scenario 1, Base Case, results for five-year increments across the 1994-2014 period. Demand across the period increases by 32 percent; refinery output increases by only 8 percent. This is not, as might be suspected, because of limited distillation capacity. Only in 2014 is distillation capacity filled; in all earlier years there is a small slack capacity. The model could import more crude, but instead elects to increase production partly by marginally higher crude runs, partly by small imports of cracker feedstock, and partly by more severe cracking (which increases volumetric yields).

Under this scenario, the 1994 pattern of trade is very close to the 1992 pattern. By 1999, however, the refiners are still long in gasoline and diesel, but short of jet; the marginal yield of jet from distillation is so small that it is more economic to import fuel oil than to increase refinery runs. This trend continues in the next century, and exportable surpluses of gasoline and diesel quickly disappear, leaving Hawaii with exports of naphtha only.

The jet fuel deficit mounts steadily in the Base Case. In 1994, imports account for 28 percent of jet fuel supply; by 2014, imports double in volume, and account for 42 percent of Hawaii's jet fuel supply.

Increasing relative prices of low-sulfur fuel oil make it most economic for Hawaii to meet its own needs from refining, and import low-cost high-sulfur and medium-sulfur fuel oil for bunkers and neighbor-island uses. Net fuel oil imports reach 10,600 b/d by 2014. Since these are imports of low-value products expected to be in long supply on the world market, this trend is not worrisome. Hawaii's balance in the jet fuel market is of some concern, however, given the importance of that fuel to the Hawaiian economy.

Table 17. Hawaii Petroleum Product Balance: Scenario 1, Base Case, 1992-2014

1992	(thousand barrels/day)				2004	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.1		4.2	LPG	4.1	1.2		5.3
Naphtha	6.1		3.0	3.2	Naphtha	7.3		4.2	3.2
Reg Mogas	21.1		5.2	15.9	Reg Mogas	19.6			19.6
Prm Mogas	9.0			9.0	Prm Mogas	9.5	0.1		9.7
Jet Fuel	33.7	14.3		48.0	Jet Fuel	35.7	20.6		56.3
Diesel	5.1			5.1	Diesel	6.0			6.0
Ind Gasoil	13.7		2.2	11.5	Ind Gasoil	13.8		0.1	13.7
HS Fuel Oil	7.0			7.0	HS Fuel Oil	8.2	1.1		9.4
MS Fuel Oil	7.4			7.4	MS Fuel Oil		7.4		7.4
LS Fuel Oil	30.9			30.9	LS Fuel Oil	37.6			37.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	140.3	14.4	10.3	144.4	TOTAL	144.2	30.5	4.3	170.4

1994	(thousand barrels/day)				2009	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	3.9	0.4		4.4	LPG	4.2	1.6		5.8
Naphtha	9.5		6.4	3.2	Naphtha	7.0		3.9	3.2
Reg Mogas	16.7			16.7	Reg Mogas	21.0			21.0
Prm Mogas	10.9		1.8	9.2	Prm Mogas	8.5	1.8		10.4
Jet Fuel	35.9	13.8		49.7	Jet Fuel	35.3	25.1		60.3
Diesel	5.3			5.3	Diesel	6.4			6.4
Ind Gasoil	14.6		2.7	11.9	Ind Gasoil	14.5			14.5
HS Fuel Oil	7.1			7.1	HS Fuel Oil	8.2	2.4		10.6
MS Fuel Oil	7.3			7.3	MS Fuel Oil	0.7	6.7		7.4
LS Fuel Oil	36.0			36.0	LS Fuel Oil	38.2			38.2
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.4	14.2	10.8	152.9	TOTAL	146.3	37.5	3.9	179.9

1999	(thousand barrels/day)				2014	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.8		4.9	LPG	4.2	2.0		6.2
Naphtha	9.8		6.7	3.2	Naphtha	7.5		4.3	3.2
Reg Mogas	18.6			18.6	Reg Mogas	22.4			22.4
Prm Mogas	9.9		0.6	9.3	Prm Mogas	7.6	3.4		11.0
Jet Fuel	37.1	15.9		53.0	Jet Fuel	36.8	27.4		64.2
Diesel	5.6			5.6	Diesel	6.8			6.8
Ind Gasoil	16.6		3.8	12.8	Ind Gasoil	15.5			15.5
HS Fuel Oil	8.0			8.0	HS Fuel Oil	5.9	6.2		12.1
MS Fuel Oil	3.4	4.0		7.4	MS Fuel Oil	3.1	4.4		7.4
LS Fuel Oil	34.1	3.1		37.2	LS Fuel Oil	39.7			39.7
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.2	23.9	11.1	162.0	TOTAL	151.6	43.4	4.3	190.6

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The outlook in the Base Case, then, is one of stagnating refinery output, increased product import reliance, and curtailment of most exports. Refinery distillation capacity is not a binding constraint; the balance cannot be improved economically by increased crude runs.

B. Scenario 2, Fuel Diversification

The Fuel Diversification scenario, as discussed earlier, involves increased use of coal in the power sector, coupled with a gradual move into alternative motor fuels toward the end of the forecast period (a 25 percent reduction in gasoline demand by the year 2010). The results, shown in Table 18, do not differ from the Scenario 1 Base Case until 2004, and do not show important differences until 2009.

In 2009, refinery output falls slightly. Imports of gasoline and fuel oil decrease, and imports of jet fuel increase. This trend continues in 2014, with further decreases in refinery output to below 1992 levels. A small gasoline surplus emerges, and jet fuel imports increase by 4,300 b/d over the Base Case, resulting in Hawaii's reliance on imports for approximately half of its jet fuel demand.

It is worth noting that any strictly demand-side (including alternative fuels) measures to cut petroleum use—other than a massive tax on air travel—will tend to have these kinds of effects. Measures directed at motor fuels or the composition of power-generation fuels will leave the jet fuel demand untouched, while reducing incentives for increased refinery production.

C. Scenario 3, Fuel Diversification/Refinery Expansion

This scenario examines the impact of refinery expansion on the economics of the Scenario 2 Fuel Diversification case. The demands and prices are as in the second scenario. The main change is that a number of technologies—crude distillation, vacuum distillation, catalytic reforming, cat cracking, hydrocracking, visbreaking, and hydrogen manufacturing—are made available for "construction" by the model at an amortized

Table 18. Hawaii Petroleum Product Balance: Scenario 2, Fuel Diversification, 1992-2014.

1992	(thousand barrels/day)				2004	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.1		4.2	LPG	4.1	1.2		5.3
Naphtha	6.1		3.0	3.2	Naphtha	7.3		4.2	3.2
Reg Mogas	21.1		5.2	15.9	Reg Mogas	19.6			19.6
Prm Mogas	9.0			9.0	Prm Mogas	9.5	0.1		9.7
Jet Fuel	33.7	14.3		48.0	Jet Fuel	35.8	20.6		56.3
Diesel	5.1			5.1	Diesel	6.0			6.0
Ind Gasoil	13.7		2.2	11.5	Ind Gasoil	13.8			13.8
HS Fuel Oil	7.0			7.0	HS Fuel Oil	8.2	1.1		9.4
MS Fuel Oil	7.4			7.4	MS Fuel Oil	0.0	7.4		7.4
LS Fuel Oil	30.9			30.9	LS Fuel Oil	37.6			37.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	140.3	14.4	10.3	144.4	TOTAL	144.2	30.4	4.2	170.5

1994	(thousand barrels/day)				2009	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	3.9	0.4		4.4	LPG	4.1	1.7		5.8
Naphtha	9.5		6.4	3.2	Naphtha	7.0		3.9	3.2
Reg Mogas	16.7			16.7	Reg Mogas	21.0			21.0
Prm Mogas	10.9		1.8	9.2	Prm Mogas	8.5	1.9		10.4
Jet Fuel	35.9	13.8		49.7	Jet Fuel	35.2	25.2		60.3
Diesel	5.3			5.3	Diesel	6.4			6.4
Ind Gasoil	14.6		2.7	11.9	Ind Gasoil	14.5			14.5
HS Fuel Oil	7.1			7.1	HS Fuel Oil	8.3	2.3		10.6
MS Fuel Oil	7.3			7.3	MS Fuel Oil	1.5	5.9		7.4
LS Fuel Oil	36.0			36.0	LS Fuel Oil	33.6			33.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.4	14.2	10.8	152.9	TOTAL	142.2	36.9	3.9	175.3

1999	(thousand barrels/day)				2014	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.8		4.9	LPG	4.4	4.1		8.5
Naphtha	9.8		6.7	3.2	Naphtha	8.8		5.7	3.2
Reg Mogas	18.6			18.6	Reg Mogas	16.8			16.8
Prm Mogas	9.9		0.6	9.3	Prm Mogas	10.2		1.9	8.3
Jet Fuel	37.1	15.9		53.0	Jet Fuel	32.6	31.7		64.2
Diesel	5.6			5.6	Diesel	6.8			6.8
Ind Gasoil	16.6		3.8	12.8	Ind Gasoil	15.6			15.6
HS Fuel Oil	8.0			8.0	HS Fuel Oil	3.4	8.6		12.1
MS Fuel Oil	3.4	4.0		7.4	MS Fuel Oil	7.4			7.4
LS Fuel Oil	34.1	3.1		37.2	LS Fuel Oil	26.5			26.5
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.2	23.9	11.1	162.1	TOTAL	134.6	44.4	7.6	171.4

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capital charge rate per barrel processed. This charge rate amounts to an annual recovery of 15 percent of the initial costs per year (or a "payback period" of 6.7 years). Note that this is not necessarily the rate of return or IRR for the unit, but rather a base charge to amortize the capital investment across each barrel. If the investment is profitable, it will extract higher returns per barrel of feedstock than merely the capital charge rate.

Table 19 shows the capital charge rates used in the model (processing fees per barrel of feedstock), and gives an idea of what kind of total investment these charges usually amount to for typical scales of investment. These costs are sensitive to the economies of scale, as well as location factors and the configuration of the particular refinery where the expansion is planned. Indeed, capital costs are the subject of much speculation today, since only a very limited number of major refinery additions have taken place in recent years. The figures quoted here are high relative to many of the numbers quoted in the mid-1980s, but are low relative to many of the grassroots expansions taking place abroad today.

Operation of new construction is possible at the capital charge rates shown from 1999 onward. The model elects to build new capacity and expand crude runs slightly in all years 1999 and beyond (precise figures are given in the summary section for the five scenarios below). The optimum capacity required fluctuates slightly between years, as is typical in such models, but the overall results are quite stable. The model calls for modest expansions of crude distillation (9-15 mb/d) and cat reforming (2-9 mb/d), and a substantial hydrocracking expansion of 17-18 mb/d (with accompanying 20-26 million cubic feet per day expansion in hydrogen manufacturing). The capital costs of such an expansion are estimated at \$340-390 million. Sensitivity tests suggest that the model is not "knife-edged" in its sensitivity to the capital costs.

Table 20 shows the product balances derived from this scenario. Refinery production increases from the 1992 level of 144 mb/d to the level of 162-167 mb/d. Fuel oil imports increase, and gasoline exports are maintained in most years, and increase at the end of the period. The most dramatic effect, however, is on the jet fuel balance.

Table 19. HAWMOD Model Capital Charges and Typical Unit Costs

	Capital Charge/b	Capital Charge/b/y	Typical Unit Size, b/day	Typical Unit Cap. Recovery, \$/y Cap. Charge	Typical Cost, \$	Years to Payback
Crude Distillation	\$0.25	\$91.25	100,000	\$9,125,000	\$60,833,333	6.7
Vacuum Distillation	\$0.70	\$255.50	40,000	\$10,220,000	\$68,133,333	6.7
Catalytic Reforming	\$2.40	\$876.00	20,000	\$17,520,000	\$116,800,000	6.7
Fluid Cat Cracking	\$4.50	\$1,642.50	20,000	\$32,850,000	\$219,000,000	6.7
Hydrocracking*	\$7.80	\$2,847.00	20,000	\$56,940,000	\$379,600,000	6.7
Visbreaking	\$2.20	\$803.00	30,000	\$24,090,000	\$160,600,000	6.7

**charge includes hydrogen plant costs*

Table 20. Hawaii Petroleum Product Balance: Scenario 3, Fuel Diversification/Refinery Expansion

1992 (thousand barrels/day)					2004 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.1		4.2	LPG	6.4		1.1	5.3
Naphtha	6.1		3.0	3.2	Naphtha	13.8		10.6	3.2
Reg Mogas	21.1		5.2	15.9	Reg Mogas	19.6			19.6
Prm Mogas	9.0			9.0	Prm Mogas	10.9		1.3	9.7
Jet Fuel	33.7	14.3		48.0	Jet Fuel	48.4	8.0		56.3
Diesel	5.1			5.1	Diesel	6.0			6.0
Ind Gasoil	13.7		2.2	11.5	Ind Gasoil	13.8			13.8
HS Fuel Oil	7.0			7.0	HS Fuel Oil	9.4			9.4
MS Fuel Oil	7.4			7.4	MS Fuel Oil	4.8	2.7		7.4
LS Fuel Oil	30.9			30.9	LS Fuel Oil	29.7	7.9		37.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	140.3	14.4	10.3	144.4	TOTAL	164.9	18.5	13.0	170.5

1994 (thousand barrels/day)					2009 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	3.9	0.4		4.4	LPG	6.4		0.6	5.8
Naphtha	9.5		6.4	3.2	Naphtha	13.1		9.9	3.2
Reg Mogas	16.7			16.7	Reg Mogas	21.0			21.0
Prm Mogas	10.9		1.8	9.2	Prm Mogas	10.4			10.4
Jet Fuel	35.9	13.8		49.7	Jet Fuel	48.5	11.8		60.3
Diesel	5.3			5.3	Diesel	6.4			6.4
Ind Gasoil	14.6		2.7	11.9	Ind Gasoil	14.5			14.5
HS Fuel Oil	7.1			7.1	HS Fuel Oil	10.6			10.6
MS Fuel Oil	7.3			7.3	MS Fuel Oil		7.4		7.4
LS Fuel Oil	36.0			36.0	LS Fuel Oil	33.6			33.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.4	14.2	10.8	152.9	TOTAL	166.6	19.2	10.6	175.3

1999 (thousand barrels/day)					2014 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	7.0		2.1	4.9	LPG	6.8	1.7		8.5
Naphtha	7.5		4.4	3.2	Naphtha	13.1		10.0	3.2
Reg Mogas	18.6			18.6	Reg Mogas	16.8			16.8
Prm Mogas	18.1		8.9	9.3	Prm Mogas	14.0		5.8	8.3
Jet Fuel	49.4	3.6		53.0	Jet Fuel	47.1	17.2		64.2
Diesel	5.6			5.6	Diesel	6.8			6.8
Ind Gasoil	15.7		2.9	12.8	Ind Gasoil	15.6			15.6
HS Fuel Oil	8.0			8.0	HS Fuel Oil	6.3	5.8		12.1
MS Fuel Oil	7.0	0.4		7.4	MS Fuel Oil	7.4			7.4
LS Fuel Oil	28.4	8.8		37.2	LS Fuel Oil	26.5			26.5
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	167.4	12.8	18.2	162.1	TOTAL	162.5	24.6	15.7	171.4

SCENARIO RESULTS

Instead of imports of 15.9 mb/d in the Base Case, the jet imports drop to 3.6 mb/d. Although the refining system cannot keep up with the steady increases in jet fuel demand, the refining expansion does make a large difference in the long-term imports; jet imports in 2014 under this scenario are 17.2 mb/d (27 percent of demand), as opposed to 27.4 mb/d (43 percent of demand) in the Base Case, or 31.7 mb/d (49 percent of demand) in the Fuel Diversification scenario.

D. Scenario 4, Aggressive Substitution

As discussed previously, the Aggressive Substitution scenario involves an aggressive push into alternative motor fuels, quantified by Acurex Environmental Corp. of HES Project 5, coupled with the electrical plan outlined in Scenario 2, Fuel Diversification, and the DSM measures proposed in the IRP underlying all of the other scenarios. It is worth noting again that even this scenario, which most observers would characterize as a major move away from oil, still does not cut Hawaii's oil demand from present levels; it merely restrains growth, so that demand in 2014 is only about 20,000 b/d greater than in 1992. (In the Scenario 1 Base Case, 2014 demand is 46,200 b/d higher than in 1992.)

The Aggressive Substitution scenario, which includes introduction of diesel alternatives to the extent deemed feasible by HES Project 5, is fairly well-spread across the barrel (with the notable exception of jet fuel). In the earlier years of substitution, refinery output actually remains at higher levels than in the Scenario 2 Fuel Diversification scenario, despite lower levels of demand. The balances, shown in Table 21, have higher refinery output but, significantly, show higher levels of product exports as well. Since exports from Hawaii normally are not economically advantageous, this suggests a fairly rapid deterioration in refinery profitability (see summary section below).

As in both the Scenario 1 Base Case and Scenario 2 Fuel Diversification scenarios, jet fuel imports continue to climb. Jet fuel imports of 31.8 mb/d in 2014 under

Table 21. Hawaii Petroleum Product Balance: Scenario 4, Aggressive Substitution, 1992-2014

1992	(thousand barrels/day)				2004	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.1		4.2	LPG	4.5	0.8		5.3
Naphtha	6.1		3.0	3.2	Naphtha	10.6		7.4	3.2
Reg Mogas	21.1		5.2	15.9	Reg Mogas	15.6		0.4	15.1
Prm Mogas	9.0			9.0	Prm Mogas	10.8		3.3	7.5
Jet Fuel	33.7	14.3		48.0	Jet Fuel	36.6	19.8		56.3
Diesel	5.1			5.1	Diesel	3.4			3.4
Ind Gasoil	13.7		2.2	11.5	Ind Gasoil	18.6		4.7	13.8
HS Fuel Oil	7.0			7.0	HS Fuel Oil	9.4			9.4
MS Fuel Oil	7.4			7.4	MS Fuel Oil	2.7	4.7		7.4
LS Fuel Oil	30.9			30.9	LS Fuel Oil	37.6			37.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	140.3	14.4	10.3	144.4	TOTAL	151.8	25.3	15.9	161.1

1994	(thousand barrels/day)				2009	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	3.9	0.4		4.4	LPG	4.4	1.4		5.8
Naphtha	9.5		6.4	3.2	Naphtha	9.1		5.9	3.2
Reg Mogas	16.7			16.7	Reg Mogas	15.3			15.3
Prm Mogas	10.9		1.8	9.2	Prm Mogas	11.1		3.6	7.5
Jet Fuel	35.9	13.8		49.7	Jet Fuel	33.9	26.4		60.3
Diesel	5.3			5.3	Diesel	3.5			3.5
Ind Gasoil	14.6		2.7	11.9	Ind Gasoil	17.1		2.5	14.5
HS Fuel Oil	7.1			7.1	HS Fuel Oil	6.9	3.7		10.6
MS Fuel Oil	7.3			7.3	MS Fuel Oil	3.7	3.7		7.4
LS Fuel Oil	36.0			36.0	LS Fuel Oil	33.6			33.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.4	14.2	10.8	152.9	TOTAL	140.8	35.2	12.0	163.9

1999	(thousand barrels/day)				2014	(thousand barrels/day)			
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.0	0.9		4.9	LPG	4.3	1.9		6.2
Naphtha	11.1		7.9	3.2	Naphtha	7.6		4.5	3.2
Reg Mogas	16.3			16.3	Reg Mogas	15.1			15.1
Prm Mogas	11.2		3.1	8.2	Prm Mogas	11.7		4.3	7.4
Jet Fuel	37.5	15.5		53.0	Jet Fuel	32.4	31.8		64.2
Diesel	3.4			3.4	Diesel	3.8			3.8
Ind Gasoil	18.9		6.1	12.8	Ind Gasoil	15.6			15.6
HS Fuel Oil	8.0			8.0	HS Fuel Oil	2.4	9.7		12.1
MS Fuel Oil	4.1	3.3		7.4	MS Fuel Oil	7.4			7.4
LS Fuel Oil	34.9	2.3		37.2	LS Fuel Oil	26.5			26.5
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	151.7	21.9	17.1	156.5	TOTAL	128.9	43.4	8.8	163.5

SCENARIO RESULTS

the Aggressive Substitution scenario are almost identical to those seen in the Fuel Diversification scenario; total refinery output is about 7.5 mb/d lower.

E. Scenario 5, Aggressive Substitution/Refinery Expansion

Scenario 5, Aggressive Substitution/Refinery Expansion, frees up refinery construction at the prices used under Scenario 3, Fuel Diversification/Refinery Expansion, but uses the demand forecast used in Scenario 4, Aggressive Substitution.

The results are strikingly similar to the results seen in the first refinery expansion case. Again, the model chooses to build small amounts of crude distillation (0-15 mb/d) and catalytic reforming (1-9 mb/d), with a substantial hydrocracking addition (15.8-17.5 mb/d) and associated hydrogen manufacturing (20-25 million standard cubic feet per day). Total investment costs range from \$308-391 million.

The effects on Hawaii's petroleum product balance are shown in Table 22. As in the earlier refinery expansion scenario, the construction of new hydrocracking capacity pulls down jet fuel imports, but is insufficient to keep up with jet demand growth. By 2014, jet imports of 21.1 mb/d account for one-third of demand—considerably lower than Scenarios 1, 2, and 4 (the Base Case, Fuel Diversification, and Aggressive Substitution scenarios), but are 50 percent higher than present import volumes. Furthermore, by 2014, the composition of demand has been changed enough to make refining less attractive than in the preceding years; total output under this scenario is no higher than in the Base Case (although the composition of output is of a higher average value).

Table 22. Hawaii Petroleum Product Balance: Scenario 5, Aggressive Substitution/Refinery Expansio

1992 (thousand barrels/day)					2004 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	4.1	0.1		4.2	LPG	6.5		1.2	5.3
Naphtha	6.1		3.0	3.2	Naphtha	13.7		10.5	3.2
Reg Mogas	21.1		5.2	15.9	Reg Mogas	15.1			15.1
Prm Mogas	9.0			9.0	Prm Mogas	15.0		7.6	7.5
Jet Fuel	33.7	14.3		48.0	Jet Fuel	47.6	8.7		56.3
Diesel	5.1			5.1	Diesel	3.4			3.4
Ind Gasoil	13.7		2.2	11.5	Ind Gasoil	17.6		3.7	13.8
HS Fuel Oil	7.0			7.0	HS Fuel Oil	9.4			9.4
MS Fuel Oil	7.4			7.4	MS Fuel Oil	3.1	4.3		7.4
LS Fuel Oil	30.9			30.9	LS Fuel Oil	28.1	9.5		37.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	140.3	14.4	10.3	144.4	TOTAL	161.6	22.5	22.9	161.1

1994 (thousand barrels/day)					2009 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	3.9	0.4		4.4	LPG	6.6		0.9	5.8
Naphtha	9.5		6.4	3.2	Naphtha	14.0		10.9	3.2
Reg Mogas	16.7			16.7	Reg Mogas	15.3			15.3
Prm Mogas	10.9		1.8	9.2	Prm Mogas	14.9		7.3	7.5
Jet Fuel	35.9	13.8		49.7	Jet Fuel	48.5	11.8		60.3
Diesel	5.3			5.3	Diesel	3.5			3.5
Ind Gasoil	14.6		2.7	11.9	Ind Gasoil	17.8		3.3	14.5
HS Fuel Oil	7.1			7.1	HS Fuel Oil	10.6			10.6
MS Fuel Oil	7.3			7.3	MS Fuel Oil		7.4		7.4
LS Fuel Oil	36.0			36.0	LS Fuel Oil	32.2	1.3		33.6
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	149.4	14.2	10.8	152.9	TOTAL	165.8	20.5	22.4	163.9

1999 (thousand barrels/day)					2014 (thousand barrels/day)				
	Production	Imports	Exports	Demand		Production	Imports	Exports	Demand
LPG	6.9		2.1	4.9	LPG	6.2			6.2
Naphtha	8.0		4.9	3.2	Naphtha	12.2		9.0	3.2
Reg Mogas	16.3			16.3	Reg Mogas	15.1			15.1
Prm Mogas	19.9		11.7	8.2	Prm Mogas	14.1		6.7	7.4
Jet Fuel	49.3	3.8		53.0	Jet Fuel	43.1	21.1		64.2
Diesel	3.4			3.4	Diesel	3.8			3.8
Ind Gasoil	19.1		6.3	12.8	Ind Gasoil	15.6			15.6
HS Fuel Oil	8.0			8.0	HS Fuel Oil	5.4	6.7		12.1
MS Fuel Oil	7.1	0.3		7.4	MS Fuel Oil	7.4			7.4
LS Fuel Oil	27.2	10.0		37.2	LS Fuel Oil	26.5			26.5
Asphalt	2.2			2.2	Asphalt	2.2			2.2
TOTAL	167.4	14.0	25.0	156.5	TOTAL	151.4	27.7	15.7	163.5

V. Comparisons and Summary

The various scenarios modeled resulted in significant changes in the projected pattern of petroleum product refining and trade. Figure 14 shows total refinery runs of crude oil under the five scenarios. In the Base Case, crude runs remain in the vicinity of 145-150 mb/d during the 1994-2014 period. Crude runs in the Fuel Diversification scenario (Scenario 2) begin to diverge from the Base Case after the year 2004; as the fuel diversification strategies begin to take effect, crude runs begin to fall. By the year 2014, crude runs amount to around 135 mb/d—around 17 mb/d less than the Base Case. Refinery crude runs drop most sharply in the Aggressive Substitution scenario (Scenario 4); after remaining at around 150 mb/d during the 1994-2004 period, they drop to 140 mb/d in 2009 and around 128 mb/d in 2014.

Scenario 3 (Fuel Diversification/Refinery Expansion) and Scenario 5 (Aggressive Substitution/Refinery Expansion), where refinery expansion is allowed, show a very different pattern of crude runs. Crude runs rise to around 165 mb/d in 1999, then hover in the range of 160-165 mb/d until 2009, when the reductions in demand inherent in the Aggressive Substitution scenario cause crude runs to return to their 1994 level of around 150 mb/d. Scenario 3 crude runs decline only moderately, from around 165 mb/d to 160 mb/d, during the 2009-2014 period.

In Hawaii's case, of course, refinery crude runs are equivalent to crude imports. HAWMOD selects the optimal level of crude to refine, and also selects the optimal crude slate given crude types and prices. Figure 15 details the crude slate chosen by HAWMOD under each scenario at each five-year increment. The main crude types displayed in the figure (refer to Table 12 for the complete list) are Asian Light, Asian Medium, Asian Heavy, Alaskan, Latin American, Middle Eastern, and other. While the exact volumes by type are not particularly important, the chart provides a look at the general trends and patterns of demand across time for the various scenarios.

Figure 14. Total HAWMOD Crude Runs under Five Scenarios, 1994-2014

Figure 15. Crude Runs by Type Under Five Scenarios, 1992-2014

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Just as crude refining behavior varies across the five scenarios, the role of refined product imports also differs markedly from scenario to scenario. Figure 16 shows the total imports of refined products into Hawaii under the five scenarios. The two cases which allowed the option of expanding the refineries (Scenarios 3 and 5) were obviously best at minimizing total imports of products, but under all scenarios product imports will rise. Indeed, the Fuel Diversification and Aggressive Substitution scenarios (Scenarios 2 and 4) actually make little difference in the total volumes of product imports relative to what would be expected in the Base Case.

As Figure 17 shows, however, the real difference in the longer term is not in total imports of products, but in imports of jet fuel. With today's refinery configuration, fuel substitution makes refining less economic in general, with the result that jet output contracts somewhat. Thus, jet imports, which are set to grow rapidly in future years, are pushed up even more rapidly.

Whether or not this is a problem is a matter of opinion. Middle distillate markets are expected to be tight in the coming decades, but no absolute shortfall in supply is anticipated. Nonetheless, in a crisis situation, it is likely to be easier to find supplies of crude oil than spare cargoes of jet fuel—especially if the trigger for the crisis is military in nature. (Turn back to Table 7 for a moment and consider what happened to jet fuel prices in Fall 1990 as a result of the Gulf War military buildup.) In the past, there was a degree of separability of the military and commercial jet fuel markets, since military planes consumed naphtha-type jet. The switchover to kerojet for military purposes has put the military and commercial industries in competition for essentially the same fuel. In a late twentieth-century crisis, perhaps the worst fuel for which to rely upon the import/export market is jet kerosene.

Figure 18 shows product output of the Hawaiian refining sector under the five scenarios. Both of the fuel-substitution scenarios (Scenarios 2 and 4) show a decline in product output and crude runs. The two corresponding EWC construction scenarios (Scenarios 3 and 5) increase output—at least for a decade—before sliding down toward

Figure 16. Hawaii Refined Product Imports Under Five Scenarios, 1994-2014

Figure 17. Hawaii Jet Fuel Imports Under Five Scenarios, 1994-2014

Figure 18. Hawaii Refinery Production Under Five Scenarios, 1994-2014

COMPARISONS AND SUMMARY

the Base Case output. Even in Scenario 5, however, it is important to remember that the same volume of total output does not mean the same composition of total output; the case with additional hydrocracking produces a much more valuable barrel of product, with more jet fuel and less fuel oil.

The combination of expanded hydrocracking capacity coupled with a fuel substitution program, as seen in the two EWC scenarios allowing refinery expansion, might seem to be the best of both worlds: substitution of other resources for oil where possible, and more effective processing of the oil that is brought in for refining. The problem, of course, is one of investment, as shown in Table 23. This table presents the unit sizes and estimated costs for the construction programs selected by the model. The optimal sizes for the investment naturally vary with the year being optimized around; the striking feature of these two scenarios is the relative stability of these optima from year to year. (Note that these are *not* the investments required per year; the figure for 2004, for example, is the amount of total investment suggested by optimizing on 2004 demands and prices.) In practice, of course, a refiner would likely install 20 mb/d or 25 mb/d of hydrocracking, rather than 17.4 mb/d, so as to have some spare capacity on hand. The expansions of distillation and reforming are generally too small to be undertaken as stand-alone projects; these would either be sized up to an economic level, or achieved by debottlenecking existing facilities. In any case, the estimated investments are very large: a minimum of \$300 million, and more likely a value closer to \$400 million.

The most interesting feature of the situation facing Hawaii is that many of the elements of the future energy mix are under some degree of public control. The fuel mix in the electric sector is now in the process of being determined by Integrated Resource Planning, which involves the electric utilities, other energy companies, state agencies, and concerned citizens' groups. Most of the plans for alternate-fueled vehicles seem to involve either mandated fuel-switching for segments of the fleets, or incentive programs to defray costs. The complementary half of these measures, however, is

Table 23. Investments and Imputed Costs for EWC Refinery Expansion Scenarios, (Scenarios 3 and 5), 1999-2014

	Scenario 3:		Scenario 5:	
	Fuel Diversification/ Refinery Expansion		Aggressive Substitution/ Refinery Expansion	
	<u>('000 b/d)</u>	<u>(mil. \$)</u>	<u>('000 b/d)</u>	<u>(mil. \$)</u>
1999 Crude Distillation	14.7	\$8.9	14.7	\$8.9
Cat Reforming	8.6	\$50.1	8.6	\$50.1
Hydrocracking	17.5	\$332.2	17.5	\$332.2
<u>Hydrogen (mmscf/d)</u>	19.8	na*	19.8	na*
Total Investment		\$391.2		\$391.2
2004 Crude Distillation	11.8	\$7.2	8.5	\$5.2
Cat Reforming	2.0	\$11.7	2.3	\$13.2
Hydrocracking	16.9	\$321.3	16.2	\$306.9
<u>Hydrogen (mmscf/d)</u>	24.9	na*	23.6	na*
Total Investment		\$340.2		\$325.2
2009 Crude Distillation	13.5	\$8.2	12.6	\$7.7
Cat Reforming	2.7	\$15.7	2.2	\$13.0
Hydrocracking	17.4	\$331.2	17.4	\$330.8
<u>Hydrogen (mmscf/d)</u>	25.0	na*	25.3	na*
Total Investment		\$355.0		\$351.4
2014 Crude Distillation	9.3	\$5.7	0.0	\$0.0
Cat Reforming	2.7	\$15.5	1.3	\$7.6
Hydrocracking	17.0	\$323.2	15.8	\$300.5
<u>Hydrogen (mmscf/d)</u>	25.7	na*	23.5	na*
Total Investment		\$344.4		\$308.1

**hydrogen plant included in hydrocracker costs*

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change in the refinery sector, and that is under wholly private control. The decision to change the configuration of Hawaii's refineries is not a state policy decision.

Yet all of the actions taken through public measures will have an impact on the viability of the refining system. Table 24 shows the Income Index developed earlier for each of the scenarios relative to the Base Case.

The Fuel Diversification (Scenario 2) case has little initial impact, but results in an annual loss of \$700,000/year relative to the Base Case by 2009, and nearly \$16 million/year by 2014. The Aggressive Substitution scenario, Scenario 4, cuts both sooner and deeper; losses relative to the Base in this case are nearly \$7 million/year by 1999, mounting to \$15 million/year in 2009, and \$28 million/year in 2014. Precise financial figures for the profitability of Hawaiian operations are not available, but these are losses at a level that certainly pose a threat to the viability of the refineries.

Balanced against this are the results of the two EWC scenarios where refinery expansion is allowed. Under Scenario 3, Fuel Diversification/Refinery Expansion, relative profits leap by nearly \$27 million/year in 1999, and remain in the range of \$35-43 million/year from 2004 through 2014. The Aggressive Substitution/Refinery Expansion scenario (Scenario 5) is slightly more restrained at \$22 million/year in 1999, rising to a peak of \$28 million/year in 2009, but then declining to \$15 million/year in 2014.

These figures are relative income *after* accounting for the recapture of capital investment. This is therefore a kind of profit. The aggregate numbers seem huge; tens of millions in profits. These returns are not so large, however, in light of the size of the investment and the risk involved. Most of these yearly profits amount to less than 10 percent of the total investment; some are closer to 5 percent. Still, these investments can provide an income stream for decades with appropriate maintenance. If the risk were minimal, there is little doubt that the investment would be forthcoming. The risk, however, is not minimal. All of these calculations are highly contingent, based on projections of price, on projections of international market conditions, on projections of local demand, and even, in the case of Hawaii, on rather uncertain base-year demand.

Table 24. Comparison of Income Index under Scenarios 2-5, 1994-2014

(relative to Scenario 1, Base Case, millions of dollars/year)

	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Fuel Diversification	Fuel Diversification/ Refinery Expansion	Aggressive Substitution	Aggr. Substitution/ Refinery Expansion
1992	\$0.0	\$0.0	\$0.0	\$0.0
1994	\$0.0	\$0.0	\$0.0	\$0.0
1999	\$0.0	\$26.7	(\$6.6)	\$22.0
2004	\$0.0	\$35.0	(\$6.1)	\$23.5
2009	(\$0.7)	\$43.4	(\$15.3)	\$27.8
2014	(\$15.7)	\$37.5	(\$28.2)	\$15.9

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Any of these factors could be off. Totally unforeseen events—a technological breakthrough, a war, a large federal tax on oil consumption—could easily change the profitability of a cracking investment.

This presents something of a conundrum for state policy making: many actions of the state in the energy sector could affect the viability of refining adversely, but any measures to ameliorate those damages are beyond state control.

In any scenario considered here, oil remains the dominant fuel in the Hawaiian energy scene well into the next century. The reductions in oil demand from fuel substitution scenarios considered here—which are the most aggressive that have been put forth in the course of the HES—will reduce the 2014 oil demand by 14 percent over the Base Case. This would be a significant achievement, to be sure, but it still leaves 2014 oil demand 13 percent higher than 1992 oil demand. Oil continues as the dominant fuel, and the most crucial fuel, throughout this forecast period.

Although the state's direct policy options in this sector are limited, Hawaii's critical reliance on oil means that the state must remain keenly aware of the effects of proposed policies on the oil sector. The place to start, as stressed in previous reports, is with improvement of basic data within the state, and with more attention to staff development and training in the technical aspects of the petroleum industry.

A second front would be to open up an IRP-type of dialogue on the future of oil in the state's energy supply. Of course, there is no regulatory equivalent to the PUC-required IRP for electrical system planning, but as state policies on alternative fuels are shaped in the 1990s, there should be ongoing discussions with the industry about the timing and impacts of measures under consideration. It is easy, of course, to recommend that all parties engage in "constructive thinking," as if simply bringing parties to a table will ensure their goodwill and cooperation. In fact, the oil companies in Hawaii are quite likely to be resistant to most state initiatives introducing alternative fuels; as seen before, these kinds of programs could damage the companies' profitability. (And, as the companies will be quick to point out as supporting grounds for their resistance, they are

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also likely to be somewhat costly either to the taxpayer-consumer directly or to the state treasury.) A lack of bias or the presence of constructive attitudes on the part of potential participants should not be prerequisites for initiating such a process. If there are good technical arguments against certain proposals, it is better to hear them across a meeting table, where there is room for discussion, rather than in a company's testimony before the legislature. In addition, ongoing talks should make it clear that the oil industry in Hawaii is far from monolithic; what serves the interests of one company may be quite damaging to another. The unified front typically displayed to the legislature breaks down quite rapidly if the details of policies are discussed in depth.

Finally, although the state's powers are quite limited in this regard, anything the state can do to encourage increased refinery flexibility via installation of additional upgrading facilities will make the future more readily manageable. Additional upgrading capacity will not only make the refiners more capable of responding to changes in the world market, but will also give much more latitude to state programs in alternative fuels.

Appendix

Figure 19. U.S. West Coast Unleaded Regular Gasoline Price Predicted From Singapore Spot Premium Gasoline and Crude Prices, 1987-92

**Figure 20. U.S. West Coast Jet Fuel Price Predicted From
Singapore Spot Jet and Crude Prices, 1987-92**

**Figure 21. U.S. Gulf Coast Diesel Prices Predicted From
Singapore Spot Diesel and Crude Prices, 1985-92**

Figure 22. Correlation Between USWC and USGC Diesel Prices, 1990-92

**Figure 23. U.S. West Coast High-Sulfur Fuel Oil Prices
Predicted From Singapore HSFO Prices, 1985-92**

Table 25. California Energy Commission Crude Oil Price Forecast, 1994-2014

Year	CEC Forecast 1991 \$	EWC Adaptation & Extension Est. 1993 \$	Year	CEC Forecast 1991 \$	EWC Adaptation & Extension Est. 1993 \$
1994	\$20.02	\$20.62	2005	\$27.21	\$28.03
1995	\$20.49	\$21.10	2006	\$27.78	\$28.61
1996	\$21.09	\$21.72	2007	\$28.37	\$29.22
1997	\$21.72	\$22.37	2008	\$28.97	\$29.84
1998	\$22.38	\$23.05	2009	\$29.60	\$30.49
1999	\$23.11	\$23.80	2010	\$30.25	\$31.16
2000	\$23.89	\$24.61	2011	\$30.93	\$31.86
2001	\$24.50	\$25.24	2012	\$31.62	\$32.57
2002	\$25.13	\$25.88	2013	--	\$33.00*
2003	\$25.80	\$26.57	2014	--	\$33.43*
2004	\$26.49	\$27.28			

From "Results of the California Energy Commission Delphi VI Survey of Oil Price Forecasts," Dec 1991.
Adjusted to Estimated 1993 dollars by inflating three percent.

*Last year of Delphi is 2012. Extended to 2014 at 1.32% annual growth