Statewide and Electricity-Sector Models for Economic Assessments of Hawai‘i Clean Energy Policies

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Economic and Environmental Modeling of Island Energy Systems

By the

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And

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1. Overview

Although petroleum manufacturing accounts for 2.7% of economic activity in Hawaii (a $2.4b industry relative to a $90.3b economy),[1] fluctuating oil prices can have a dramatic effect on real economic activity (Coffman, Konan and Surles (2007); Coffman (2008); and cites therein). More specifically, Hawaii is particularly vulnerable to increases in oil prices, because unlike most other U.S. states Hawaii meets nearly 80% of its electricity needs through oil-burning. Hawaii, led by the State Energy Office, currently plans a significant shift away from fossil fuels towards renewable energy sources. Decision-makers will need to understand the sector-level and economy-wide impacts of policy decisions. To this end, this work develops two complementary models: 1) a statewide economy model with a focus on energy consumption and supply, and 2) a detailed electricity sector model.

The Hawaii Computable General Equilibrium Model (H-CGE) is based on a Social Accounting Matrix of macro-economic and sector-level activity for a baseline year; in this case, 2005. The 2005 State of Hawaii Input-Output (I-O) Study developed by the State of Hawaii Department of Business, Economic Development and Tourism, is the most recent I-O table available for Hawaii. A total of sixty-eight sectors are represented in this dataset including petroleum manufacturing, electricity, ground transportation, water transportation, and aviation. In addition, there are eleven agents of final demand including households, visitors, and federal and state governments. The sectors are aggregated for reporting purposes, based on modeling results and recommendations from the project team.

H-CGE is a dynamic model, projecting in five-year intervals to the year 2030 under three oil price scenarios provided by the Energy Information Administration's (EIA) *Annual Energy Outlook2010*: reference, high and low. The benefit of a general equilibrium framework is that it shows interaction between consumers and producers, including price feedbacks and capital accumulation over time.

The Hawaii Electricity Model (HELM) is a detailed "bottom-up" representation of the electricity sector. HELM is calibrated to existing electricity units in the year 2005 for Hawaii's four counties: the City & County of Honolulu, Maui County, Kauai County, and Hawaii County. HELM is a cost-minimization linear program model (i.e. a partial equilibrium representation of the electricity sector for the State) that uses H-CGE consistent assumptions regarding the world price of oil and electricity demand for the state to determine electricity generation type to the year 2030 (in five-year intervals). Electricity generation fuels include diesel, fuel oil, coal, municipal solid waste, geothermal, hydro, biodiesel, biomass, solar photovoltaic, and wind.

The following report provides a detailed overview of both H-CGE and HELM, discussing current model calibration, model harmonization and integration, and future scenario building. Section II of the report presents H-CGE; Section III presents HELM; and

[1] DBEDT (2008). Based on the value of petroleum manufacturing relative to total output.

Section IV discusses how the models are integrated. In conclusion, Section V proposes scenarios for analysis and subsequent necessary model development.

2. The Hawaii Computable General Equilibrium Model (H-CGE)

H-CGE is an economy-wide computable general equilibrium model calibrated to the 2005 State of Hawaii Input-Output (I-O) Table maintained by the State of Hawaii Department of Business, Economic Development and Tourism.

The I-O Table provides a Social Account Matrix (SAM) of economic activity for Hawaii, at the macroeconomic level, sector level, and for final demand amongst key agents such as households, visitors, state and federal government. The I-O Table details 68 sectors of Hawaii's economy, 11 agents of final demand, and value-added in the form of capital endowments, wage labor, and proprietor income.

The term "general equilibrium" means that the model illustrates the interaction between both producers and consumers, including price effects in an equilibrium setting (i.e. equilibrium prices are calibrated to clear markets where supply equals demand).

Hawaii's economy is depicted as a small open economy. This means that Hawaii producers are modeled as world price takers, including the world price of oil. The oil price projections provided in EIA's *Annual Energy Outlook 2010* (reference, low, and high) are used to provide baseline scenarios to the year 2030. The model projects dynamically in five-year intervals to the year 2030, with endogenous capital accumulation and propelled by a historic rate of economic growth of 2.2% annually. Five-year intervals were chosen (rather than year-to-year) because of the large capital investments required in the electricity sector, thus negating smooth transitions on an annual basis.

H-CGE is solved using GAMS (General Algebraic Modeling System) and MPSGE (Mathematical Programming for General Equilibrium Analysis). For more information on these modeling platforms, refer to Brooke et al., 1988, and Rutherford, 1987 and 1999, respectively.

2.a. Data Inputs

The primary data inputs into H-CGE are the 2005 State of Hawaii Input-Output Table and EIA's 2010 oil price forecasts.

State of Hawaii Input-Output Table

The following provides a list of detailed sectors within the 2005 State of Hawaii Input-Output Study and the aggregation used for reporting purposes (and for the following sections of this report). The sectors are presented in the order they appear within the I-O Table:

I-O Table Sector List

1 Sugarcane
2 Vegetables
3 Macadamia nuts
4 Pineapples
5 Flowers and Nursery Products
6 Other Crops
7 Animal Production
8 Aquaculture
9 Commercial Fishing
10 Forestry and Logging
11 Support Activities for Agriculture
12 Mining
13 Single Family Construction
14 Construction of Other Buildings
15 Heavy and Civil Engineering Construction
16 Maintenance & Repairs
17 Food Processing
18 Beverage Manufacturing
19 Apparel and Textile Manufacturing
20 Petroleum Manufacturing
21 Other Manufacturing
22 Air Transportation
23 Water Transportation
24 Truck and Rail Transportation
25 Transit and Ground Passenger Transportation
26 Scenic and Support Activities for Transportation
27 Couriers and Messengers
28 Warehousing and Storage
29 Publishing including internet
30 Motion Picture and Source Recording Industries
31 Broadcasting
32 Telecommunications
33 Internet providers, web, and data processing
34 Other Information Services
35 Electricity
36 Gas Production & Distribution
37 Wholesale Trade
38 Retail Trade
39 Credit Intermediation and Related Activities
40 Insurance Carriers and Related Activities
41 Other Finance and Insurance
42 Owner-Occupied Dwellings
43 Real Estate
44 Rental & Leasing and Others
45 Legal Services
46 Architectural and Engineering Services
47 Computer Systems Design Services
48 R&D in the Physical, Engineering & Life Sciences
49 Other Professional Services
50 Management of Companies and Enterprises
51 Travel Arrangement and Reservation Services
52 Administrative and Support Services
53 Waste Management and Remediation Services
54 Colleges Universities and Professional Schools
55 Other Educational Services
56 Ambulatory Health Care Services
57 Hospitals
58 Nursing and Residential Care Facilities
59 Social Assistance
60 Arts and Entertainment
61 Accommodations
62 Eating and Drinking
63 Repair and Maintenance
64 Personal and Laundry Services
65 Organizations
66 Federal Government Military
67 Federal Government Civilian
68 State and Local Government

14-Sector Aggregation

20. Petroleum Manufacturing
35. Electricity
(1*9,11).Agriculture
10. Forestry
(13*16). Construction
(12,17*19,21). Other Manufacturing
22. Air Transportation
23. Water Transportation
(24*28).Other Transportation
(37,38). Wholesale and Retail Trade
(42*44).Real Estate and Rentals
(29*34,36,39*41,45*65). Other Services
(66,67). Federal Government
68. State Government

The 14-sector aggregation was chosen based on energy sectors of interest (i.e. electricity and petroleum manufacturing), potentially instrumental sectors in energy and climate change policy (such as agriculture and forestry), and other relatively highly energy-intensive sectors (such as transportation). Other sectors are aggregated based on generalized groupings (such as other services).

Industry Composition

On the production side, the 2005 State of Hawaii I-O Table provides the value of sector-level and value-added activity. In addition, it details the value of imports to each sector and the number of jobs. The following table, Table 1, provides a summary of the I-O Table.

Table 1. Overview of Hawaii's Production

	Total Output*	Inter-Industry Demand	Imports	Labor Income	Proprietor Income	Other Value-Added	Jobs**
	$ 2005 Billion						#
Total	**$90.3**	**$23.4**	**$11.9**	**$32.5**	**$3.0**	**$19.6**	**838,588**
Electricity	2.1%	4.5%	2.8%	0.9%	0.1%	3.0%	0.3%
Petroleum Manufacturing	2.7%	5.4%	14.4%	0.2%	0.8%	0.5%	0.1%
Agriculture	0.8%	1.4%	0.9%	0.8%	0.4%	0.6%	1.9%
Forestry & Logging	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Construction	7.9%	3.6%	15.0%	7.0%	12.3%	2.9%	5.3%
Other Manufacturing	3.2%	5.5%	8.7%	2.0%	8.0%	0.2%	2.2%
Air Transportation	2.4%	0.6%	3.9%	1.7%	0.1%	0.7%	1.2%
Water Transportation	1.9%	1.5%	4.4%	0.5%	0.0%	0.5%	0.4%
Other Transportation	1.6%	2.4%	0.8%	1.9%	4.1%	1.4%	2.1%
Wholesale and Retail Trade	10.0%	9.3%	9.2%	9.4%	9.5%	12.9%	13.2%
Real Estate and Rentals	15.5%	17.7%	4.4%	1.9%	15.4%	43.4%	5.1%
Other Services	37.2%	45.3%	32.4%	39.1%	49.3%	27.7%	47.6%
Federal Government	8.4%	1.1%	0.6%	20.9%	0.0%	3.1%	10.1%
State & Local Government	6.3%	1.7%	2.3%	13.6%	0.0%	3.1%	10.5%

Source: Department of Business, Economic Development, and Tourism, State of Hawaii (2008). The 2005 State Input-Output Study for Hawaii.
* The value of total output is equal to the summed value of inter-industry demand, imports, labor income, proprietor income and other value-added. These components provide a "production function" for each sector detailed within the I-O Table.
** "Jobs" represents both the quantity of employee labor and proprietor labor.

Hawaii's economy produces over $90 billion of output annually. There are 839,000 jobs, with the largest employment in the service sector, including wholesale and retail trade (13% of jobs), and other services (48%). The state and local government is also a large employer, with nearly 11% of jobs and 14% of wages paid. The electric sector accounts for 2% of overall economic activity. Petroleum manufacturing accounts for nearly 3% of economic output and other energy-intensive sectors like transportation (including air transportation, water transportation and other transportation) account for nearly 6% of economic activity.

Final Demand

Goods and services are consumed as intermediate inputs into the production of other industries, as well as by agents of final demand. Table 2 shows consumption of goods and services within Hawaii's economy by residents (households), visitors, state and local government, federal government, as well as the value that is put into investment and exported from the State.

Table 2. Overview of Hawaii's Final Consumption

	Household Demand	Visitor Demand	State and Local Gov*	Federal Gov**	Investment	Exports
	$ 2005 Billion					
Total	**$36.4**	**$16.4**	**$6.8**	**$9.0**	**$7.9**	**$3.9**
Electricity	1.8%	0.0%	2.9%	0.3%	0.0%	0.0%
Petroleum Manufacturing	1.1%	0.2%	0.8%	0.6%	0.0%	15.5%
Agriculture	0.4%	0.2%	0.0%	0.0%	0.0%	5.5%
Forestry & Logging	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Construction	0.0%	0.0%	10.7%	4.8%	65.3%	0.0%
Other Manufacturing	1.7%	0.5%	0.5%	0.5%	1.3%	18.7%
Air Transportation	1.0%	9.7%	0.3%	0.0%	0.1%	0.4%
Water Transportation	1.3%	2.6%	0.2%	0.0%	2.4%	5.4%
Other Transportation	0.7%	3.0%	0.5%	0.0%	0.3%	1.7%
Wholesale and Retail Trade	11.6%	11.4%	1.3%	0.1%	7.1%	2.6%
Real Estate and Rentals	20.4%	12.7%	1.3%	0.1%	0.5%	5.7%
Other Services	36.9%	45.7%	3.1%	2.9%	5.6%	29.7%
Federal Government	1.1%	0.5%	0.0%	76.5%	0.0%	0.0%
State & Local Government	0.7%	0.0%	73.5%	0.0%	0.0%	0.0%
Imports	21.2%	13.6%	4.8%	14.1%	17.5%	14.8%

Source: Department of Business, Economic Development, and Tourism, State of Hawaii (2008). The 2005 State Input-Output Study for Hawaii.
* State and Local Government includes both investment and consumption
** Federal Government includes both civilian and military, investment and consumption.

Residents consume $36 billion of goods and services annually, the largest portions being services (37%), real estate (20%) and imported products (21%). Residents spend $654 million on electricity and $416 million on petroleum products (primarily gasoline). Visitors, on the other hand, do not consume electricity "directly" (i.e. they are not customers of the electric utilities) but rather "indirectly" through hotel services and other amenities. The benefit of an I-O framework is that this "indirect" consumption of electricity is accounted for within the model.

State and local government spend $200 million annually on electricity, while the federal government spends $24 million.

Interestingly, petroleum manufacturing is amongst the largest *physical* exports from the State, a value of $609 million.[2]

[2] Visitors are also typically classified as an "export good."

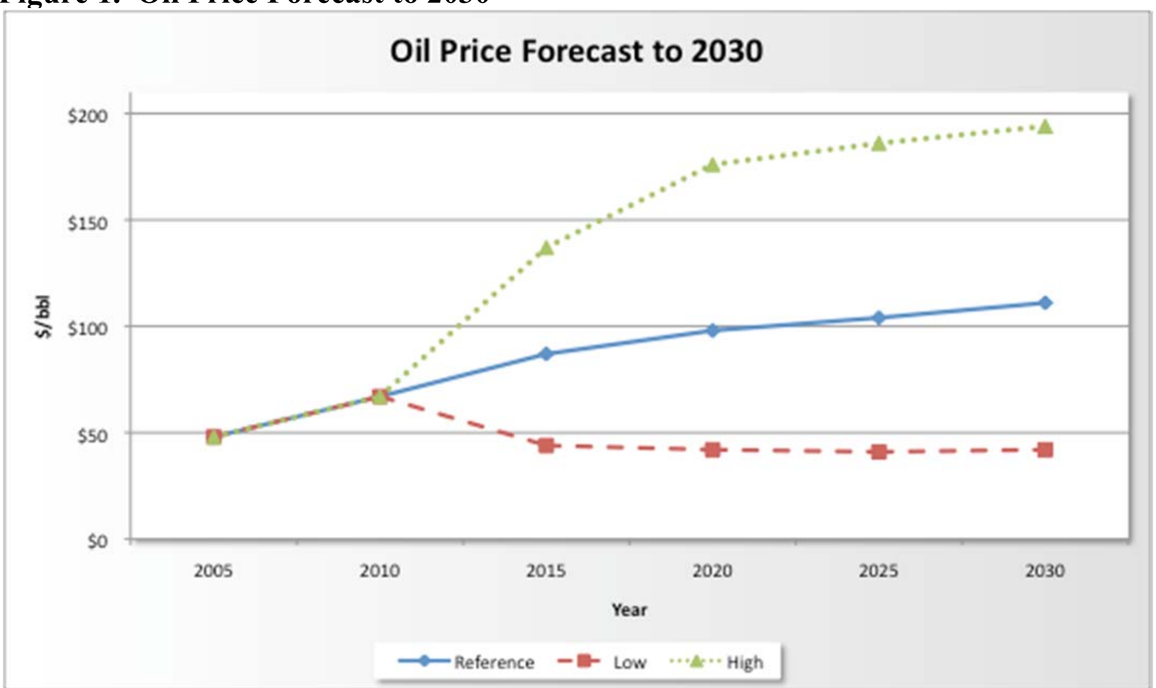
EIA Oil Price Projections

The EIA *Annual Energy Outlook 2010* includes oil price forecasts on a reference scenario, high oil prices, and low oil prices. The *Annual Energy Outlook* creates the projections using the EIA's National Energy Modeling System, based on varying economic growth projections. The following table, Table 3, details the forecast on an annual basis and Figure 1 shows a graphical representation.

Table 3. Oil Price Forecast

	Reference		Low		High	
Year	**$/bbl**	**Relative to 2005**	**$/bbl**	**Relative to 2005**	**$/bbl**	**Relative to 2005**
2005	$48	1.00	$48	1.00	$48	1.00
2010	$67	1.40	$67	1.40	$67	1.40
2015	$87	1.81	$44	0.92	$137	2.85
2020	$98	2.04	$42	0.88	$176	3.67
2025	$104	2.17	$41	0.85	$186	3.88
2030	$111	2.31	$42	0.88	$194	4.04

Figure 1. Oil Price Forecast to 2030



The forecast is used to determine baseline economic conditions, projecting to the year 2030 in five-year intervals. The projections are used for both H-CGE and HELM to determine a baseline assessment of Hawaii's economic growth, energy demand including electricity, and the relative cost of alternative energies. This baseline will then be used as three reference scenarios against which to assess policy alternatives (discussed in Section 5).

2.b. Model Structure

H-CGE represents a classical Walrasian system where goods are produced under perfect competition and constant returns to scale using intermediate commodities, imports, labor (provided by households) and capital.

Production of Non-Energy Sectors

Production in the economy is represented through a nested-Leontief function. At the first level, a Leontief production function represents final output (Y_j) in sector j=1,..n as made up of intermediate inputs (Z_{ij}) of commodity i=1,..n, and energy/value-added (EV_j). Final output of sector j and intermediate input of commodity i include all sectors with the exception of energy (petroleum manufacturing and electricity):

$$Y_j = \min[Z_{1j} / \alpha_{1j}, ...Z_{nj} / \alpha_{nj}, EV_j / \alpha_{vj}] \tag{1}$$

where α_{ij}, α_{vj} are unit input coefficients for intermediates and energy/value-added respectively.

At the second level, intermediate inputs consist of flexible domestically-produced and importable commodities represented through an Armington[3] constant elasticity of substitution (CES) production nest:

$$Z_{ij} = [\theta_{Dij} D_{ij}^{(\varepsilon_{ijm}-1)/\varepsilon_{ijm}} + \theta_{Mj} M_j^{(\varepsilon_{ijm}-1)/\varepsilon_{ijm}}]^{\varepsilon_{ijm}/(\varepsilon_{ijm}-1)} \tag{2}$$

where ε_{ijm} is the CES substitution between domestically-produced good i and imports by producer j. ε_{ijm} takes the value 1.0. D_{ij} is what producer j demands of sector i for domestically-produced goods and M_j is the composite import good demanded by sector j. The parameter shares are represented by θ_{Dij} and θ_{Mj}, respectively.

For the energy/value-added (EV_j) nest, energy sectors (E_j) are represented as substitutable with value-added (V_j):

$$EV_j = [\alpha_{Ej} E_j^{(\sigma_{EVj}-1)/\sigma_{EVj}} + \alpha_{Vj} V_j^{(\sigma_{EVj}-1)/\sigma_{EVj}}]^{\sigma_{EVj}/(\sigma_{EVj}-1)} \tag{3}$$

where σ_{EVj} is the CES among energy and value-added variables and α_{Ej}, α_{Vj} are the respective parameter shares. σ_{EVj} takes the value 0.5.

Value-added consists of capital (K_j) and labor (L_j), where labor is a composite of wage labor and proprietor income:

[3] The "Armington assumption" states that goods are differentiated by country of origin and is often used in regional CGE models to account for cross-hauling in trade data and to preclude unrealistic extreme specialization within countries. See Armington (1969).

$$V_j = [\alpha_{Lj} L_j^{(\sigma_{Vj}-1)/\sigma_{Vj}} + \alpha_{Kj} K_j^{(\sigma_{Vj}-1)/\sigma_{Vj}}]^{\sigma_{Vj}/(\sigma_{Vj}-1)} \tag{4}$$

where σ_{Vj} is the CES among value-added variables and α_{Lj}, α_{Kj} are the respective parameter shares. σ_{Vj} takes the value 1.0.

Labor (L_j) is a composite between wage labor (W_j) and proprietor income (R_j), which are, represented in a Leontief relationship:

$$L_j = \min[W_j / \alpha_{Wj}, R_j / \alpha_{Rj}] \tag{5}$$

where α_{Wj}, α_{Rj} are unit input coefficients for wage labor and proprietor income respectively.

Energy sectors include electricity (EL_j) and petroleum manufacturing (PM_j) such that:

$$E_j = [\alpha_{ELj} EL_j^{(\sigma_{Ej}-1)/\sigma_{Ej}} + \alpha_{PMj} PM_j^{(\sigma_{Ej}-1)/\sigma_{Ej}}]^{\sigma_{Ej}/(\sigma_{Ej}-1)} \tag{6}$$

where σ_{Ej} is the CES among energy sector variables and α_{ELj}, α_{PMj}, are the respective parameter shares. σ_{Ej} takes the value 0.2.

The initial endowment of wage labor, proprietor income, and capital ($\overline{W}_0, \overline{R}_0, \overline{K}_0$) are given within the baseline dataset. In calibration, the value of the initial endowment of wage labor, proprietor income and other value-added must equal the sum of each factor over all j industries.

$$W = \overline{W}_0 = \sum_j W_j \tag{7}$$

$$R = \overline{R}_0 = \sum_j R_j \tag{8}$$

$$K \equiv \overline{K}_0 = \sum_j K_j \tag{9}$$

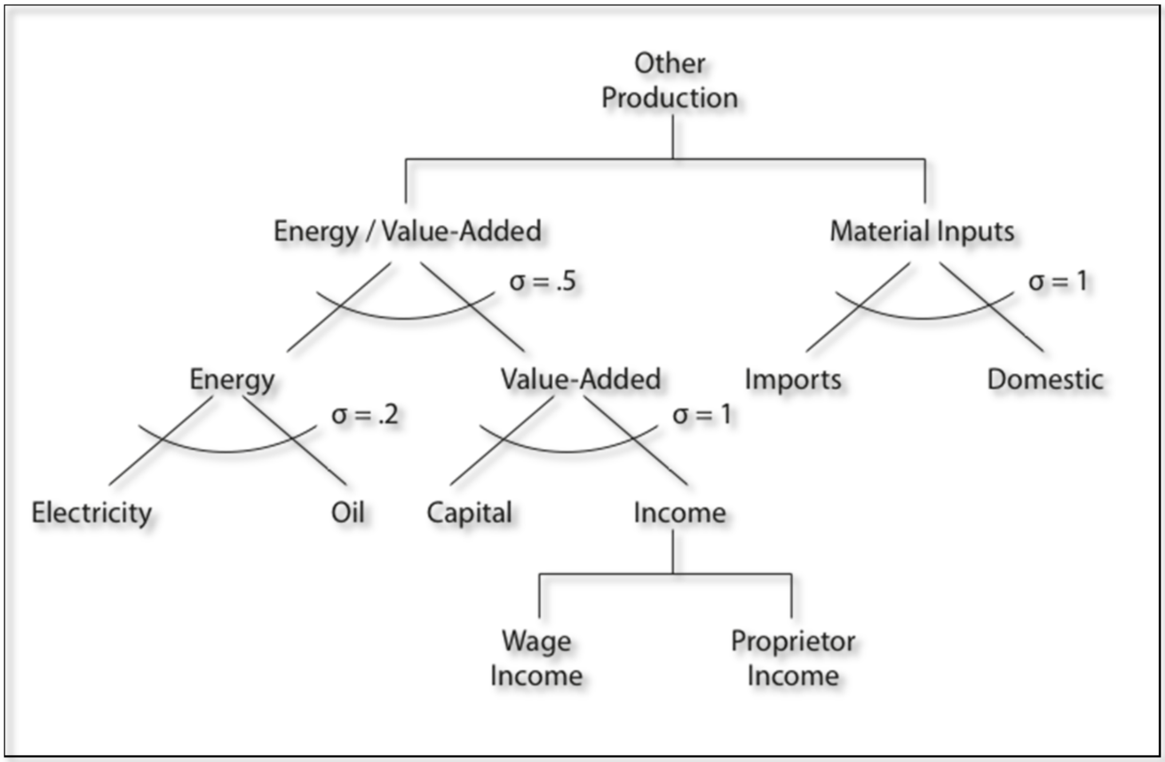
Output commodity Y_j can either be consumed domestically or exported and, under the Armington assumption, is differentiated for those markets using a constant elasticity of transformation (CET) function between domestic (D_j) sales and exports (X_j):

$$Y_j = [\beta_{Dj} D_j^{(\varepsilon_j-1)/\varepsilon_j} + \beta_{Xj} X_j^{(\varepsilon_j-1)/\varepsilon_j}]^{\varepsilon_j/(\varepsilon_j-1)} \tag{10}$$

where ε_j is the elasticity of transformation and β_{Dj}, β_{Xj} are parameter shares. ε_j equals 5.0.

Figure 2 provides a graphical representation of the described production function for non-energy sectors.

Figure 2. Non-Energy Sector Production Structure

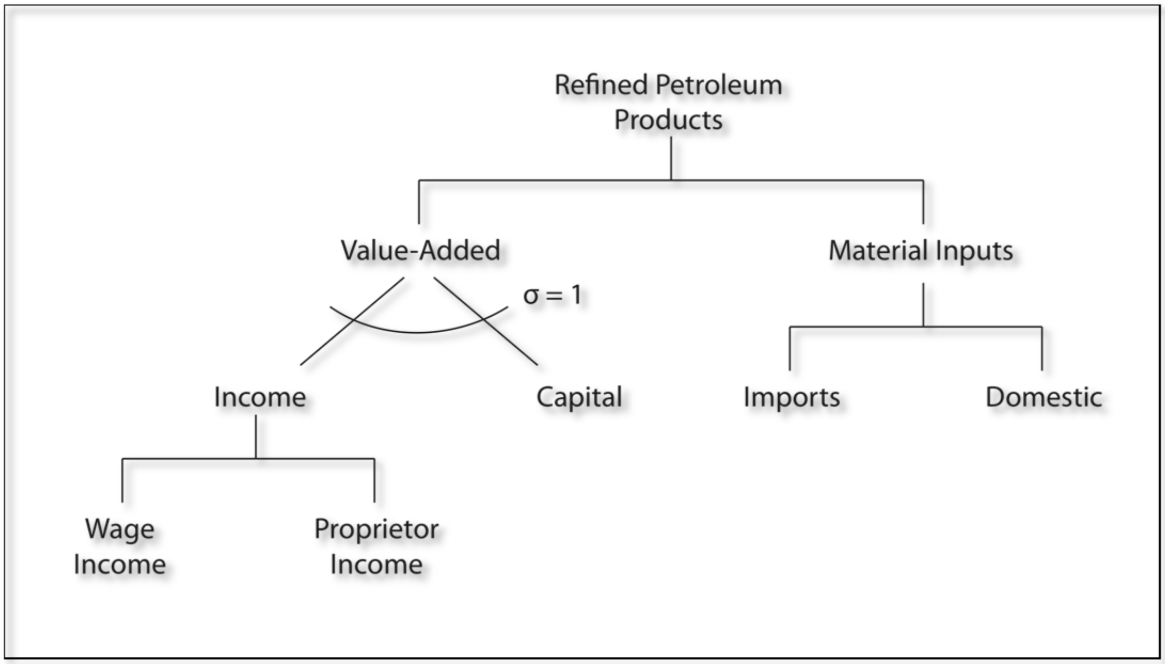


Production of Petroleum Manufacturing

The production of the petroleum manufacturing sector is assumed to be somewhat more "rigid" than other sectors. Specifically, the production of petroleum manufacturing output (i.e refined petroleum products) is assumed to be a nested Leontief structure, with the exception of the value-added nest (which takes the form of Cobb-Douglas). This means that there is ability to upgrade capital stocks to alter sectoral output. Otherwise, without capital upgrades, refinery technology is such that inputs are taken in fixed proportions.

In addition, for the purpose of the EIA oil price scenarios, the value of imports into the petroleum manufacturing sector is assumed to be primarily crude oil. Figure 3 shows a graphical representation of the production function for the petroleum manufacturing sector. Besides elasticity values, the equations remain unchanged relative to the production function for non-energy sectors and thus equations are not again provided.

Figure 3. Petroleum Manufacturing Production Structure



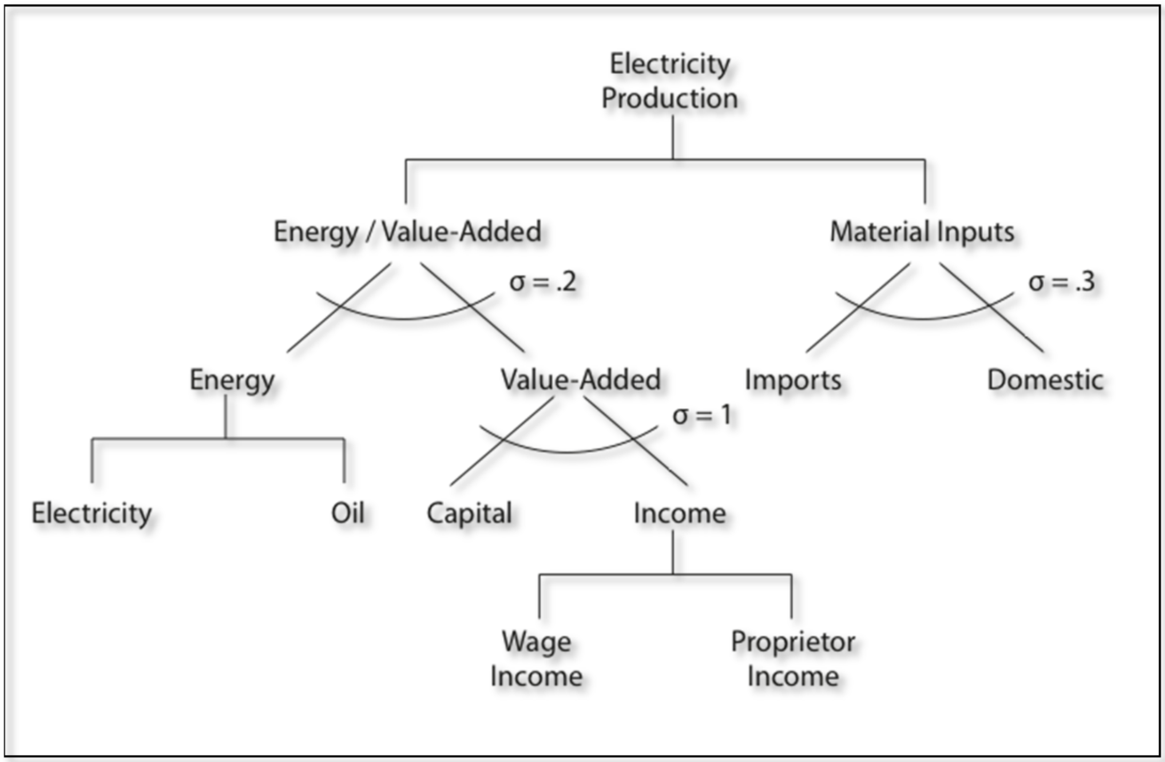
Production of Electricity

While the electric sector is the primary sector of interest for this analysis, the sector is defined in detail within HELM. Thus the electricity sector within H-CGE acts as a placeholder in which results from HELM are used as inputs to produce new equilibrium conditions.

In terms of H-CGE's output being used as input into HELM, H-CGE provides the dynamic projection of baseline electricity demand for the State under the three EIA oil price scenarios. To more accurately represent demand over time, an exogenous electricity efficiency parameter is used to represent gains in both technology and federal programs (which are not explicitly modeled in H-CGE). The parameter is estimated using EIA data on residential energy intensities and economy-wide efficiency parameters (energy per GDP) over time (U.S. Energy Information Administration, 1999; U.S. Energy Information Administration, 2009). The figure is taken to be a 0.8% annual efficiency gain (4.0% over a five-year time period).

Figure 4 provides a graphical representation of the production function for the electricity sector.

Figure 4. Electricity Sector Production Structure



Household Consumption

Household consumption, at the first level, is represented by a Cobb-Douglas utility function between transportation (TC) and other consumption (OC):

$$U = [\rho_{TC} TC^{(\sigma-1)/\sigma} + \rho_{OC} OC^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)} \tag{11}$$

where U is the utility level, TC is consumption of transportation, and OC is the consumption of other goods; ρ_{TC}, ρ_{OC} are the resident income expenditure share on transportation and other consumption, respectively; and σ is the CES parameter, taking a Cobb-Douglas form (value of 1).

Within other consumption (OC), households consume both energy goods (EH) and non-energy goods (C):

$$OC = [\theta_{EH} EH^{(\sigma_{OC}-1)/\sigma_{OC}} + \theta_C C^{(\sigma_{OC}-1)/\sigma_{OC}}]^{\sigma_{OC}/(\sigma_{OC}-1)} \tag{12}$$

where EH is the energy consumption of households, and C is the consumption of other goods; θ_{EH}, θ_C are the parameter shares, respectively; and σ_{OC} is the CES parameter, taking the value of 0.25.

Households consume energy goods in the form of electricity (EL) and gas (GS):

$$EH = [\theta_{EL} EL^{(\sigma_{EH}-1)/\sigma_{EH}} + \theta_{GS} GS^{(\sigma_{EH}-1)/\sigma_{EH}}]^{\sigma_{EH}/(\sigma_{EH}-1)} \tag{13}$$

where EL is the electricity consumption of households, and GS is the gas consumption of households; θ_{EL}, θ_{GS} are the parameter shares, respectively; and σ_{EH} is the CES parameter, taking the value of 0.1.

Residents flexibly consume both domestically-produced goods (i=1,…,n) and an imported composite good (m):

$$C_i = [\theta_{Di} D_i^{(\varepsilon_M-1)/\varepsilon_M} + \theta_M M^{(\varepsilon_M-1)/\varepsilon_M}]^{\varepsilon_M/(\varepsilon_M-1)} \tag{14}$$

where ε_M is the Armington CES between domestically-produced good i and imports m, taking the value of 1.0. D_i is resident demand for domestically-produced good i and M is imported demand. The parameter shares are represented by θ_{Di} and θ_M, respectively.

For transportation consumption, households consume purchased transportation (PT) and private transportation (i.e. private vehicles, "cars," represented through the purchase of gasoline) (CR):

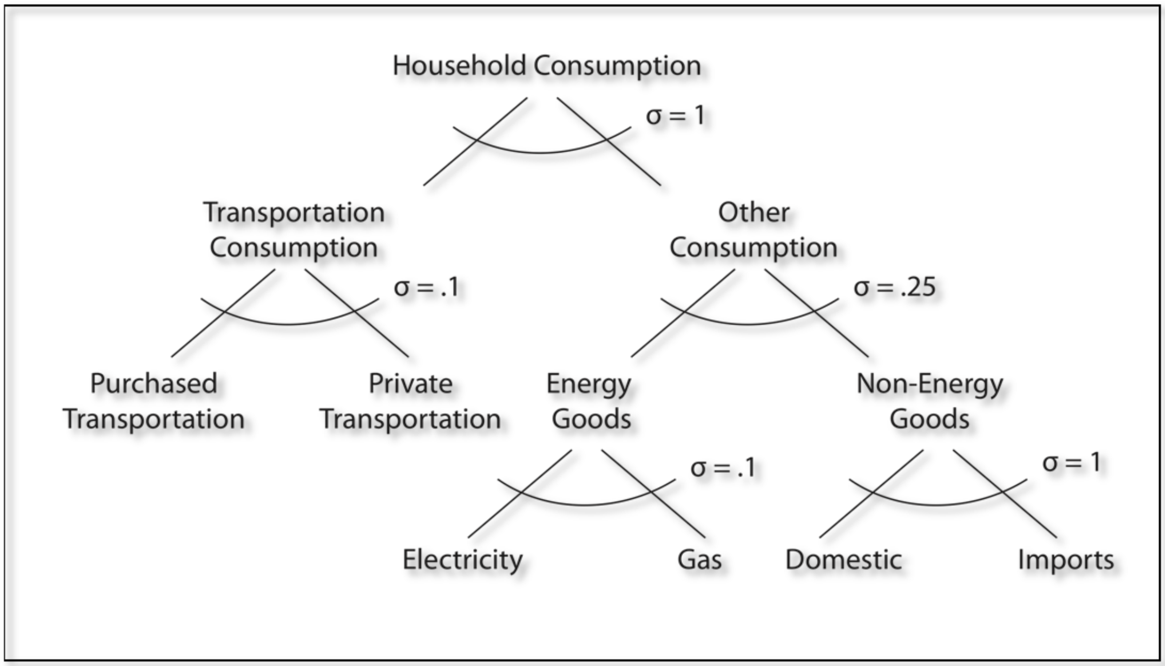
$$TC = [\theta_{PT} PT^{(\sigma_{TC}-1)/\sigma_{TC}} + \theta_{CR} CR^{(\sigma_{TC}-1)/\sigma_{TC}}]^{\sigma_{TC}/(\sigma_{TC}-1)} \tag{15}$$

where PT is the consumption of purchased transportation by households,[4] and CR is the consumption of gasoline (and diesel) for ground transportation; θ_{PT}, θ_{CR} are the parameter shares, respectively; and σ_{TC} is the CES parameter, taking the value of 0.1. This level of detail is provided within the household sector because the oil price scenarios will greatly impact household transportation patterns.

Figure 5 provides a graphical representation of the utility function.

[4] Including air transportation, water transportation, trucking, bus transit, and sightseeing transportation.

Figure 5. Household Consumption



Household Budget Constraint

A representative resident's expenditure constraint can be written as:

$$\sum_i p_i C_{ri} + p_m C_{rm} = p_w W + p_R R + p_K K + \overline{p}_{fx} BP - T_r \tag{16}$$

where prices p_i represent the market prices for commodities i = 1,..*n* and p_m is the price of imports. C_{ri} is resident consumption of good i and C_{rm} is the consumption of imported goods. The resident derives income from factors of production including wage labor (*W*), proprietor income (*P*), and capital (*K*), where p_W, p_R, and p_K are the market price of the respective factors. The resident pays a lump-sum tax (T_r), net of transfer payments, to the State and Local Government. The resident also receives foreign exchange ($\overline{p}_{fx} BP$) from a balance of payment deficit, described below.

Visitors

Visitor consumption is represented through a simple Cobb-Douglas utility function:

$$U_v = [\sum_i \rho_{vi} C_{vi}^{(\sigma_{vi}-1)/\sigma_{vi}} + \rho_m C_{vm}]^{\sigma_{vi}/(\sigma_{vi}-1)} \tag{17}$$

where U_v is the visitor utility level, C_{vi} is consumption of domestic goods and services, C_{vm} is the consumption of imported goods, and ρ_{vi} and ρ_{vm} are the visitor income expenditure share on commodities i = 1,..*n* and imports, respectively. σ_{vi} is the CES parameter, taking a Cobb-Douglas form (value of 1).

Because visitors do not provide labor or earn income within Hawaii, a representative visitor's income (I_v) is taken to be exogenous:

$$I_v \equiv I_{v0} = \sum_i p_i C_{vi} + p_m C_{vm} \tag{18}$$

where I_{v0} is the initial visitor expenditure.

Government

Government activity is represented through the State and Local Government (*SG*) and the Federal Government (*FG*). Each government type purchases domestic commodities (G_{gi}) and imports (G_{gm}) according to a Leontief utility function to assure a constant level of public provision:

$$U_g = \min[G_{g1},..,G_{gn},G_{gm}] \tag{19}$$

where $g = SG, FG$.

The State and Local Government depends entirely on the economy for the tax base:

$$\sum_i p_i G_{SLi} + p_m G_{SLm} = \sum_i p_i Y_i \tau_i + T_r \tag{20}$$

where p_i and p_m are the price of commodities i=1,..,n and imports, respectively. Thus the left-hand side represents the cost of public expenditures. These expenditures are funded primarily through the State's general excise tax (τ_i) on producer output (Y_i) of commodity *i*. The State and Local Government also impose a variety of taxes (T_r), such as property and income taxes on residents.

The market clearing conditions must hold such that the cost of public expenditures balances government income.

$$\sum_i p_i G_{gi} + p_m G_{gm} = I_{g0} \equiv I_g \tag{21}$$

Balance of Payments

A balance of external payments (*BP*) is maintained under the assumption of a fixed exchange rate ($\overline{p}_{fx}$), where $\overline{p}_{fx}$ is the exchange rate with the "rest of the world." This assumption is made because Hawaii uses the U.S. dollar as a means of currency and, as a small economy, has no effect on the exchange rate. The quantity of imports (*M*) is constrained by the inflow of dollars obtained from visitor expenditures (I_v), Federal Government expenditures (I_{FG}), and Hawaii exports (X_j). Because Hawaii is a price taker, import and export prices are exogenous.

$$\overline{p}_{fx}BP = \overline{p}_m M - I_v - I_{FG} - \sum_j \overline{p}_{xj} X_j \qquad (22)$$

Market Clearing

Constant returns to scale and perfect competition ensure that the producer price (p_j) equals the marginal cost of output in each sector j. In addition, the State and Local Government collects a general excise tax (τ_j) on sales. This implies that the value of total output (supply) equals producer costs, where p_W, p_R, and p_K equal the market price of labor, proprietor income, and capital respectively.

$$p_j Y_j (1+\tau_j) = \sum_{i=1,..n} p_i Z_{ij} + p_W W_j + p_R R_j + p_m M_j \qquad (23)$$

In addition, sector j output, which supplies to the domestic market (D_j), is demanded by households and visitors $a \in \{h,v\}$, and government $g \in \{SG,FG\}$, and industries Z_i = $1,..,n$.

$$D_j = \sum_a C_{aj} + \sum_g G_{gj} + \sum_i Z_i \qquad (24)$$

In equilibrium, the value of output balances the value of inter-industry, consumer, and government agencies demand.

Elasticity Values

Table 4 provides the elasticity values used within H-CGE, provided above, and documented with a source where available.

Table 4. Model Elasticity Values and Source

Elasticity Between:	Value	Source
Domestic Consumption & Exports	5	Konan & Kim (2005); Ross (2007) uses 3.0
Non-Energy Sector Production		
Energy/Value-Added & Material Inputs	0	Ross (2007), standard assumption
Energy & Value-Added	0.5	Ross (2007)
Electricity & Oil	0.2	Ross (2007) uses 0.5, adjusted downwards
Capital & Income	1	Ross (2007), standard assumption
Wage Income & Proprietor Income	0	Assumes fixed relationship between proprietors and labor
Domestic Goods & Imported Goods	1	Armington Assumption, Cobb-Douglas
Petroleum Manufacturing Sector		
Value-Added & Material Inputs	0	Leontief Production, standard assumption
Capital & Income	1	Ross (2007), standard assumption
Wage Income & Proprietor Income	0	Assumes fixed relationship between proprietors and labor
Domestic Goods & Imported Goods	0	Armington Assumption, Leontief due to rigid technology
Electricity Sector		
Energy/Value-Added & Material Inputs	0	Ross (2007)
Energy & Value-Added	0.2	Ross (2007)
Electricity & Oil	0	Ross (2007)
Capital & Income	1	Ross (2007), standard assumption
Wage Income & Proprietor Income	0	Assumes fixed relationship between proprietors and labor
Domestic Goods & Imported Goods	0.3	Ross (2007)
Household Consumption		
Transportation & Other Consumption	1	Ross (2007)
Energy Goods & Non-Energy Goods	0.25	Ross (2007)
Electricity & Gas	0.1	Ross (2007) uses 0.4 for general "energy", adjusted down
Purchased & Private Transportation	0.1	Ross (2007) uses 0.2, but HI has few public transit options
Other Goods and Services	0.5	Ross (2007)
Domestic Goods & Imported Goods	1	Konan & Kim (2005)
Visitor Consumption		
Consumption Goods	1	Konan & Kim (2005)
Government		
Public Expenditures	0	Konan & Kim (2005)

Elasticity values primarily follow the ADAGE model, a global (multi-country, multi-region) energy-CGE model developed by Martin Ross and documented in Ross (2007). In addition, figures are adopted from previous Hawaii-specific CGE modeling platforms, documented in Konan and Kim (2005). Leontief production functions (CES=0) and Cobb-Douglas preferences (CES=1) are generally standard CGE assumptions, as special cases of CES production and utility functions.

Dynamic Calibration

H-CGE is a recursive-dynamic model, projecting in five-year intervals between the year 2005 and 2030. The primary driver of overall economic growth is an exogenous parameter based on Hawaii's historic growth rate, *g*, of 2.2% annually (11.6% growth rate over five years). This is calculated from historic estimates of real Gross State

Product, 1977 to 2008 (DBEDT, 2009). Capital accumulation is endogenous within the model, meaning that investment in one period leads to new capital stock in the next:

$$p_K K_{t+1} = (1-\delta)(p_K K_{t-1} + p_K K_t) \tag{25}$$

$$p_K K_t = (r+\delta)(p_{INV} INV_{t-1}) \tag{26}$$

where δ is the capital depreciation rate and r is the rate of return on investment. The rate of return, r, is assumed to take the value of 5% annually (27.6% over five years) and δ is calibrated such that it is consistent with the overall growth rate, g, and r, given initial values of capital and investment provided in the benchmark dataset:

$$INV_0 = {(\delta+g) p_K K_0} \big/ {(\delta+r)} \tag{27}$$ [5]

where δ is calculated to take the value of 1.0% annually (5.1% over a five-year time period).[6]

Other drivers of economic growth, such as labor, visitor expenditures, and the balance of payments, are assumed to grow exogenously at the steady-state growth rate g:

$$p_W W_{t+1} = (1+g) p_W W_t \tag{28}$$

$$p_R R_{t+1} = (1+g) p_R R_t \tag{29}$$

$$\bar{p}_{fx} BP_{t+1} = (1+g) \bar{p}_{fx} BP_t \tag{30}$$

EIA Oil Price Scenarios

The oil price forecast, presented in Table 3, is treated as an exogenous "shock" to Hawaii's economy. The petroleum manufacturing industry is treated as a world price-taker of crude oil. The relative price change of crude oil is treated as a "tax" on the value of imports into the petroleum manufacturing sector, where the revenue accrues to an agent outside of Hawaii's economy, thus creating a wedge between the initial price and the new price of crude oil imports. For this purpose, it is assumed that the entire value of imports into petroleum manufacturing is crude oil.

2.c. Model Results: Baseline Scenarios

Macroeconomic Results

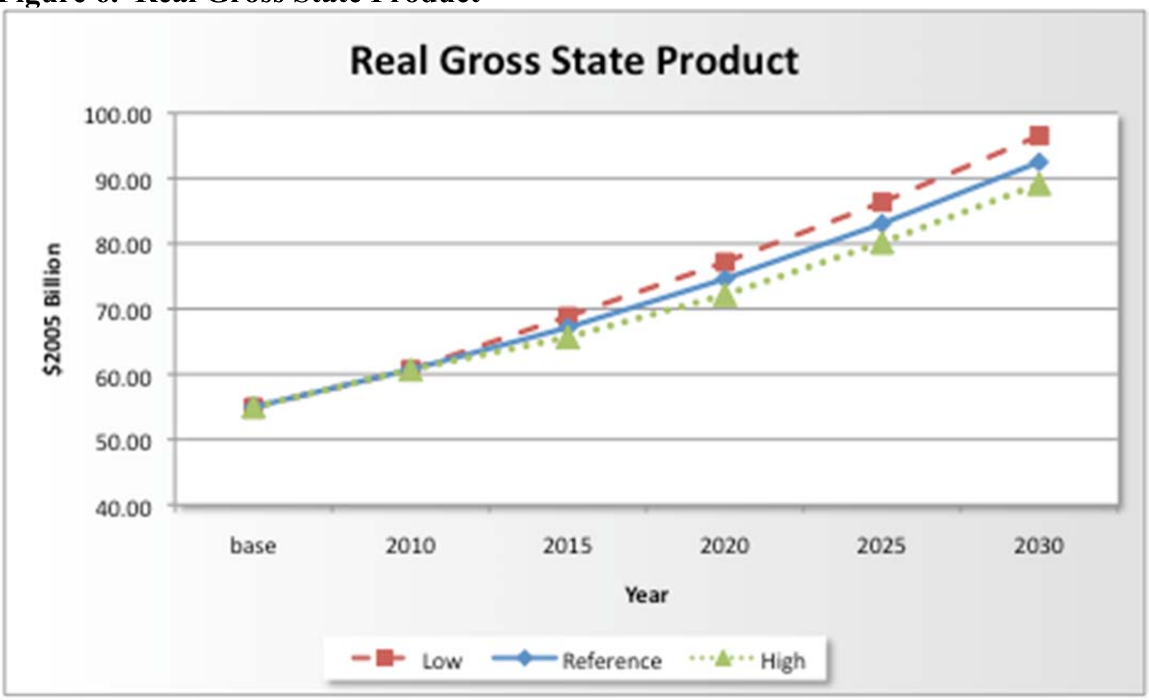
The literature on oil price increases and macroeconomic performance suggest a largely negative relationship. Hamilton (1983) was seminal in linking oil price increases to U.S. recessions, demonstrating that oil price increases have contributed to the timing,

[5] See Paltsev (2004) for documentation. This assumes an investment on a steady-state.
[6] In future iterations of H-CGE, this assumption will be checked for sensitivities to model outcomes.

magnitude, and duration of downturns (see also Rasche and Tatom, 1981; Darby, 1982; Burbidge and Harrison, 1984; Olson, 1988; and Perron, 1989). Sudden oil price increases are shown to decrease real output and cause inflation (Barsky and Killian, 2002 and 2004). For further discussion of oil price increases in the context of Hawaii and the larger literature, see Coffman, Konan and Surles (2007) and Coffman (2008).

Figure 6 shows Real Gross State Product for Hawaii's economy to the year 2030 under low, reference and high oil price scenarios. Real Gross State Product is an indicator of overall economic health, where gross state product accounts for the value of total output, net the value of imports, in constant 2005 dollars.

Figure 6. Real Gross State Product



Although petroleum manufacturing accounts for less than 3% of the value of total productivity, it enters either directly or indirectly (through electricity) into the production (and cost function) of every sector of Hawaii's economy. Thus there are real aggregated impacts of oil price increases throughout the economy. As such, the economy clearly performs best under the low oil price scenario. It is important to note, however, that this scenario does not yet include renewable energy technologies and thus provides three baseline scenarios against which to assess Hawaii's clean energy alternatives. Although oil price increases have been linked to recessionary economic conditions in their aftermath, this is nonetheless a fairly "short-term" assessment of oil price increases. The long-term impacts include allowing for price signals to alternative energy types (which will occur through the link with HELM).

There is a general trend of inflation within the economy, though the high oil price scenario exacerbates the trend while the low oil price scenario mutes the trend. Rising oil prices tend to be inflationary because it increases the marginal cost of sector-level activity through both direct (i.e. gasoline) and indirect (i.e. electricity) means.

Figure 7. Consumer Price Index

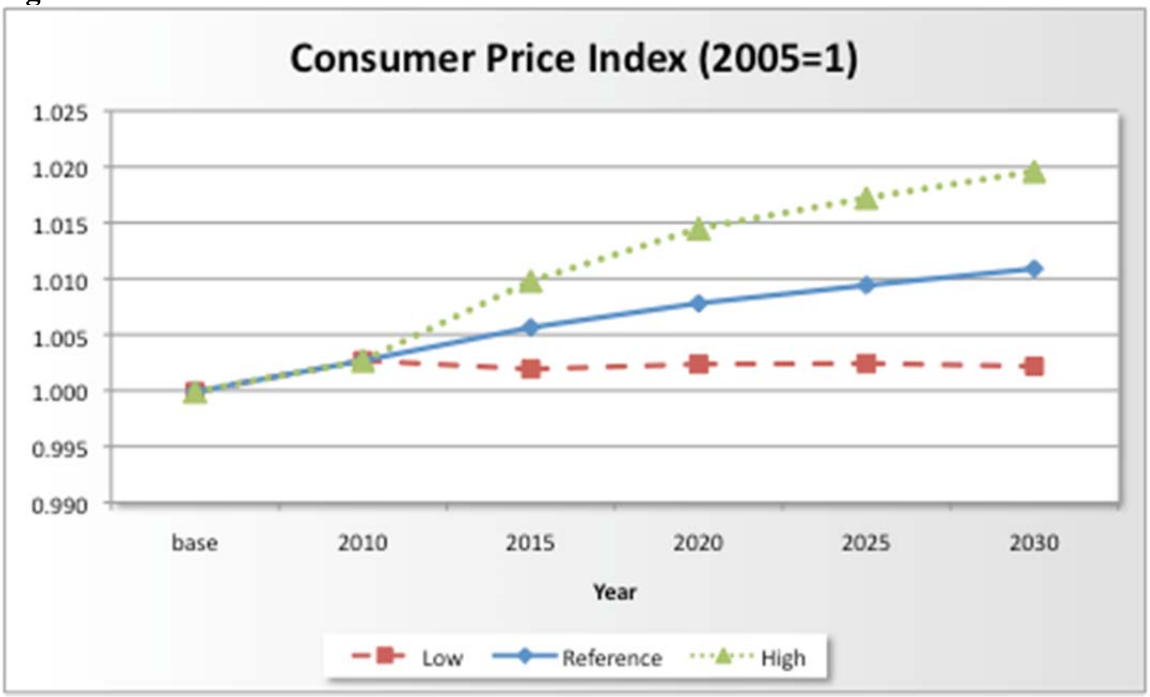
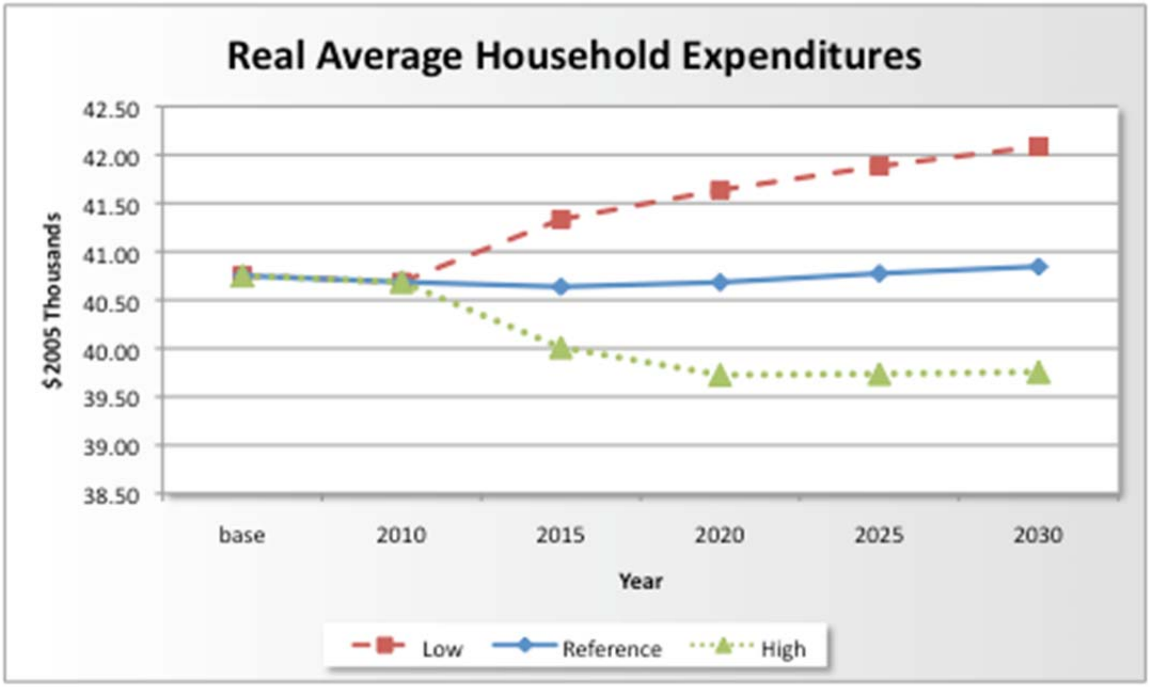


Figure 8 shows real average household expenditures, a proxy for resident welfare. Given there are no renewable energies currently modeled in H-CGE (only after iteration with HELM, see Section 4), households are clearly better-off with lower oil prices.

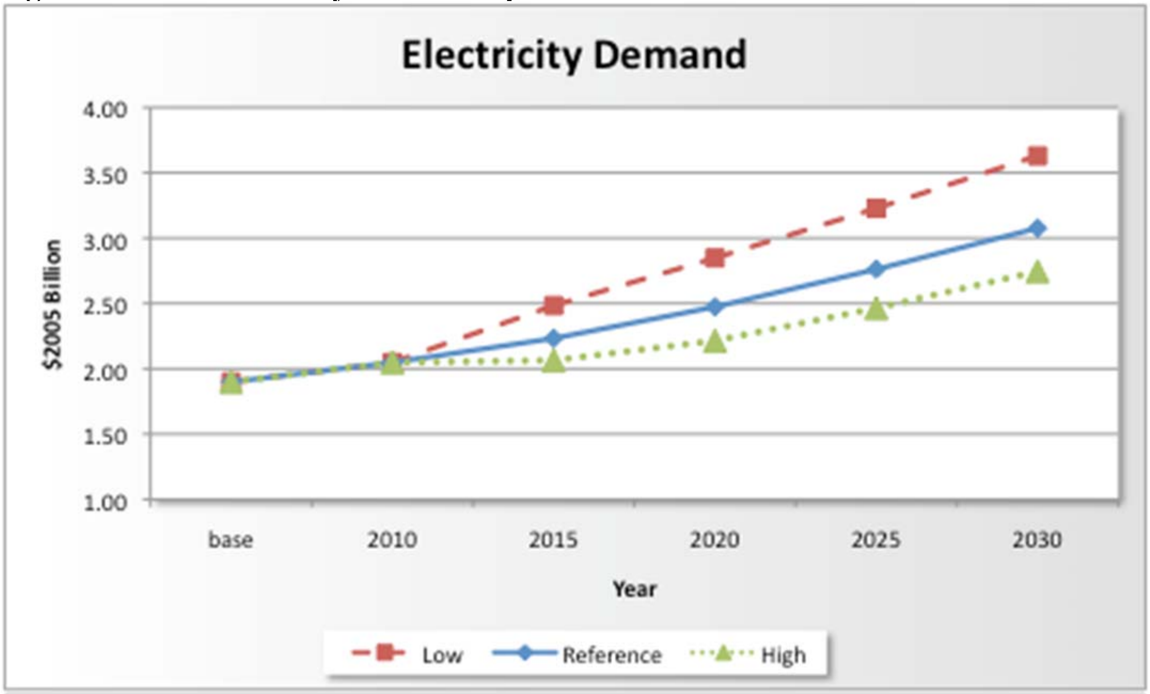
Figure 8. Real Average Household Expenditures ($ 2005 thousands)



Energy Sector Results

Industry, households and other consumers of electricity react to prices within the model, where the changing price of oil is passed-on to the electricity sector. Consequently, consumers demand more electricity when prices are low, and less electricity when prices are high. Figure 9 shows real electricity sector output under the three oil price scenarios.

Figure 9. Real Electricity Sector Output



The world price of oil is 1.7 times higher under the high oil price scenario in the year 2030 than the reference case, and 4.6 times greater than the low oil price scenario. Whereas crude oil is the largest input into the petroleum manufacturing industry, refined petroleum manufacturing output (a composite good of petroleum types) increases by similar rates. The electric sector purchases nearly 600 million gallons of oil product from the petroleum manufacturing sector (U.S. Energy Information Administration, 2010b). Prices in the electricity sector are 1.3 times greater in the high oil price scenario relative to the reference case, and 1.7 times greater than the low oil price scenario. This shows that, while there is pass-through of prices from the petroleum manufacturing sector to the electricity sector, it is not perfect pass-through (i.e. not one-for-one).

Table 4 shows the growth rate of electricity over time, from period to period while Table 5 shows the change relative to the base year, 2005.

Table 4. Electricity Sector Demand Projection for HELM: Growth Rate

	Growth Rate (interval to interval)		
	Low	**Reference**	**High**
2005-2010	1.08	1.08	1.08
2010-2015	1.21	1.09	1.01
2015-2020	1.15	1.11	1.07
2020-2025	1.13	1.12	1.11
2025-2030	1.12	1.11	1.11

Table 5. Electricity Sector Demand Projection for HELM: Relative Change

	Relative Change (based on 2005)		
2005	1.00	1.00	1.00
2010	1.08	1.08	1.08
2015	1.31	1.18	1.09
2020	1.50	1.30	1.17
2025	1.70	1.45	1.30
2030	1.91	1.62	1.45

The electricity demand forecast provided in Table 5 is used to solve HELM in terms of provided a constraint on total electricity demand (see Section 4 for further discussion).

3. HELM

The Hawaii Electricity Model (HELM) is a detailed "bottom-up" representation of Hawaii's electricity sector. HELM is calibrated to existing electricity units in the year 2005 for Hawaii's four counties: the City & County of Honolulu, Maui County, Kauai County, and Hawaii County. HELM is a linear program model (i.e. a partial equilibrium representation of the electricity sector for the State) that solves for the least cost mix of generation subject to satisfying demand, environmental, and system constraints.

The database for HELM is constructed from several data sources. The various integrated resource plans (IRPs) for the utilities provide extensive detail on the operating characteristics and costs of new generating units. These IRPs, combined with various company filings with state and federal regulators, provide details on the characteristics and operating costs of the current electricity systems.

Being a linear program, HELM's objective function and constraints are linear. Therefore, HELM's objective function (i.e. function that computes the cost of providing electricity) is linear in the model variables, namely capacity and generation. Similarly, all of HELM's constraints are linear in terms of the variables in the model. Thus, the model fails to account for the "lumpiness" of capital investments because capacity can be smoothly added to the system. Because there are in reality not smooth transitions for capital investment and accumulation, five-year time intervals were chosen by the project team for producing model results.

For this first phase, there is a one-way link between H-CGE and HELM (see Section 4 for further detail). H-CGE provides oil prices and electricity demand forecasts for HELM, thus ensuring consistency between the two models in the variables that they have in common. HELM is fully dynamic and therefore solves for the generation mix in all years simultaneously. To be consistent with H-CGE, the model calibrates and solves for the years 2005 to 2030 in five-year intervals.

HELM is solved using GAMS (General Algebraic Modeling System) and a linear programming solver. For more information on this modeling platform, refer to Rosenthal, 2008.

3a. Data Inputs

The data for HELM describe Hawaii's existing electricity system, the future availability of new units, and the evolution of the system in terms of electricity demand and energy prices.

Existing Unit data

Data on existing units, fuel prices, and system characteristics describe today's system. Table 6 includes information used to calibrate and solve HELM in the baseline year.

Although data is provided for most necessary fields, verification and refinement of data is still needed.

Table 6: Data for Existing Units in Hawaii

	Capacity	FOM	VOM	HR	Maximum Cap Fact	Minimum Cap Fact	derate	RPS Credit	CO2 Emissions
	(MW)	($/kW)	($/MWh)	(MMBtu/MWh)	(%)	(%)	(%)	(%)	(g/MMBtu)
HECO									
AES	200	50	3	10.0	90%	20%			94
Hon	107.3	100	3	12.3	65%	10%			73
Waiau-ST	379	60	3	10.5	85%				73
Waiau-CT	101.8	60	3	20.0	50%				73
Kahe-ST	620.5	60	3	10.0	85%				73
DG	29.4	25	3	11.0	10%				73
Kalaeloa	208	60	3	9.8	85%				73
Hpower	46	75	3	10.0	85%			100%	40
HELCO									
Apollo	20.5	11.1	1.7		41%		80%	100%	0
DG-HELCO	4	8.6	0.9	9.8	10%				73
Hamakua	60	53.5	1.2	8.5	85%				73
Hawi	10.6	11.1	1.7		41%		80%	100%	0
Kanoelehua	49.5	20	5	14.4	85%				73
Keahole	60.3	37.9	0.8	8.5	85%				73
Keahole-Solar	0.5	298.9	34		20%		80%	100%	0
Lalamilo	2.2	11.1	1.7		41%		80%	100%	0
H-Hydro	17.1	0.3	2.4		33%		80%	100%	0
Puna-MSFO	14.1	164.2	1.2	16.2	85%				73
Puna-Diesel	20.4	45.8	0.1	13.3	85%				73
PGV	30	5.5	22.5		85%			100%	0
Shipman-MSFO	14.4	158.9	2.4	17.0	85%				73
WHHill	33.7	20.5	0.9	13.3	85%				73
Waimea	8.3	20.5	0.9	10.8	85%				73
KIUC									
Kapaia	26.6	0	1.4	8.2	85%				73
K-Hydro	4.1	0.3	2.4		67%		60%		0
Kaumakani-Wood	2.8	10.5	11.7	14.6	80%			80%	0
Kaumakani-Oil	0.9	0	4.3	11.4	85%				73
Slr-PioneerHwy	0.2	298.9	34		20%		80%	100%	0
PA1	7.5	25.9	7.8	10	85%				73
PA2	30.4	25.9	7.8	8.6	85%				73
PA3	40.1	25.9	7.8	9.8	85%				73
PA4	3.4	25.9	7.8	10	85%				73
PA-Steam	9	25.9	1.6	14.2	85%		50%		73
MECO									
HCS	12	6.1	4.7	15.6	85%			100%	0
Kaheawa	30	11.1	1.7		41%		80%		73
Kahului1	9.5	168	1.1	14.6	85%				73
Kahului2	22.9	159.8	1.1	12.1	85%				73
Maalaea1	12.5	24.4	7.8	9.2	85%				73
Maalaea2	49.2	34.4	7.8	9.2	85%				73
Maalaea3	33	18.9	7.8	9.2	85%				73
Maalaea4	113.6	67.2	0.5	9.2	85%				73
MikiBasin	10.4	25.9	7.8	10.3	85%	60%			73
Palaau	15.2	25.9	7.8	10.1	85%	60%			73
Palaau-Solar	2.2	298.9	34		20%		80%	100%	0

Source: (Hawaiian Electric Company, Inc., 2008), (U.S. Energy Information Administration, 2008), (Hawaii Electric Light Company, Inc., 2007), (Maui Electric Company, Ltd., 2007) (Kauai Island Utility Cooperative, 2005)

Costs

Several parameters are needed to fully define the existing units' costs and operating characteristics (see Table 6). Existing unit costs include fuel, fixed and variable operating costs. A unit's fuel costs equal the product of its heat rate (MMBtu/MWh) and fuel price (in $/MMBtu). For geothermal, solar, and wind units, these costs are zero. Fuel costs exist for all fossil-fired and biofuel-fired units; therefore, a heat rate is specified for all these units.

All units have fixed operating and maintenance (FOM) and variable operating and maintenance (VOM) costs. A unit's annual FOM cost equals its capacity times its' per kW FOM cost. The initial capacity is provided as an input for all existing units. Over time, a unit can retire and hence reduce its capacity to zero. FOM accounts for labor and other costs that are almost always fixed throughout a given year. A unit's annual VOM cost equals its per MWh VOM times its annual generation. VOM accounts for costs that are proportional to usage, such as materials like lubricants.

In the next phase of the analysis, the project team will work to incorporate known future large capital expenditures that would need to occur for a unit to continue to operate. In addition, the next version of HELM will include the capital costs to repower specific oil-fired units and allow existing oil-fired units to burn biofuels.

Operating Characteristics

Costs represent one part of a unit's characteristics; the other part involves operating characteristics such as utilization and emissions. Physically, units are unavailable to operate all hours in a year either because they must undergo routine maintenance or because they require emergency maintenance. To account for this unavailability, a maximum capacity factor is used to define the maximum percentage of the year a unit can operate. Capacity factors are computed from data on historical operations when possible. For units in which there was no readily available information, capacity factor estimates are adopted from similar unit types provided within the IRPs. In particular, the IRPs provided capacity factors for wind units. In addition, a minimum capacity factor is also utilized where appropriate, as some units must operate at a minimum threshold.

For all systems, model constraints require that capacity is meets demand (where the demand forecast is provided by H-CGE). Accounting for capacity, however, involves more than simply adding the capacity of all units. Generating units fall into two categories – firm resources and as-available resources. Firm resources (e.g., oil or biofuels fired combustion turbines) are those on which the system operator can rely for a given amount of power generation; whereas the output from as-availables depends on an unpredictable and intermittent energy source (e.g., wind or solar units).

For firm units, the entire amount of capacity contributes toward the reserve requirement. With as-available energy types, however, only a portion of their capacity contributes. This is due to the uncertainty regarding the generation capacity of intermittent energy sources at any given time. For example, the capacity of wind units is difficult to predict given fluctuations in wind patterns. To account for this, the as-available units are subject to a "derate" when applying their capacity against the reserve margin requirement within HELM. For wind and solar photovoltaic, the "derate" is assumed to be 80%, meaning that only 20% of the units' capacity will count toward the reserve margin requirement.

The sum of all appropriate capacity of currently operating units, or overall capacity, must then meet the reserve margin constraint.

The reserve margin constraint requires this valid capacity to equal or exceed the peak load plus a reserve margin, which is defined to be 15% of the peak load. In reality, the PUC requires utilities to have enough reserve capacity on hand to compensate for the failure of their largest operating unit. This is close to requiring a 15% reserve margin, which is generally consistent with high end of mainland systems. The reserve margin is meant to provide a "cushion," should demand be unexpectedly higher than in the past year or a unit unexpectedly goes off-line.

In the anticipation that HELM may in the future be used to assess existing or possible future environmental policies relating to the electricity sector, the table on existing unit data includes information on each unit's percentage of generation that counts toward existing renewable portfolio standards and carbon dioxide emissions per MMBtu. The emission factors for fossil fuel units are taken from the EIA (EIA, 2010c). Emissions from biofuels are assumed to be 25% of the emissions from oil to account for emissions involved in the procuring of the biofuels.[7]

New Unit Data

The data fields for new units include all the fields for existing units. In addition, new units are characterized by their cost per kW to build (i.e. construction costs) and the first year the unit could be available. Table 7 reports the values for the new units considered in this exercise.

[7] The California EPA provides a range of emission numbers for alternate fuels. The model currently assumes the low end of the range since it is assumed that emissions from land-use changes would be small.

Table 7: Data on New Units Available to HELM

	Capacity (MW)	FOM ($/kW)	VOM ($/MWh)	HR (MMBtu/MWh)	Maximum Cap Fact (%)	Minimum Cap Fact (%)	derate (%)	RPS Credit (%)	CO2 Emissions (g/MMBtu)	Capital Cost ($/kW)	First Year
HECO											
CIP	110	40	3	9	75%			80%	18	3000	2010
O-Wind	60	30	2		35%		80%	100%	0	2000	2015
O-BioFuel1	500	80	7	10	75%			80%	18	2500	2015
O-BioFuel2	1500	80	7	10	75%			80%	18	4500	2015
O-LFG	50	80	7	10	15%			100%	0	6000	2015
O-NewCoal	200	40	4	9	90%	20%			18	4000	2015
HELCO											
H-Geo1	8	8.3	22.5		85%	0		100%	0	5000	2015
H-Geo2	30	8.3	22.5		85%	0		100%	0	5000	2015
H-Wind	29.9	20.07	1.68		45%		80%	100%	0	3700	2015
H-BioFuel1	35	3.6	8.3	9.8	60%	0		80%	18	2357	2015
H-BioFuel2	35	3.6	8.3	9.8	60%	0	0	80%	18	4500	2015
H-BioFuel3	500	3.6	8.3	9.8	60%	0	0	80%	18	6000	2015
H-MSW	7.3	107.8	21.9	18.8	83%			100%	0	4296	2015
KIUC											
K-Wind	29.9	20.1	1.7	0	45%	0	80%	100%	0	3700	2015
K-BioFuel1	35	3.6	8.3	9.8	60%	0	0	80%	18	2357	2015
K-BioFuel2	35	3.6	8.3	9.8	60%	0	0	80%	18	4500	2015
K-BioFuel3	500	3.6	8.3	9.8	60%	0	0	80%	18	6000	2015
K-MSW	7.3	107.8	21.9	18.8	83%	0	0	100%	0	4296	2015
MECO											
M-Wind	29.9	20.1	1.7	0	40%	0	80%	100%	0	3700	2015
M-BioFuel1	35	3.6	8.3	9.8	60%	0	0	80%	18	2357	2015
M-BioFuel2	35	3.6	8.3	9.8	60%	0	0	80%	18	4500	2015
M-BioFuel3	500	3.6	8.3	9.8	60%	0	0	80%	18	6000	2015
M-MSW	7.3	107.8	21.9	18.8	80%	0	0	100%	0	4296	2015

Source: (Maui Electric Company, Ltd., 2006), (Kauai Island Utility Cooperative, 2005), (Hawaii Electric Light Company, Inc., 2006), (Hawaiian Electric Company, Inc., 2005), EIA 2010c.

For first phase of this project, the project team focused on calibrating HELM to existing units and thus only a few types of new capacity are considered, such as more wind and solar photovoltaic. In the next phase of the project, however, HELM will represent the current electricity systems better in two ways. First, HELM will include wind and solar production profiles so that the model better captures the variability in the availability of power from these units in terms of time of day and seasonality. Second, the model will force in new units that are currently scheduled to be built by the electric utilities.

System wide data and forecasts

Load Data -Energy

Time-of-day demand and seasonality load curves are developed based on historical load data for each hour for the City & County of Honolulu from FERC's Annual Electric Control and Planning Area Report for Oahu in the year 2004. This is the best available data and thus is also used to represent the other counties. The data is used by aggregating the hours into 84 categories based on season, time of day, and day of the week. The categories were selected based on periods with similar demand levels (i.e. power requirements)[8] and one hour on the Monday through Thursday days was selected to capture the daily demand "peak." Total demand represented in each of the 84 categories is then summed up to compute its share of annual generation. These shares are applied to the forecasted annual demand to compute the demand for each of the 84 categories in the future.

[8] See Appendix II of HELM model listing for details on the 84 load blocks.

H-CGE provides electricity demand forecast indices from 2010 to 2030. These indices are for Hawaii as a whole because H-CGE represents Hawaii at the state level. Therefore, these indices are applied for each of the four systems. Thus, demand for a particular system's load block and year is the product of the demand share for that load block, the 2010 level of electric generation for the specific system, and the index for the year of interest.[9]

Load Data - Peak

Just as total system load determines the annual energy requirement, peak demand determines the system's capacity requirement. In this phase, it is assumed that each system's peak evolves similar to its annual energy demand. Therefore, the system peak in all future years equals the system peak in 2010 times the appropriate H-CGE electricity demand index.[10]

The reserve margin constraint requires this valid capacity to equal or exceed the peak load plus a reserve margin, which is defined to be 15% of the peak load. The reserve margin is meant to provide a cushion should demand be unexpectedly higher than in the past year or a unit unexpectedly goes off-line.

Environmental Policies

In this phase, no RPS requirements or emission limits were included because the initial analysis is meant to establish a "no policy" baseline.

Fuel Prices

HELM relies on fuel price forecasts for coal, petroleum products, and biofuels. For petroleum products, HELM applies the same EIA 2010 forecast as H-CGE. The EIA price crude oil price index is applied to each petroleum product. With an index of one for 2005, all future oil product prices are equal to the 2005 actual product price times the index for the year of interest. Therefore, the prices of all petroleum products move in parallel. For this phase of the analysis, the 2005 price for diesel and fuel oil were taken from HECO's IRP-4 and these were applied to all diesel-fired and fuel oil-fired units, respectively.

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[9] Each system's 2010 annual demand is taken from the system's most recent IRP.
[10] Each system's 2010 peak is taken from the system's most recent IRP.

Table 8: Fuel Prices for Electric Generation (2007$/MMBtu)

	2010	2015	2020	2025	2030
Fossil Diesel					
None	13.7	13.7	13.7	13.7	13.7
Low	19.3	12.5	11.9	11.8	12.0
Base	19.3	24.8	28.1	29.9	31.9
High	19.3	39.2	50.3	53.1	55.5
Fuel Oil					
None	7.4	7.4	7.4	7.4	7.4
Low	10.4	6.8	6.4	6.4	6.5
Base	10.4	13.4	15.2	16.1	17.2
High	10.4	21.1	27.2	28.7	30.0
Coal	3.8	3.8	3.8	3.8	3.8
BDsl	30.4	31.7	23.3	21.7	21.7
CPO	22.6	21.2	15.5	15.5	15.5

Source: (EIA, 2010a), (HECO IRP-4, 2008)

HECO's IRP-4 provides low and high price forecasts for biodiesel and crude palm oil. But only the high-end of the range of the forecast seems to be consistent with the EIA's oil price forecast. Therefore, for this phase of the project, only the high price forecast for these biofuels is used. To be consistent with the EIA, a flat coal price forecast from 2010 onward is assumed.

3.b Model Description

HELM is a detailed "bottom-up" representation of Hawaii's electricity sector. HELM is calibrated to existing electricity units in the year 2005 for Hawaii's four counties: the City & County of Honolulu, Maui County, Kauai County, and Hawaii County. HELM is a fully dynamic linear program model (i.e. a partial equilibrium representation of the electricity sector for the State) that solves for the least cost mix of generation to satisfy demand while complying with system operating conditions and environmental policies. The system of constraints and the objective function of HELM are based on Martin Ross's Electric Markets Analysis (EMA) model (Ross, 2008) and ICF's Integrated Planning Model (IPM) (U.S. EPA, 2008).

HELM is modeled in GAMS, which allows it to have an extremely flexible structure so that one can easily expand the model's dimensions such as number of technologies and time periods. The remainder of this section details the model's objective function and constraints.

Objective function

The objective function represents the discounted present value of the costs of generation: fuel costs, fixed and variable operating and maintenance costs, and capital costs of new units.

$$z = e = \sum\Big(t, DF(t) * \Big(\sum\big((f,g,b), FuelPrice(f,t) *$$
$$HeatRate(g,f) * Gen(g,f,b,t)\big) +$$
$$\sum\big((f,g,b), VOM(g) * Gen(g,f,b,t)\big) +$$
$$\sum\big((f,g), FOM(g) * Cap(g,f,t)\big) +$$
$$\sum\big((f,g), CapCost(g) * Bld(g,f,t)\big)\Big)\Big) \tag{31}$$

Where the sets *t, g, f,* and *b* are defined:
t = time periods, *g* = generators, *f* = fuels, and *b* = load blocks

Where the parameters *DF, FuelPrice, HeatRate, VOM, FOM,* and *CapCost* are defined:
DF(*t*) = discount factor (*DF*(2010) = 1)
FuelPrice(*f,t*) = Price of fuel, *f*, in year t
HeatRate(*g,f*) = heat rate for unit *g* burning fuel *f* (MMBtu/MWh)
VOM(*g*) = Variable operating cost of unit *g* ($/MWh)
FOM(*g*) = Fixed operating cost of unit *g* ($/kW)
CapCost(*g*) = Capital cost to build a new unit ($/kW)

Where the variables *Cap, Gen, and Bld* are defined:
Gen(*g,f,b,t*) = Generation of unit *g* using fuel *f* in load block *b* during year *t* (TWh)
Cap(*g,f,t*) = Capacity of unit *g* used to burn fuel *f* (GW)
Bld(*g,f,t*) = Capacity of new unit *g* built to burn fuel *f* in year *t* (GW)

Constraints

Combined with the objective function, the electric system defined in HELM is governed by the following constraints. To account for each unit's typical operation throughout the year, HELM imposes maximum and minimum capacity utilization constraints on each unit's operation:

$$\sum\big(f, Gen(g,f,b,t)\big) = G = MinCapFac(g,b) * BlkHr(b) * \sum\big(f, Cap(g,f,t)\big) \tag{32}$$

$$\sum\big(f, Gen(g,f,b,t)\big) = L = MaxCapFac(g,b) * BlkHr(b) * \sum\big(f, Cap(g,f,t)\big) \tag{33}$$

These constraints are denoted in units of generation. The minimum and maximum utilization rates remain constant over an individual year and from year to year. Because some units can burn multiple fuels, the model must ensure that the sum of the capacities used for each unit does not exceed its total capacity.

$$MaxCap(g,t)..Sum\big(f, Cap(g,f,t)\big) = L = MaxCap(g,t) \tag{34}$$

HELM targets an exogenous demand projection and forces total generation to meet demand on each of the four major systems. The demand forecast represents end-use demand while generation measures output of each generator to the grid. Therefore, the demand constraint must account for transmission losses to deliver power from the generators to the end-users.

$$\sum\left(\left(g,f\right),Gen\left(g,f,b,t\right)\right)*\left(1-TrnLoss\left(p\right)\right)=G=\sum\left(c,Demand\left(c,p,b,t\right)\right) \tag{35}$$

Where
p = represents the set of power pools (HECO, HELCO, KUIC, and MECO)
TrnLoss(*p*) = Average transmission by power pool (assumed to be 8%)

For all systems, the Hawaii PUC requires the utility systems to have enough reserve capacity on-line at all times to meet demand and account for any contingencies. HELM's reserve margin constraint represents this requirement. It ensures that the sum of all available capacity times one plus the reserve margin requirement exceeds the peak generation in the year.

$$\begin{aligned}&\sum\left(\left(f,g\right)\$\left(mapg2p\left(g,p\right)\right),Cap\left(g,f,t\right)*\left(1-derate\left(g\right)\right)\right)=\\&G=\left(1+\mathrm{Re}serveM\arg in\left(p\right)\right)*PeakDemand\left(p,t\right)\end{aligned} \tag{36}$$

Where
mapg2p(*g,p*) = mapping of generators to power pools
ReserveMargin(*p*) = reserve margin requirement by power pool (equal to 15%)
PeakDemand(*p,t*) = Peak demand for power pool *p* in year *t* (GW)

To account for decisions to build new capacity, retrofit existing units, or retire capacity, HELM has two constraints that track the transition of capacity from one time period to the next. The first constraint initializes the capacity in the first endogenous model year (i.e., 2010); and the second constraint tracks the evolution of the capacity of each unit.

$$Cap\left(g,f,t\right)=E=Cap0\left(g,f\right)+Bld\left(g,f,t\right)\$CapCost\left(g\right)-\mathrm{Re}t\left(g,f,t\right) \quad \text{(t=2010)} \tag{37}$$

Where
CapCost(*g*) = Cost to build capacity for unit *g*
Ret(*g,f,t*) = Variable that denotes amount of retirement of unit *g* using fuel *f* in year *t* (GW)

For all model years after the first year:

$$Cap\left(g,f,t\right)=E=Cap\left(g,f,t-1\right)+Bld\left(g,f,t\right)\$CapCost\left(g\right)=\mathrm{Re}t\left(g,f,t\right) \tag{38}$$

HELM includes constraints to represent Hawaii's current RPS mandates. This constraint is active only if RPS targets are put in place in the scenario modeled.

$$\sum\left(\left(f,g,b,p\right)\$\left(mapg2p\left(g,p\right)\text{ and }\right.\right.$$
$$\left.\left.mapp2rps\left(p,rps\right)\right),RPSCredit\left(g,f\right)*Gen\left(g,f,b,t\right)\right)=$$
$$G=RPSTgt\left(rps,t\right)*Sum\left(\left(f,g,b\right)Gen\left(g,f,b,t\right)\right) \tag{39}$$

Where

mapp2rps(*p,rps*) = mapping of power pools to RPS regions (i.e., under the current RPS regulations, HECO, HELCO, and MECO would be mapped to one RPS region representing the HECO utility)
RPSCredit(*g,f*) = Percentage of unit *g*'s generation using fuel *f* that counts toward the RPS requirement
RPSTgt(*rps,t*) = RPS target in year *t* for RPS region *rps*

Last, the HELM model represents emission caps for CO_2. The model could easily be expanded to account for emissions from other pollutants and hence include emission targets for other pollutants. Currently, HELM's emission constraint accounts only for CO_2 and is active only if an emissions target is specified for CO_2.

$$\sum\left(\left(f,g,b\right),EmisRate\left(f\right)*HeatRate\left(g,f\right)*Gen\left(g,f,b,t\right)\right)=L=EmisTgt\left(t\right) \tag{40}$$

Where

EmisRate(*f*) = Emissions rate for fuel *f* (metric tons of CO_2/MMBtu)
EmisTgt(*t*) = Emissions target for CO_2 (millions of metric tons)

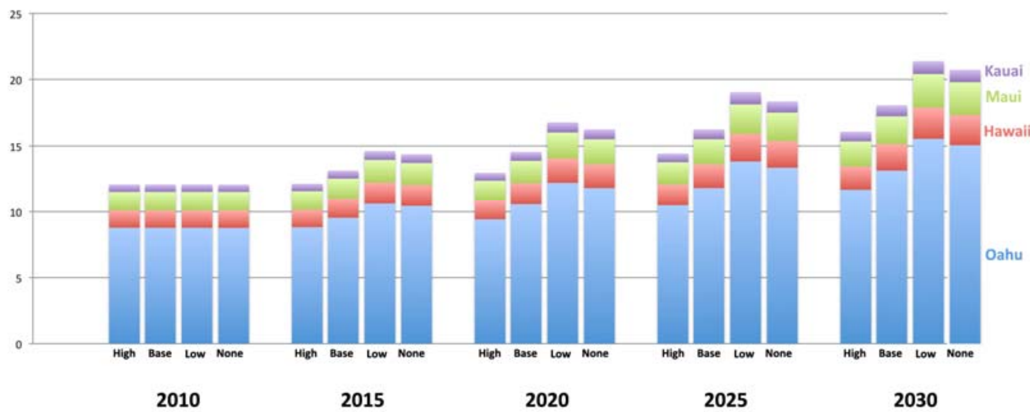
3.c Results

This section describes the resulting capacity and generation mix for the four electric utilities under the four scenarios: none, low, base, and high. These scenarios differ in the price for petroleum products and electricity demand.

State level

Figure 10 reports the total generation over time. The growth in generation corresponds to the exogenous demand forecast furnished by the H-CGE model. Generation as with the rest of the economy is inversely related to the change in oil prices: the highest for the low oil price case and lowest for the high oil price case.

Figure 10: Electricity Generation by Utility System (TWh)



The mix of generation used to meet load differs by scenario. Figures 13,15,17, and 19 show how generation changes by scenario for the four systems.

Figure 11 reports the total island wide capacity additions by type of unit. In 2010, the only new addition is the new CIP unit on the HECO system. In 2015, the capacity additions are strikingly different between the high case and the other three cases. Because of the higher oil prices great changes in the generation mix are made. About 0.3 GW and 0.04 GW of diesel-fired and residual fuel oil-fired units are retired, respectively. To compensate for this loss of capacity and more cost-effectively combat the higher fuel prices, about 0.2 GW of coal-fired, 0.3 GW of CPO-fired, 0.1 GW wind power, and 0.03 GW of geothermal generation are installed. For the other cases a mix of about 0.1 GW of coal-fired generation and 0.1 GW of CPO-fired generation is added.

In 2020, the remaining available coal capacity is added under the base, low, and none cases. In addition, a bit of wind is added in the high case, while CPO-fired generation is added in the low and none cases to accommodate greater increases in demand. From 2025 onward, only CPO-fired generation is added in the high and base cases because as the price of CPO falls over time, this becomes the least cost option. For the low and none cases, the increase in demand is larger so the higher cost tier of CPO-fired generation is required. But before this is added the system, the available MSW and remaining amount of geothermal capacity is added to the generation mix because these units have lower lifecycle costs than the second tier of CPO.

Figure 11: New Capacity Additions to all Systems (GW)

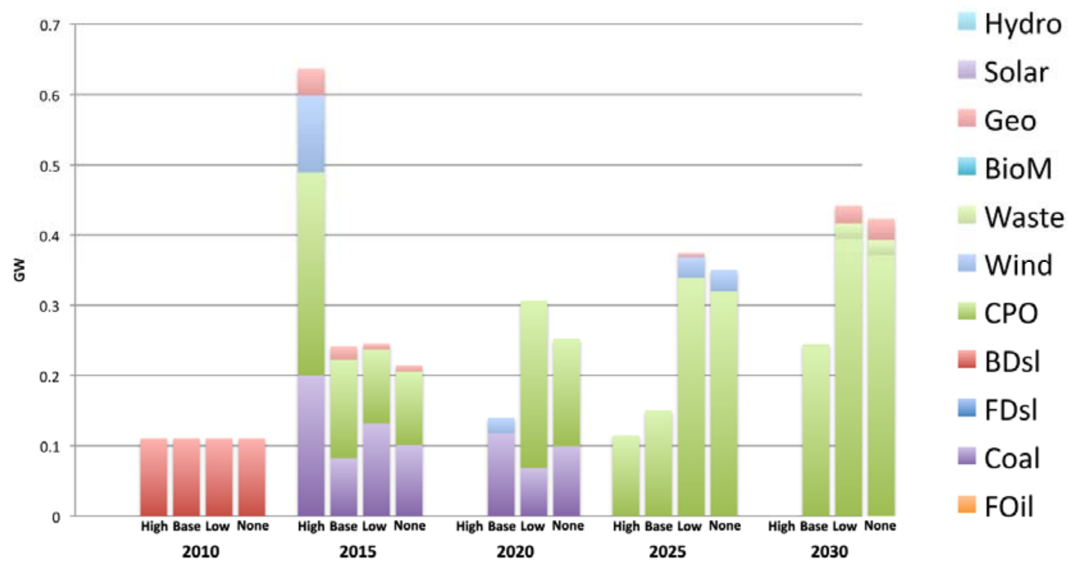
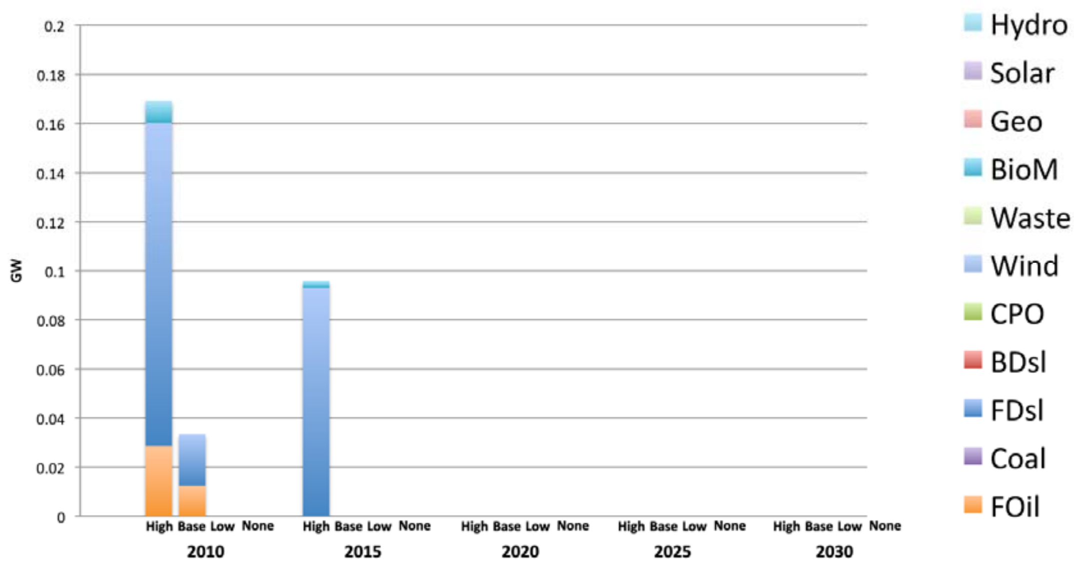


Figure 12: Unit Retirements for Hawaii (GW)



Oahu

Figure 13 and Figure 14 report respectively the generation and capacity by unit type for Oahu. In 2010, the Campbell Industrial Park CT unit is forced on-line and assigned biodiesel as its fuel. However because the price of biodiesel greatly exceeds that of fossil diesel in 2010, this unit never operates. In 2015, HELM allows Oahu to add coal-fired capacity. The amount of capacity added for each case depends on the how demand and oil prices evolve. For the base and high oil price cases, this capacity is added mainly to replace oil-fired generation because it has much lower operating costs. For the high case, an additional 0.05 GW of new wind is added to lower overall system costs. In the low and none cases, this capacity is added because it is the least cost method of meeting rising demand.

In 2020, new coal-fired capacity reaches its maximum available new capacity of 0.2 GW. Again, for the base and none cases, the capacity is used to meet demand; whereas for the high and base cases, the capacity is partly to meet increased demand and partly to displace oil-fired generation. Because by 2020 oil prices approach that of biodiesel prices in the high case, the HECO system begins generating electricity from the CIP unit in this case.

Moving from 2020 to 2030, units burning CPO are added to the system. These units are added to meet rising demand. They are the only firm capacity available to HELM after the coal unit. Because of the lack of generation options, the CIP unit produces some power in all scenarios. In the high and base case, this unit is cost-effective to operate so it produces power at its maximum permissible output level; whereas for the base, low, and none cases, it is only cost-effective to operate at certain times and hence its utilization is lower than in the high oil price case.

Figure 13: Generation on the HECO System (TWh)

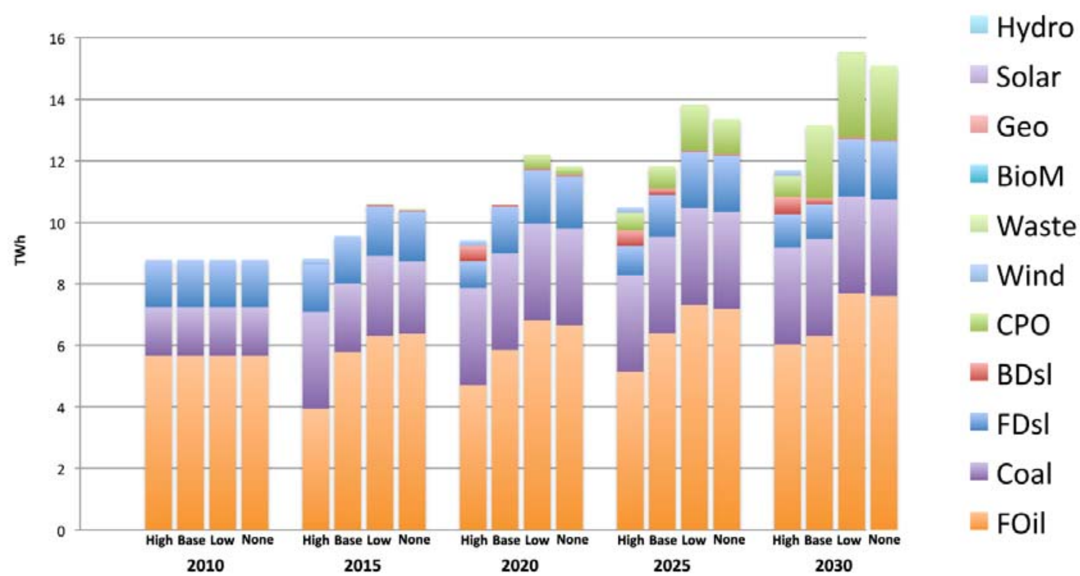
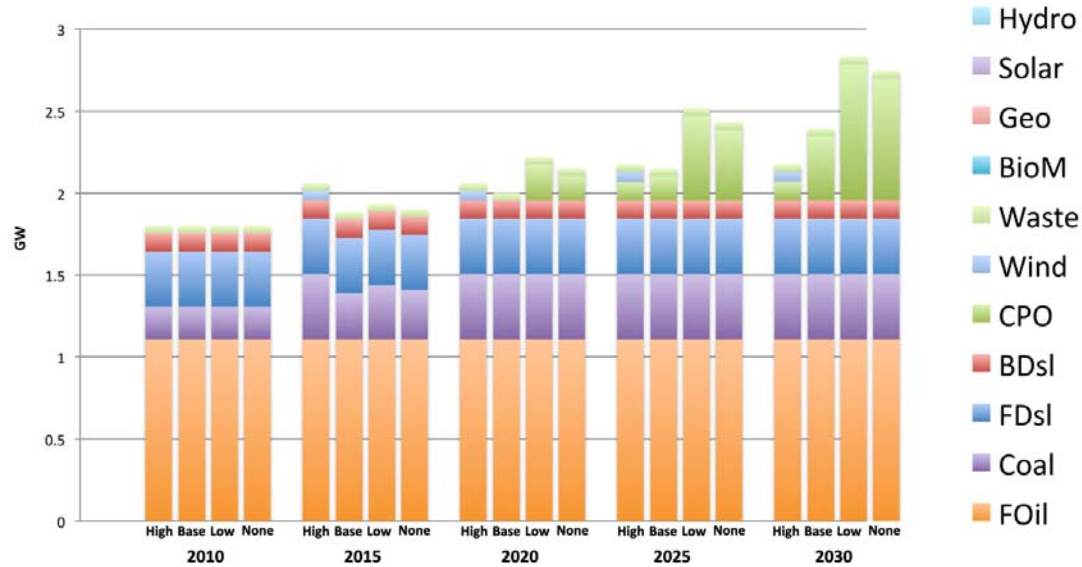


Figure 14: Capacity on the HECO system by type (GW)



Hawaii

Figure 15 and Figure 16 report respectively the generation and capacity by unit type for the island of Hawai'i. In 2010, generation is the same across all scenarios, but in anticipation of higher oil prices, some capacity of oil-fired units retire. In 2015, HELM can add new capacity to the HELCO system. For all cases, new geothermal and CPO-fired capacity comes on-line to meet rising demand. The amount of non-oil fired capacity added increases with increasing oil prices.

The capacity profile in each case changes little from 2015 to2025. But the utilization increases for the oil-fired units over time. By 2030, more capacity is required to meet the rising demand in the none and low scenarios. The remaining available geothermal capacity is added until the new geothermal reaches 0.04 MW. Also, an MSW unit is added. To fill the remaining capacity needed in the low oil price case, which has the highest demand, an additional block of CPO-fired capacity is built. The lifecycle cost of this unit is higher than that of the geothermal and MSW unit hence it comes on line last used.

Figure 15: Generation on the HELCO system (TWh)

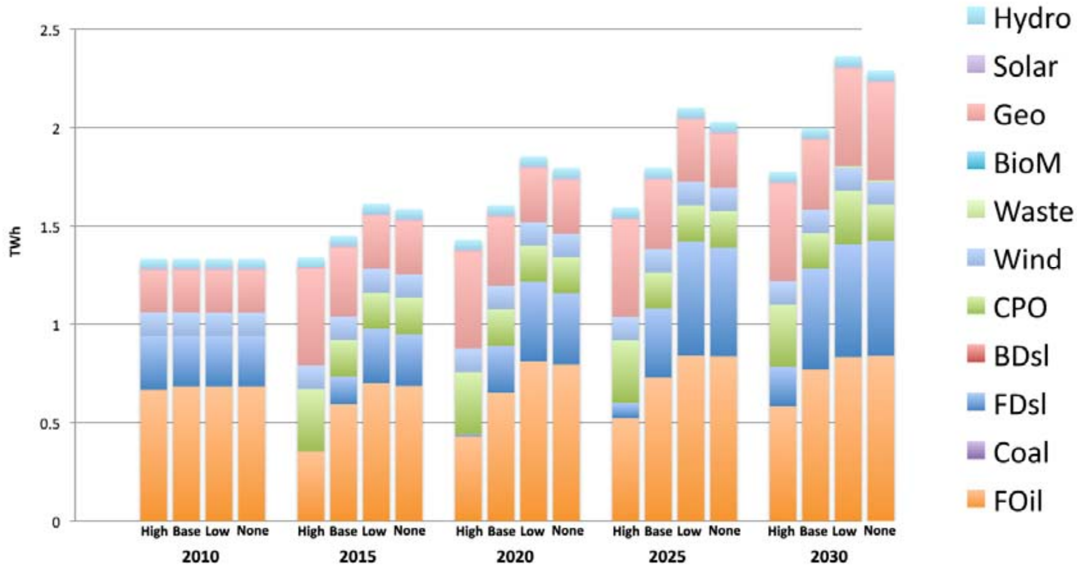
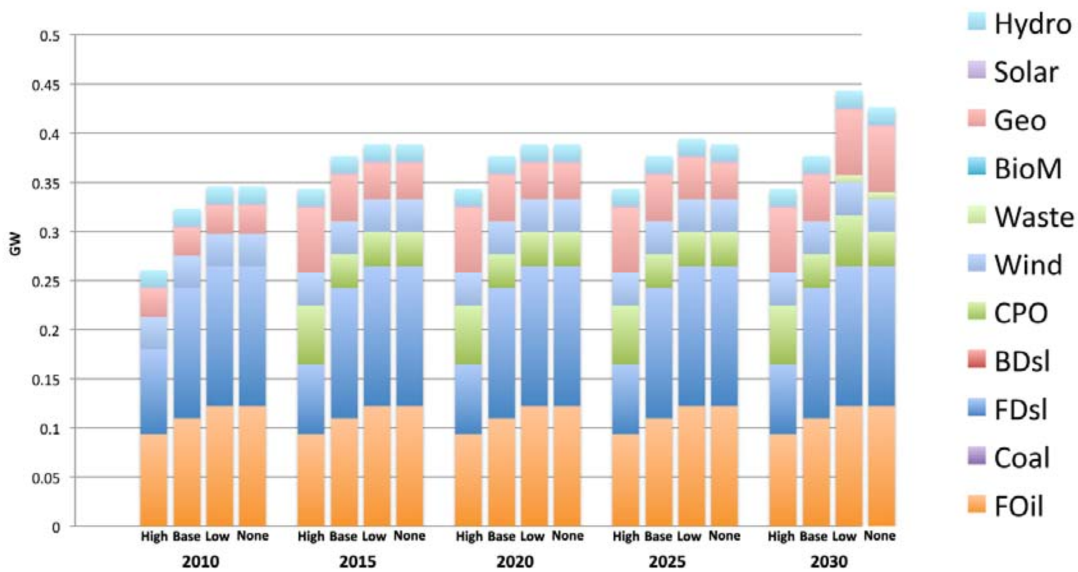


Figure 16: Capacity on the HELCO system by type (GW)



Kauai

Figure 17 Figure and Figure 18 report respectively the generation and capacity by unit type for Kauai. The difference in 2010 capacity across scenarios is similar to that of the Big Island with some diesel-fired capacity retiring in anticipation of higher future oil prices in the base and high scenarios. In 2015, new CPO-fired capacity comes on-line to meet rising demand for all cases and to counteract higher oil prices in the high and base cases. In addition, wind powered generation is installed in these cases. The amount of non-oil fired capacity added increases with increasing oil prices.

In each scenario, the capacity remains fairly constant from 2015 to 2025, but the utilization increases for the oil-fired units as increasing their utilization is less expensive than adding new capacity. By 2030, more capacity is required to meet the rising demand in the none and low scenarios. In both cases, the maximum available MSW capacity is added because it has the lowest lifecycle costs of all possible unit additions. Then the next lowest cost option, the second tier of CPO-fired generation, is added to the system. In the low oil price case, which has the highest demand, more generation is added.

Figure 17: Generation on the Kauai System (TWh)

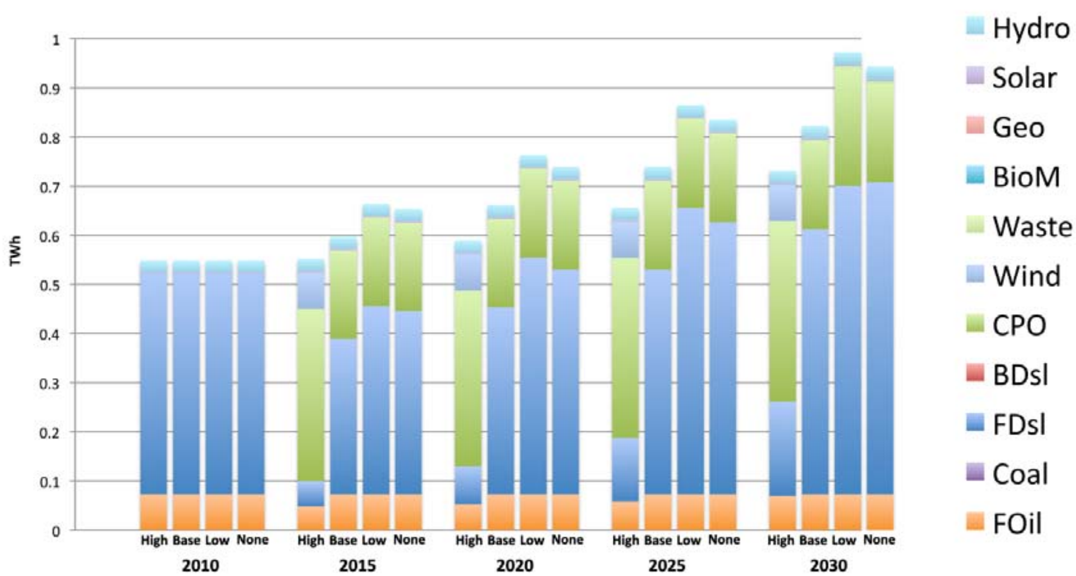
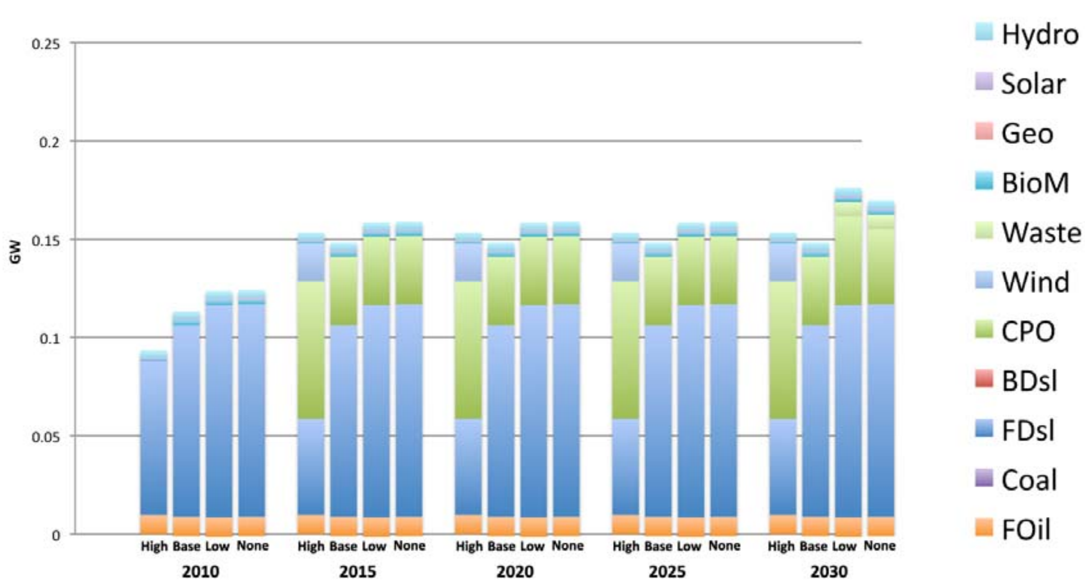


Figure 18: Capacity on the Kauai System (GW)



Maui

Figure 19 and Figure 20 report respectively the generation and capacity by unit type for Kauai. In 2010, some diesel-fired capacity retires in anticipation of higher future oil prices in the high scenarios. Capacity is not retired in other cases because this existing capacity will provide a more cost-effective source of generation than building more capacity to meet the higher future levels of demand. In 2015, new CPO-fired capacity comes on-line to meet rising demand for all cases and to counteract higher oil prices in the high and base cases. In addition, wind powered generation is installed in the high case. As with all systems, the amount of non-oil fired capacity added increases with increasing oil prices. With the addition of new capacity, more diesel-fired generation is retired in the high case.

In each case, its capacity remains fairly constant from 2015 to 2020 with a slight increase in CPO and wind power under all cases except the high one to meet the rising demand. The utilization of oil-fired units increases also as demand increases. In moving from 2020 to 2025, the generation and capacity patterns are similar to those as in moving from 2015 to 2020 except now there is no change in capacity for the high and base cases.

By 2030, more capacity is required to meet the higher demand in the none and low scenarios. In both cases, the maximum available MSW capacity is added because it has the lowest lifecycle costs of all possible new units. Then the next lowest cost option, the second tier of CPO-fired generation, is added to the system. In low oil price case, which has the highest demand, more CPO-fired generation is added.

Figure 19: Generation on the Maui System (TWh)

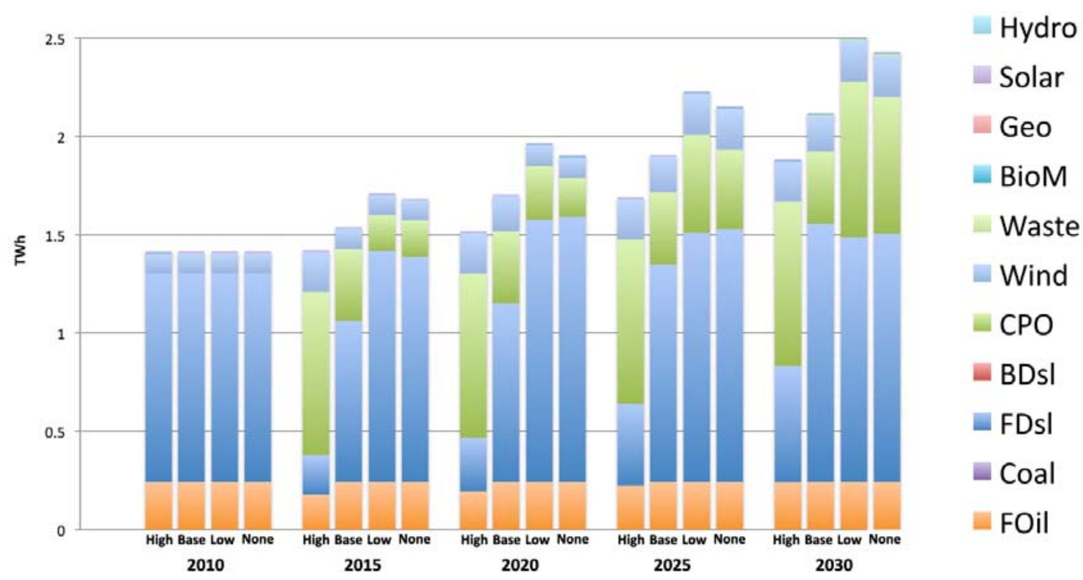
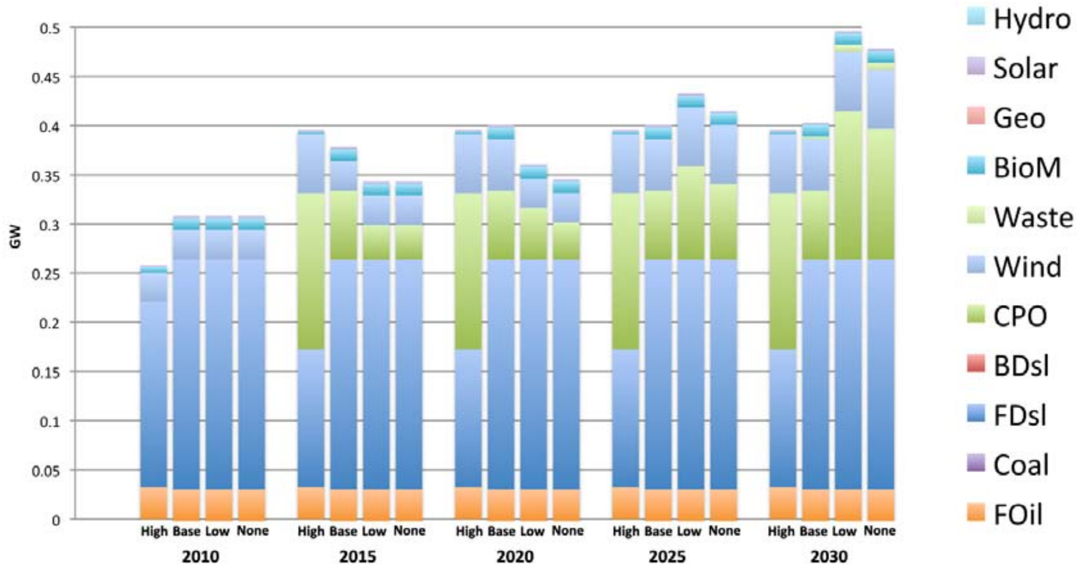


Figure 20: Capacity on the Maui system (GW)



Caveats

The above model results are sensitive to its data inputs and its structure. Energy price forecasts, demand forecasts, and available technologies for new generation are the most critical data. The value for most of these inputs is preliminary. In this analysis, the price of biofuels remains constant across all oil price forecasts. History suggests that there is a positive correlation between biofuels and fossil fuel prices, which should be incorporated in the next phase of this project. In addition, further research is needed to develop an overall more consistent price relationship between biofuels and fossil fuels. The growth rate for the demand for electricity exceeds that of the state's gross product. This differs from recent history; therefore, the next phase of analysis will need to address this relationship and adjust the demand for electricity downward. Last, the set of new technologies was quite restrictive for this analysis because the goal of this phase was to develop a working model that produces qualitatively suitable results.

In addition to using preliminary data, the HELM model will be enhanced to include the ability for existing oil-fired units to convert to burn biofuels and the ability for eligible units to be repowered. HELM's current formulation of its objective function has a bias against low operating cost units because this function currently fails to account for post model horizon costs. The next version of HELM will better address the trade-off between capital and operating costs by accounting for the full life cycle costs of new units.

4. Model Integration

Within energy modeling techniques, there are two basic "types" of models: top-down and bottom-up. Top-down models are often general equilibrium representations of the entire economy, with specific focus on the energy sector. Top-down models are often utilized because they lend themselves to analysis of links of the energy sector to overall economic activity, welfare impacts, and policy. Top-down models do not, however, contain a detailed representation of the energy sector and thus lack the ability to realistically represent various engineering constraints and other discontinuities.

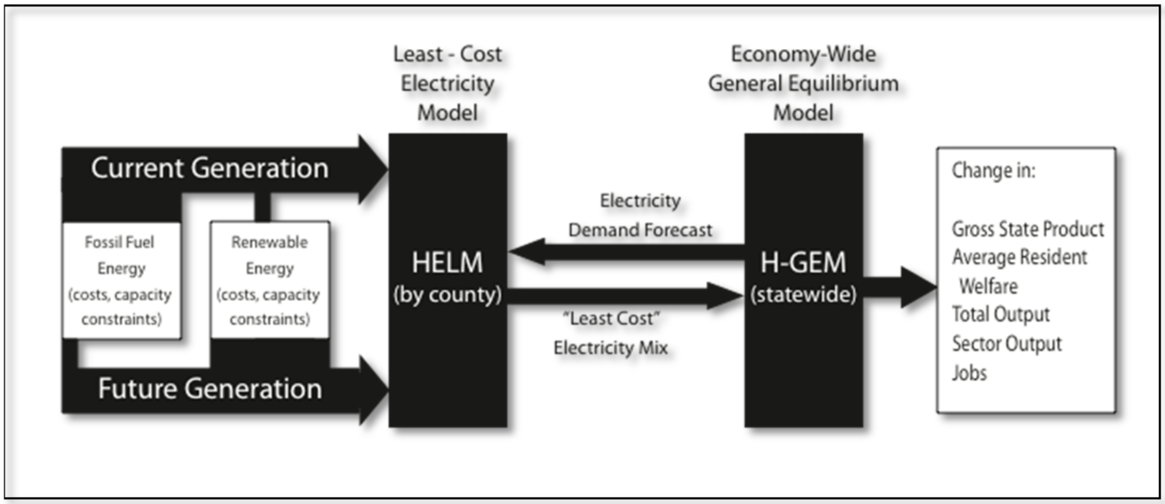
Bottom-up models, on the other hand, are partial equilibrium representations of the energy sector with great detail on energy types, capital costs, operating costs, and environmental factors. Bottom-up models are usually least-cost optimization programs, iterating under various policy scenarios. They lack the ability to provide macroeconomic insights or link to activities of other sectors. Thus they provide only limited insight into welfare effects or indirect/induced impacts of selected policies.

Given the advantages and disadvantages of both modeling platforms, there is a wide-range of hybrid models that combine top-down and bottom-up methods (Bohringer and Rutherford, 2007). Most often, models contain a "soft-link,"[11] as is the case with H-CGE and HELM.

Whereas H-CGE is a top-down representation of Hawaii's economy and HELM is a bottom-up representation of its electricity sector, the two models are calibrated with consistent baseline assumptions. Specifically, 1) the models are both calibrated to data in the year 2005, 2) the EIA oil price forecasts (low, reference, high) are used to drive results in each model over five-year time periods, and 3) the electricity demand forecast is determined by H-CGE under the three scenarios and fed into HELM as the quantity constraint for total electricity consumption within Hawaii. Figure 21, H-CGE and HELM Interaction, shows the inputs and outputs of each model.

[11] While it is possible to entirely integrate top-down and bottom-up models through the reformatting of the bottom-up model as a mixed complementary problem (see Bohringer and Rutherford, 2007, for a full proof), the dimensionality and level of data aggregation of the two models make this a difficult proposition. It was decided early-on by the study team to build two detailed and harmonized models with a "soft-link" as a first exercise, with the possibility of full integration in future work.

Figure 21. H-CGE and HELM Interaction



The preliminary results presented within this report, for H-CGE in Section 2 and HELM in Section 3, provide three baseline scenarios under low, reference and high oil price cases. The electricity demand forecast was generated by H-CGE (through the growth of the overall economy and subsequent sector-level demand), as shown in Figure 9, and used as the demand constraint for HELM. As policy scenarios are developed within HELM, the outputs will serve to inform changes in the production of the electricity sector within H-CGE and thus providing insight into policy impacts to the macroeconomy, impacted sectors including employment shifts, household welfare, and greenhouse gas emissions.

5. Discussion of Preliminary Scenario Selection

While H-CGE and HELM can be further developed to address a wide variety of energy policy scenarios, given the adoption by the Hawaii State Legislature of a more stringent Renewable Portfolio Standard (RPS) targets and the exclusion of energy efficiency from the RPS with the creation of the Energy Efficiency Portfolio Standard (EEPS), the study team proposes to first model the optimal energy technology selection to achieve 40% renewable energy by the year 2030. This work will serve as a baseline by which to later address the EEPS.

The RPS will be modeled within HELM based on the constraints of two regulated electric utilities in the state: one operating solely on the island of Kauai (KIUC) and the other operating on all other islands (HECO, MECO, and HELCO).

To best address the question of the optimal technology mix, by county, to meet the RPS, several uncertainties need to be addressed. Specifically, the scenario will be assessed under 1) the case that an undersea cable is built connecting Maui County to the City & County of Honolulu, and 2) that each island has an isolated grid system. Within the "cable scenario," installation costs will be reflected through amortized "loan payback" by taxpayers. Thus, the macroeconomic impacts of the cable, as well as the renewable energies that it allows (i.e. greater wind penetration) will be accounted for within the model.

Final scenario selection will be made by August 2010 and a scenario report provided in November 2010.

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Appendix I. H-CGE Model Code

1. Social Accounting Matrix Aggregation & Data Entry – titled "Bench"

```
$TITLE Hawaii Benchmark Data 2005

SET    MASTER  List of all labels /
       1        Sugarcane
       2        Vegetables
       3        Macadamia nuts
       4        Pineapples
       5        Flowers and Nursery Products
       6        Other Crops
       7        Animal Production
       8        Aquaculture
       9        Commercial Fishing
       10       Forestry and Logging
       11       Support Activities for Agriculture
       12       Mining
       13       Single Family Construction
       14       Construction of Other Buildings
       15       Heavy and Civil Engineering Construction
       16       Maintenance & Repairs
       17       Food Processing
       18       Beverage Manufacturing
       19       Apparel and Textile Manufacturing
       20       Petroleum Manufacturing
       21       Other Manufacturing
       22       Air Transportation
       23       Water Transportation
       24       Truck and Rail Transportation
       25       Transit and Ground Passenger Transportation
       26       Scenic and Support Activities for Transportatin
       27       Couriers and Messengers
       28       Warehousing and Storage
       29       Publishing including internet
       30       Motion Picture and Source Recording Industries
       31       Broadcasting
       32       Telecomunications
       33       Internet providers, and data processing
       34       Other Information Services
       35       Electricity
       36       Gas Production & Distribution
       37       Wholesale Trade
       38       Retail Trade
       39       Credit Intermediation and Related Activities
       40       Insurance Carriers and Related Activities
       41       Other Finance and Insurance
       42       Owner-Occupied Dwellings
       43       Real Estate
       44       Rental & Leasing and Others
       45       Legal Services
       46       Architectural and Engineering Services
       47       Computer Systems Design Services
```

48	R&D in the Physical, Engineering & Life Sciences
49	Other Professional Services
50	Management of Companies and Enterprises
51	Travel Arrangement and Reservation Services
52	Administrative and Support Services
53	Waste Management and Remediation Services
54	Colleges Universities and Professional Schools
55	Other Educational Services
56	Ambulatory Health Care Services
57	Hospitals
58	Nursing and Residential Care Facilities
59	Social Assistance
60	Arts and Entertainment
61	Accommodation
62	Eating and Drinking
63	Repair and Maintenance
64	Personal and Laundry Services
65	Organizations
66	Federal Government Military
67	Federal Government Civilian
68	State and Local Government
MDM	Imports
WGE	Compensation of employees
PRF	Proprietor's income
ITX	Indirect Business Taxes
RNT	Other capital costs
PCE	Private Consumer Expenditures
VIS	Visitor Expenditures
IVN	Change in Inventories
PIN	Gross Private Investment
SIN	State and Local Government Investment
SLG	State and Local Government Consumption
MIL	Federal Military Consumption
MIN	Federal Military Investment
FED	Federal Civilian Consumption
FIN	Federal Civilian Investment
EXP	Exports
WSJ	Wage and salary job count
PRJ	Proprietor job count

*==
* Labels for aggregated data
*==
* SUG Sugarcane
* VEG Vegetables
* MAC Macadamia nuts
* PNE Pineapples
* FLO Flowers and Nursery Products
* CRO Other Crops
* ANI Animal Production
* AQU Aquaculture
* FIS Commercial Fishing
* LOG Forestry and Logging
* SAG Support Activities for Agriculture
* MNG Mining
* HOU Single Family Construction

* BLD Construction of Other Buildings
* CON Heavy and Civil Engineering Construction
* MAI Maintenance & Repairs
* FOO Food Processing
* BEV Beverage Manufacturing
* CLO Apparel and Textile Manufacturing
* OMN Other Manufacturing
* AIR Air Transportation
* WAT Water Transportation
* TRU Truck and Rail Transportation
* BUS Transit and Ground Passenger Transportation
* SCE Scenic and Support Activities for Transportatin
* COU Couriers and Messengers
* STO Warehousing and Storage
* PUB Publishing including internet
* MOV Motion Picture and Source Recording Industries
* BRO Broadcasting
* TEL Telecomunications
* WEB Internet providers, web, and data processing
* OIS Other Information Services
* WHL Wholesale Trade
* RTL Retail Trade
* CRE Credit Intermediation and Related Activities
* INS Insurance Carriers and Related Activities
* FNI Other Finance and Insurance
* DWE Owner-Occupied Dwellings
* REA Real Estate
* REN Rental & Leasing and Others
* LEG Legal Services
* ARC Architectural and Engineering Services
* COM Computer Systems Design Services
* ELS R&D in the Physical, Engineering & Life Sciences
* OPS Other Professional Services
* MAN Management of Companies and Enterprises
* TRV Travel Arrangement and Reservation Services
* ADM Administrative and Support Services
* WAS Waste Management and Remediation Services
* UNI Colleges Universities and Professional Schools
* EDU Other Educational Services
* HLT Ambulatory Health Care Services
* HOS Hospitals
* NUR Nursing and Residential Care Facilities
* SOC Social Assistance
* ART Arts and Entertainment
* HOT Accommodation
* EAT Eating and Drinking
* REP Repair and Maintenance
* LAU Personal and Laundry Services
* ORG Organizations
* GAS The Gas Company
* FGO Federal Government 66,67
* STG State and Local Government

SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
RTL,CRE,INS,FNI,DWE,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,

```
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,

        ELE,PET / ;

SET     BIGRC(MASTER)     IO Row and Columns /
        1*68, MDM, WGE, PRF, ITX, RNT, PCE, VIS, IVN,
        PIN, SIN, SLG, MIL, MIN, FED, FIN, EXP, WSJ, PRJ /,

        ROWCOL(MASTER)  Rows and Columns for aggregated IO /
        MDM, WGE, PRF, ITX, RNT, PET, ELE, PCE, VIS, PIN, SIN,
        SLG, FIN, FED, EXP,

        SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
        RTL,CRE,INS,FNI,DWE,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,

        WSJ, PRJ /,

        I(BIGRC) Base Intermediate Input-Output Sectors / 1*68 /;

SET     LBL(ROWCOL) Labels for Aggregated IO sectors /
        SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
        RTL,CRE,INS,FNI,DWE,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,

        PET, ELE, MDM, WGE, PRF, ITX, RNT,

        PCE, VIS, PIN, SIN, SLG, FIN, FED, EXP,

        WSJ, PRJ /,

        MAP(BIGRC,LBL)/
        1.SUG,
        2.VEG,
        3.MAC,
        4.PNE,
        5.FLO,
        6.CRO,
        7.ANI,
        8.AQU,
        9.FIS,
        10.LOG,
        11.SAG,
        12.MNG,
        13.HOU,
        14.BLD,
        15.CON,
        16.MAI,
        17.FOO,
        18.BEV,
        19.CLO,
        21.OMN,
        22.AIR,
        23.WAT,
```

24.TRU,
25.BUS,
26.SCE,
27.COU,
28.STO,
29.PUB,
30.MOV,
31.BRO,
32.TEL,
33.WEB,
34.OIS,
37.WHL,
38.RTL,
39.CRE,
40.INS,
41.FNI,
(42,43).REA,
44.REN,
45.LEG,
46.ARC,
47.COM,
48.ELS,
49.OPS,
50.MAN,
51.TRV,
52.ADM,
53.WAS,
54.UNI,
55.EDU,
56.HLT,
57.HOS,
58.NUR,
59.SOC,
60.ART,
61.HOT,
62.EAT,
63.REP,
64.LAU,
65.ORG,
36.GAS,
(66,67).FGO,
68.STG,

MDM.MDM,
WGE.WGE,
PRF.PRF,
ITX.ITX,
RNT.RNT,
35.ELE,
20.PET,
PCE.PCE,
VIS.VIS,
(IVN,PIN).PIN,
SIN.SIN,
SLG.SLG,
(MIN,FIN).FIN,

```
      (MIL,FED).FED,
      EXP.EXP,

      WSJ.WSJ,
      PRJ.PRJ /;

SET     ROW(ROWCOL) Sector Rows /
      SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
      BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
      RTL,CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
      EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG /,

      COL(ROWCOL)  Sector Columns  /
      SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
      BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
      RTL,CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
      EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,ELE,PET /,

      DEMCOL(ROWCOL) Final Demand Columns /
      PCE     Private Consumer Expenditures
      VIS     Visitor Expenditures
      PIN     Gross Private Investment
      SIN     State and Local Government Investment
      SLG     State and Local Government Consumption
      FIN     Federal Investment
      FED     Federal Consumption
      EXP     Exports /,

      VAROW(ROWCOL) Value Added Rows /
      MDM     Imports
      WGE     Compensation of employees
      PRF     Proprietor's income
      ITX     Indirect Business Taxes
      RNT     Other capital costs /,

      ENFD(ROWCOL) Energy sectors / ELE, PET /,

      VAEN(ROWCOL) Value Added and Energy / ELE, PET, MDM, WGE, PRF, ITX, RNT /,

      JOBROW(ROWCOL)  Job count by sector /
      WSJ     Wage salary jobs
      PRJ     Proprietor jobs        /   ;


ALIAS (BIGRC,BB), (ROWCOL,RC), (LBL,LL);

PARAMETER
      IOBIG(BIGRC, BB)           Full IO Table as given ($million)
      IODATA(ROWCOL,RC)          Aggregated Full IO
      IOSEC(ROW,COL)             Input Output Sectors
      FDCOL(ROW,DEMCOL)          Final Demand Column
      MFD(DEMCOL)                Imported final demand
      ENE(ENFD,DEMCOL)           Energy final demand
      FACTOR(VAEN,COL)           Factor Demand   ,

      JOBCT(JOBROW,COL)
```

```
        ITX(I)                Adjusted ITX
        RNT(I)                Adjusted RNT
        MDM(I)                Adjusted MDM  ;

*================================================================================
* Import Benchmark Data from Excel file
*================================================================================

$LIBINCLUDE XLIMPORT IOBIG BASEIO.XLS     B3:CC78

*================================================================================
* Convert the negative taxes (ITX) to zero and attribute difference to other capital costs (RNT)
* Convert the negative (RNT) to zero and attribute difference to imports (MDM)
*================================================================================
        RNT(I) = IOBIG("RNT",I);
        RNT(I)$(IOBIG("ITX",I) LT 0) = (IOBIG("RNT",I)+IOBIG("ITX",I));
* Convert the adjusted RNT back to the IOBIG set
        IOBIG("RNT",I) = RNT(I);

        ITX(I) = IOBIG("ITX",I);
        ITX(I)$(IOBIG("ITX",I) LT 0) = 0;
* Convert the adjusted ITX back to teh IOBIG set
        IOBIG("ITX",I) = ITX(I);

        MDM(I) = IOBIG("MDM",I);
        MDM(I)$(IOBIG("RNT",I) LT 0) = (IOBIG("MDM",I)+IOBIG("RNT",I));
* Convert the adjusted ITX back to teh IOBIG set
        IOBIG("MDM",I) = MDM(I);

        RNT(I) = IOBIG("RNT",I);
        RNT(I)$(IOBIG("RNT",I) LT 0) = 0;
* Convert the adjusted RNT back to the IOBIG set
        IOBIG("RNT",I) = RNT(I);


*================================================================================
* Aggregate the IO table
*================================================================================

        IODATA(LBL,LL)    = SUM((BIGRC,BB)$(MAP(BIGRC,LBL)*MAP(BB,LL)),IOBIG(BIGRC,BB));

        FACTOR(VAEN,COL)  = IODATA(VAEN,COL);

        JOBCT(JOBROW,COL) = IODATA(JOBROW,COL);

        FDCOL(ROW,DEMCOL) = IODATA(ROW,DEMCOL);

        IOSEC(ROW,COL)    = IODATA(ROW,COL);

        MFD(DEMCOL)       = IODATA("MDM",DEMCOL);

        ENE(ENFD,DEMCOL)  = IODATA(ENFD,DEMCOL);

*================================================================================
* Move "Mining" in Electricity Sector & Gas Sector to Imports
* Move residual of "Mining" to Exports - will get aggregated to
```

```
*    other manufacturing in general
* Problem of National Sharing of IO, likely Coal Sector
*==========================================================================================

        FACTOR("MDM","ELE")=FACTOR("MDM","ELE")+IOSEC("MNG","ELE");
        FDCOL("MNG","EXP")=FDCOL("MNG","EXP")+IOSEC("MNG","ELE");
        IOSEC("MNG","ELE")=0;

        FACTOR("MDM","GAS")=FACTOR("MDM","GAS")+IOSEC("MNG","GAS");
        FDCOL("MNG","EXP")=FDCOL("MNG","EXP")+IOSEC("MNG","GAS");
        IOSEC("MNG","GAS")=0;

*==========================================================================================
* Export Aggregated Benchmark Data to Excel file
*==========================================================================================

PARAMETER IMRPT(*,DEMCOL);
        IMRPT("MDM", DEMCOL) = MFD(DEMCOL);

$LIBINCLUDE XLEXPORT IOSEC          BASEDATA.XLS  B3:BP67
$LIBINCLUDE XLEXPORT FDCOL          BASEDATA.XLS  BR3:BZ67
$LIBINCLUDE XLEXPORT FACTOR         BASEDATA.XLS  B69:BP76
$LIBINCLUDE XLEXPORT IMRPT          BASEDATA.XLS  BR78:BZ80
$LIBINCLUDE XLEXPORT ENE            BASEDATA.XLS  BR69:BZ71
$LIBINCLUDE XLEXPORT JOBCT          BASEDATA.XLS  B78:BP80

* Scale data to help solver:
*$ontext
       IOSEC(ROW,COL)            = IOSEC(ROW,COL)/1000;
       FDCOL(ROW,DEMCOL)         = FDCOL(ROW,DEMCOL)/1000;
       MFD(DEMCOL)               = MFD(DEMCOL)/1000;
       FACTOR(VAEN,COL)          = FACTOR(VAEN,COL)/1000;
       ENE(ENFD,DEMCOL)          = ENE(ENFD,DEMCOL)/1000;
*$offtext
*==========================================================================================
* Export Aggregated Benchmark Data in GAMS readable form
*==========================================================================================

FILE KBMK /BENCH.BMK/;
$BATINCLUDE WRTPRM.INC KBMK IOSEC          ROW     COL
$BATINCLUDE WRTPRM.INC KBMK FDCOL          ROW     DEMCOL
$BATINCLUDE WRTPRM.INC KBMK FACTOR         VAEN         COL
$BATINCLUDE WRTPRM.INC KBMK JOBCT          JOBROW       COL
$BATINCLUDE WRTPRM.INC KBMK MFD            DEMCOL
$BATINCLUDE WRTPRM.INC KBMK ENE            ENFD         DEMCOL
```

2. H-CGE Model Code

```
$TITLE Hawaii 2005 Dynamic Model

*=================================================================================
*     Hawaii General Equilibrium Model (H-GEM)
*     Developed for the Hawaii Natural Energy Institute 2010-2011
*     Programmer: Makena Coffman
*     Date Initiated: January 2010
*     Based on 2005 Input-Output Table
*=================================================================================

*=================================================================================
* Set Default Oil Shock Case (i.e. "none")
*=================================================================================

$if not set case $set case none
Display "Case = %case%";
*$exit

*=================================================================================
* Define "flag" for endogenous unemployment (UNEMPE=1=flexible unemployment)
*=================================================================================

SCALAR UNEMPE Flag to allow endogenous unemployment;
*Reason to not always allow endogenous unemployment
*is that it causes relative depreciation - true long-run equilibrium model
*    UNEMPE = 1;
   UNEMPE = 0;

*=================================================================================
* Define "flag" for neutral government expenditures (FIXG=1=neutral)
*=================================================================================

SCALAR FIXG Flag to fix state and local government expenditures;
*    FIXG = 1;
   FIXG = 0;

*=================================================================================
* Select Solver
*=================================================================================

*OPTION MCP = MILES;
OPTION MCP = PATH;

*=================================================================================
* Define Relevant Sets
*=================================================================================

SET     IND All Sectors including Imports /
        SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
        RTL,CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,

        PET, ELE,
```

```
        IMP /,

        SEC(IND) All Sectors /
        SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
        RTL,CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,

        PET, ELE /,

        ROW(SEC) Sector Rows /
        SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,
        RTL,CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,
        EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG /,

        SE(SEC)     Sectors Energy / ELE,PET /,

        ENFD(SEC) Energy Final Demand / ELE, PET /,

DEMCOL   Final Demand Columns /
        PCE    Private Consumer Expenditures
        VIS    Visitor Expenditures
        PIN    Gross Private Investment
        SIN    State and Local Government Investment
        SLG    State and Local Government Consumption
        FED    Federal Civilian Consumption
        FIN    Federal Civilian Investment
        EXP    Exports /,

FGV(DEMCOL) Federal government / FED, FIN /,

SGV(DEMCOL) State government / SIN, SLG /,

VAEN     Value Added & Energy Rows /
        ELE     Electricity
        PET     Petroleum
        MDM  Imports
        WGE   Compensation of employees
        PRF     Proprietor's income
        ITX      Indirect Business Taxes
        RNT     Other capital costs    /,

EN(VAEN) Energy Sector Factors / ELE, PET /,


VAROW(VAEN)   Value Added Rows /
        MDM    Imports
        WGE     Compensation of employees
        PRF      Proprietor's income
        ITX       Indirect Business Taxes
        RNT      Other capital costs    /,

JOBROW  Job types  /
        WSJ    Wage and Salary job count
```

```
        PRJ     Proprietor job count/,

SC      Scenarios / base, 1*5 / ;

SET     SNE(SEC)    Sectors Non-Energy / SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,
        LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,
        STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,RTL,CRE,INS,FNI,REA,REN,LEG,ARC,
        COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,
        LAU,ORG,GAS,FGO,STG /,

        SEL(SEC)    Sector Electricity / ELE /,

        SPET(SEC)   Sector Petroleum / PET /,

        AG(SEC)     Sectors Agriculture / SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,
        FIS,LOG,SAG /,

        MS(SEC)     Sectors Manufacturing and Services/MNG,HOU,BLD,CON,MAI,FOO,
        BEV,CLO,OMN,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,RTL,CRE,INS,FNI,
        REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,EDU,HLT,HOS,NUR,SOC,
        ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG/,

        MSPG(SEC)   Sectors Manufacturing and Services including PetM/ MNG,HOU,
        BLD,CON,MAI,FOO,BEV,CLO,OMN,COU,STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,RTL,
        CRE,INS,FNI,REA,REN,LEG,ARC,COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,EDU,
        HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG,GAS,FGO,STG,PET /,

        PTR(ROW)    Purchased Transportation/ AIR,WAT,TRU,BUS,SCE /,

        SNT(ROW)    Sectors Non-Energy & Non-Transportation & Non-Gas / SUG,VEG,MAC,PNE,
        FLO,CRO,ANI,AQU,FIS,LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,BEV,CLO,OMN,COU,
        STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,RTL,CRE,INS,FNI,REA,REN,LEG,ARC,
        COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,
        LAU,ORG,FGO,STG /,

        SNP(SEC)    Sectors NonPetroleum / SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,
        LOG,SAG,MNG,HOU,BLD,CON,MAI,FOO,BEV,CLO,OMN,AIR,WAT,TRU,BUS,SCE,COU,
        STO,PUB,MOV,BRO,TEL,WEB,OIS,WHL,RTL,CRE,INS,FNI,REA,REN,LEG,ARC,
        COM,ELS,OPS,MAN,TRV,ADM,WAS,UNI,EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,
        LAU,ORG,GAS,FGO,STG,ELE /;


ALIAS (SEC,SECC), (AG,AGG),(SNE,SNEE),(SE,SEE),(SEL,SELL),(SPET,SPETT),
        (MS,MSS), (MSPG,MSPGG), (PTR,PTRR);

*=================================================================================
* Import Benchmark Model Data
*=================================================================================

PARAMETER
      IOSEC(ROW,SEC)           Intermediate Input-output exc imports ($m)
      FDCOL(ROW,DEMCOL)        Final demand exc imports ($m)
      FACTOR(VAEN,SEC)         Factor demand
      JOBCT(JOBROW,SEC)        Job count by sector
      MFD(DEMCOL)              Imported final demand
      ENE(ENFD,DEMCOL)         Energy final demand
```

```
       CRUDEINDEX(SC,*)          Crude Oil Price Index;

* Import Benchmark Data
$INCLUDE BENCH.BMK

DISPLAY IOSEC;

*=====================================================================================
* Set Benchmark Unemployment Rate
*=====================================================================================

*Unemployment rate in 2005 was 2.7% (UHERO Data Portal)
Scalar U0 / 0.027 /;

*=====================================================================================
* Import EIA Oil Price Scenarios
*=====================================================================================

$LIBINCLUDE XLIMPORT CRUDEINDEX OilSH.XLS     A1:E7

Display CRUDEINDEX ;
*$exit
*=====================================================================================
* Calibrate Baseline Parameters
*=====================================================================================

PARAMETER
        IO0(ROW,SEC)     IO intermediate demand
        VAEN0(SEC)       Benchmark value added and energy
        VA0(SEC)         Benchmark value added
        EN0(SEC)         Benchmark energy
        LD0(SEC)         Benchmark labor demand
        PR0(SEC)         Benchmark proprietor's income
        INC0(SEC)        Benchmark Income
        IM0(SEC)         Benchmark intermediate import demand aggregate
        GT0(SEC)         Benchmark gross excise tax (indirect business tax)
        KD0(SEC)         Benchmark other capital costs
        L0               Benchmark labor stock
        R0               Benchmark proprietor stock
        K0               Benchmark capital
        M0               Benchmark imports

        HD0(IND)         Benchmark household expenditures
        VD0(IND)         Benchmark visitor expenditures
        PI0(IND)         Benchmark private investment and inventories
        EX0(IND)         Benchmark export demand

        TY0(SEC)         Benchmark goods and services tax
        PY0(SEC)         Benchmark output net producer price

        YFD0(SEC)        Benchmark total domestic demand
        YD0(SEC)         Benchmark final domestic demand
        DOMY0(SEC)       Benchmark supply domestic use
        CD0(DEMCOL)      Benchmark final demand by agent
        GTOT             Benchmark gov expenditures
        FG0              Federal Government Expenditures incl investment
```

```
SG0             State and Local gov expenditures incl investment
GDEF            Benchmark gov deficit
INVTOT          Benchmark investment expenditures
CV0             Benchmark visitor expenditures
C0              Benchmark PCE
BOP0            Benchmark BOP deficit ;

* Production
    IO0(ROW,SEC) = IOSEC(ROW,SEC) ;
    LD0(SEC) = FACTOR("WGE",SEC) ;
    PR0(SEC) = FACTOR("PRF",SEC) ;
    INC0(SEC) = PR0(SEC)+LD0(SEC) ;
    IM0(SEC) = FACTOR("MDM",SEC) ;
    GT0(SEC) = FACTOR("ITX",SEC) ;
    GTOT = SUM(SEC,GT0(SEC)) ;
    KD0(SEC) = FACTOR("RNT",SEC) ;
    VA0(SEC) = SUM(VAROW, FACTOR(VAROW,SEC)) - IM0(SEC) - GT0(SEC) ;
    VAEN0(SEC) = VA0(SEC) + SUM(EN,FACTOR(EN,SEC)) ;
    EN0(SEC) = VAEN0(SEC)-VA0(SEC) ;

* Value added
    L0 = SUM(SEC, LD0(SEC)) ;
    R0 = SUM(SEC, PR0(SEC)) ;
    K0 = SUM(SEC, KD0(SEC)) ;

* Imports
    M0 = SUM(SEC, IM0(SEC)) + SUM(DEMCOL, MFD(DEMCOL)) ;

* Final Demand
* Households
    HD0(ROW) = FDCOL(ROW,"PCE") ;
    HD0("IMP")= MFD("PCE") ;
    HD0(ENFD) = ENE(ENFD,"PCE") ;

    C0 = SUM(IND,HD0(IND)) ;

* Visitors
    VD0(ROW) = FDCOL(ROW,"VIS") ;
    VD0("IMP") = MFD("VIS") ;
    VD0(ENFD) = ENE(ENFD,"VIS") ;

    CV0 = SUM(IND, VD0(IND));

* Exports
    EX0(ROW) = FDCOL(ROW,"EXP") ;
    EX0("IMP") = MFD("EXP") ;
    EX0(ENFD) = ENE(ENFD,"EXP") ;

* Private Investment
    PI0(ROW) = FDCOL(ROW,"PIN") ;
    PI0("IMP") = MFD("PIN") ;
    PI0(ENFD) = ENE(ENFD,"PIN") ;

    INVTOT = SUM(ROW,PI0(ROW))+PI0("IMP")+SUM(ENFD,PI0(ENFD)) ;

* Total Output
```

```
        YFD0(ROW) = SUM(DEMCOL, FDCOL(ROW,DEMCOL)) ;
        YFD0(ENFD) = SUM(DEMCOL, ENE(ENFD,DEMCOL)) ;
        YD0(ROW) = SUM(SEC,IOSEC(ROW,SEC)) + YFD0(ROW) ;
        YD0("ELE") = SUM(SEC,FACTOR("ELE",SEC)) + YFD0("ELE") ;
        YD0("PET") = SUM(SEC,FACTOR("PET",SEC)) + YFD0("PET") ;

* Final Demand by Agent
        CD0(DEMCOL) = SUM(ROW ,FDCOL(ROW,DEMCOL)) + MFD(DEMCOL) +
SUM(ENFD,ENE(ENFD,DEMCOL));

* Government
        FG0 = SUM(FGV, CD0(FGV)) ;
        SG0 = SUM(SGV, CD0(SGV)) ;

* Government Deficit & Balance of Payments
        GDEF = SUM(SEC, GT0(SEC)) - SG0 ;
        DOMY0(SEC) = YD0(SEC) - EX0(SEC) ;
        BOP0 = M0 - SUM(IND, EX0(IND)) - CV0 - FG0;

* Goods and services tax
        TY0(SEC) = GT0(SEC)/YD0(SEC) ;
        PY0(SEC) = 1 - TY0(SEC) ;


Parameter
        JOBS0 Total number of jobs in benchmark
        EMP0  Total number of wage jobs in benchmark
        OWN0  Total number of proprietor jobs in benchmark  ;

        EMP0 = SUM(SEC,JOBCT("WSJ",SEC)) ;
        OWN0 = SUM(SEC,JOBCT("PRJ",SEC)) ;
        JOBS0 = EMP0 + OWN0 ;

Display GDEF, DOMY0, BOP0, VAEN0, EN0, C0, JOBS0, EMP0, OWN0, GT0, GTOT, SG0, TY0 ;

*$exit

*==============================================================================
*  Define Recursive Dynamic Parameters
*==============================================================================

*       Define quantities to capital market for savings and investment
Parameter DEP0                  Depreciation Rate of Capital
         LBaseYr                Initial Wages
         PRBaseYr               Initial Proprietor Income
         BOPBaseYr              Initial Balance of Payments
         VisBaseYr              Initial Visitor Expenditures
         VisConsBaseYr(IND)     Initial Visitor Consumption
         EmpBaseYr              Initial Workforce
         OwnBaseYr              Initial Proprietors  ;

Scalar
        RET0 Return on 5-Year Investment / 0.2763 /,
*Ad hoc assumption based on 5% annual rate of return
        GRW0 Steady-State 5-Year Growth Rate / 0.1163 / ;
*Based on 30-year average (1968 to 2008)
```

```
        DEP0 = (GRW0*(SUM(SEC,KD0(SEC)))-RET0*INVTOT)/(INVTOT-SUM(SEC,KD0(SEC))) ;
*Based on Paltsev (1999)

Display DEP0 ;

        LBaseYr = L0 ;
        PRBaseYr = R0 ;
        BOPBaseYr = BOP0 ;
        VisBaseYr = CV0 ;
        VisConsBaseYr(IND) = VD0(IND) ;
        EmpBaseYr = EMP0 ;
        OwnBaseYr = OWN0 ;

Parameter
        ks_n        New vintage capital
        ks_s        Sunk capital (flexible coefficient) ;

*Define Growth Rate of Capital (New and Old)

ks_n = k0 * (dep0 + grw0) / (1 + grw0);
ks_s = k0  - ks_n;

*==============================================================================
*  Define Oil Shock Placeholder in MPSGE code
*==============================================================================

PARAMETER
        IMSHK      Petroleum Import Price Shock ;

        IMSHK = 1 ;

*==============================================================================
*  Define Exogenous Electricity Efficiency Parameter in MPSGE code
*==============================================================================

PARAMETER
        EFFP    Exogenous Efficiency Parameter (i.e. federal programs or tech improvement) ;

        EFFP = 1 ;

*==============================================================================
*  Model Definition in MPSGE Vector Syntax
*==============================================================================

$ONTEXT

$MODEL:ENERGY

$ECHOP:TRUE

$SECTORS:
* Production
        Y(SEC)         ! Domestic Output
        AR(SEC)        ! Armington Nest for Imports and Domestics
        EVA(SNP)       ! Energy and Value Added Nest
```

```
        ENER(SNP)       ! Energy Nest between Petroleum and Electricity
        VA(SEC)         ! Value added
        INCOME(SEC)     ! Income Nest
        M               ! Imports

*Final Demand
        X(SEC)$EX0(SEC) ! Exports
        C               ! PCE
        CC              ! PCE Composite - Domestic & Imports
        FG              ! Federal Government
        G               ! State and Local Government
        INVT            ! Investment expenditures
        V               ! Visitor expenditures
        KN              ! New vintage capital

        OC
        TC
        HEN

$COMMODITIES:
        PD(SEC)         ! Price of domestically consumed goods
        PI(SEC)         ! Intermediate Inputs & Imports
        PE(SEC)$EX0(SEC) ! Price of exports
        PEVA(SNP)       ! Price of Energy and Value Added Nest
        PEN(SNP)        ! Price of Energy Nest
        PVA(SEC)        ! Price of Value Added Nest
        PM              ! Price of Imports
        PINC            ! Composite Price of Income
        PL              ! Price of Sector Mobile Labor
        PPR             ! Price of Proprietor Labor
        PMK             ! Price of Sector Mobile Capital (Return to capital)
        RKN             ! Return to new-vintage capital
        PC              ! Price of Household Consumption
        PCC             ! Price of Household Consumpion of Composite Domstic-Imported Good
        PG              ! Price of State and Local Government
        PFX             ! Exchange Rate
        PINV            ! Price of Investment
        PV              ! Price of Visitor Consumption
        PFC             ! Price of Federal Government Consumption

        POC
        PTC
        PHEN

$CONSUMERS:
        RA              ! Representative Agent
        GOV             ! State Government
        VIS             ! Visitors
        FC              ! Federal Government Consumption
        SUNK            ! Outside agent

$AUXILIARY:
        UNEMP$UNEMPE    ! Endogenous Unemployment
*       TAU_LUMP$FIXG       ! Lump sum tax replacement
*       TAU_LO$FIXG         ! Lump sum tax replacement
```

```
*================================================================================
* Production of Sectors Not Energy (SNE)
*================================================================================

$PROD:Y(SNE)     s:0     t:5
        O:PD(SNE)              Q:DOMY0(SNE)   P:PY0(SNE)  A:GOV  T:TY0(SNE)
        O:PE(SNE)$EX0(SNE)     Q:EX0(SNE)     P:PY0(SNE)  A:GOV  T:TY0(SNE)
* Intermediate Inputs, Value Added & Energy
        I:PI(SNE)       Q:(SUM(ROW,IO0(ROW,SNE)) +IM0(SNE))
        I:PEVA(SNE)     Q:VAEN0(SNE)

* Armington Nest for Production
$PROD:AR(SNE)    s:1     a:0
        O:PI(SNE)       Q:(SUM(ROW, IO0(ROW,SNE)) + IM0(SNE))
        I:PD(ROW)       Q:(IO0(ROW,SNE)) a:
        I:PM            Q:IM0(SNE)

* Energy and Value Added
$PROD:EVA(SNE)   s:0.5
        O:PEVA(SNE)     Q:VAEN0(SNE)
        I:PVA(SNE)      Q:VA0(SNE)
        I:PEN(SNE)      Q:(VAEN0(SNE)-VA0(SNE))

* Value Added Nest
$PROD:VA(SNE)    s:1
        O:PVA(SNE)      Q:VA0(SNE)
        I:PINC          Q:(LD0(SNE)+PR0(SNE))
        I:PMK           Q:KD0(SNE)

* Income Nest
$PROD:INCOME(SNE) s:0
        O:PINC          Q:(LD0(SNE)+PR0(SNE))
        I:PL            Q:LD0(SNE)
        I:PPR           Q:PR0(SNE)

* Energy Nest
$PROD:ENER(SNE)  s:0.2
        O:PEN(SNE)      Q:(VAEN0(SNE)-VA0(SNE))
        I:PD("ELE")     Q:FACTOR("ELE",SNE)
        I:PD("PET")     Q:FACTOR("PET",SNE)

*================================================================================
* Production of Petroleum Manufacturing (SPET)
*================================================================================

$PROD:Y(SPET)    s:0     t:5
        O:PD(SPET)               Q:DOMY0(SPET)   P:PY0(SPET)  A:GOV  T:TY0(SPET)
        O:PE(SPET)$EX0(SPET)     Q:EX0(SPET)     P:PY0(SPET)  A:GOV  T:TY0(SPET)
* Intermediate Inputs, Value Added & Energy
        I:PI(SPET)          Q:(SUM(ROW,IO0(ROW,SPET)) +IM0(SPET))
        I:PVA(SPET)         Q:VA0(SPET)
        I:PD("ELE")         Q:FACTOR("ELE",SPET)
        I:PD("PET")         Q:FACTOR("PET",SPET)

* Armington Nest for Production
$PROD:AR(SPET)    s:0     a:0
```

```
        O:PI(SPET)          Q:(SUM(ROW, IO0(ROW,SPET)) + IM0(SPET))
        I:PD(ROW)           Q:(IO0(ROW,SPET)) a:
        I:PM                Q:IM0(SPET)     A:SUNK  T:(IMSHK-1)

* Value Added Nest
$PROD:VA(SPET)    s:1
        O:PVA(SPET)         Q:VA0(SPET)
        I:PINC              Q:(LD0(SPET)+PR0(SPET))
        I:PMK               Q:KD0(SPET)

* Income Nest
$PROD:INCOME(SPET) s:0
        O:PINC              Q:(LD0(SPET)+PR0(SPET))
        I:PL                Q:LD0(SPET)
        I:PPR               Q:PR0(SPET)

*==============================================================================
* Production of Electricity (SEL)
*==============================================================================

$PROD:Y(SEL)     s:0     t:5
        O:PD(SEL)                   Q:DOMY0(SEL)   P:PY0(SEL)  A:GOV  T:TY0(SEL)     A:SUNK  T:(1-EFFP)
        O:PE(SEL)$EX0(SEL)          Q:EX0(SEL)     P:PY0(SEL)  A:GOV  T:TY0(SEL)
* Intermediate Inputs, Value Added & Energy
        I:PI(SEL)           Q:(SUM(ROW,IO0(ROW,SEL)) +IM0(SEL))
        I:PEVA(SEL)         Q:VAEN0(SEL)

* Armington Nest for Production
$PROD:AR(SEL)    s:0.3     a:0
        O:PI(SEL)           Q:(SUM(ROW, IO0(ROW,SEL)) + IM0(SEL))
        I:PD(ROW)           Q:(IO0(ROW,SEL)) a:
        I:PM                Q:IM0(SEL)

* Energy and Value Added
$PROD:EVA(SEL)   s:0.2
        O:PEVA(SEL)         Q:VAEN0(SEL)
        I:PVA(SEL)          Q:VA0(SEL)
        I:PEN(SEL)          Q:(VAEN0(SEL)-VA0(SEL))

* Value Added Nest
$PROD:VA(SEL)    s:1
        O:PVA(SEL)          Q:VA0(SEL)
        I:PINC              Q:(LD0(SEL)+PR0(SEL))
        I:PMK               Q:KD0(SEL)

* Income Nest
$PROD:INCOME(SEL) s:0
        O:PINC              Q:(LD0(SEL)+PR0(SEL))
        I:PL                Q:LD0(SEL)
        I:PPR               Q:PR0(SEL)

* Energy Nest
$PROD:ENER(SEL)  s:0
        O:PEN(SEL)          Q:(VAEN0(SEL)-VA0(SEL))
        I:PD("ELE")         Q:FACTOR("ELE",SEL)
        I:PD("PET")         Q:FACTOR("PET",SEL)
```

```
*==============================================================================
* Imports & Exports
*==============================================================================

$PROD:M
      O:PM          Q:(M0 - MFD("EXP"))
      I:PFX         Q:(M0 - MFD("EXP"))

$PROD:X(SEC)$EX0(SEC)
      O:PFX               Q:EX0(SEC)
      I:PE(SEC)           Q:EX0(SEC)

*==============================================================================
* Final Demand
*==============================================================================

* Households
$PROD:C   s:1
      O:PC          Q:C0
      I:PTC         Q:(SUM(PTR,FDCOL(PTR,"PCE")) + ENE("PET","PCE"))
      I:POC         Q:(SUM(SNT,FDCOL(SNT,"PCE"))+MFD("PCE")+ENE("ELE","PCE")+FDCOL("GAS","PCE"))

$PROD:OC s:0.25
      O:POC         Q:(SUM(SNT,FDCOL(SNT,"PCE"))+MFD("PCE")+ENE("ELE","PCE")+FDCOL("GAS","PCE"))
      I:PCC         Q:(SUM(SNT,FDCOL(SNT,"PCE"))+MFD("PCE"))
      I:PHEN        Q:(ENE("ELE","PCE")+FDCOL("GAS","PCE"))

$PROD:HEN   s:0.1
      O:PHEN              Q:(ENE("ELE","PCE")+FDCOL("GAS","PCE"))
      I:PD("ELE")         Q:ENE("ELE","PCE")
      I:PD("GAS")         Q:FDCOL("GAS","PCE")

$PROD:CC  s:1          a:1
      O:PCC               Q:(SUM(SNT,FDCOL(SNT,"PCE"))+MFD("PCE"))
      I:PD(SNT)           Q:FDCOL(SNT,"PCE")      a:
      I:PM                Q:MFD("PCE")

$PROD:TC  s:0.1        a:1
      O:PTC               Q:(SUM(PTR,FDCOL(PTR,"PCE")) + ENE("PET","PCE"))
      I:PD(PTR)           Q:FDCOL(PTR,"PCE")    a:
      I:PD("PET")         Q:ENE("PET","PCE")

* Visitors
$PROD:V   s:1     a:1
      O:PV                Q:CV0
      I:PD(ROW)           Q:VD0(ROW)      a:
      I:PD(ENFD)          Q:VD0(ENFD)
      I:PM                Q:VD0("IMP")

* Federal Government expenditures treated as exogenous
$PROD:FG  s:0  a:0
      O:PFC                          Q:FG0
      I:PD(ROW)#(FGV)                Q:FDCOL(ROW,FGV) a:
      I:PD(ENFD)#(FGV)               Q:ENE(ENFD,FGV)
      I:PM#(FGV)                     Q:MFD(FGV)
```

```
* State Government expenditures Leontief
$PROD:G  s:0  a:0
        O:PG                        Q:SG0
        I:PD(ROW)#(SGV)             Q:FDCOL(ROW,SGV) a:
        I:PD(ENFD)#(SGV)            Q:ENE(ENFD,SGV)
        I:PM#(SGV)                  Q:MFD(SGV)

*==============================================================================
* Investment, Cobb-Douglas
*==============================================================================

$PROD:INVT  s:1  a:1
        O:PINV              Q:INVTOT
        I:PD(ROW)           Q:PI0(ROW) a:
        I:PD(ENFD)          Q:PI0(ENFD) a:
        I:PM            Q:PI0("IMP")

*==============================================================================
* Endowments
*==============================================================================

$DEMAND:VIS
        D:PV            Q:CV0
        E:PFX           Q:CV0

$DEMAND:GOV
        D:PG            Q:SG0
        E:PG            Q:(-GDEF)
*         E:PC          Q:1           R:TAU_LUMP$FIXG
*         E:PC          Q:-1          R:TAU_LO$FIXG

$PROD:kn
       O:PMK            Q:1
       I:RKN            Q:1

$DEMAND:FC
        D:PFC           Q:FG0
        E:PFX           Q:FG0

$DEMAND:SUNK
        D:PFX           Q:1
        E:PFX           Q:1

$DEMAND:RA
        D:PC            Q:C0
        D:PINV                  Q:INVTOT
        E:PL$(NOT UNEMPE)      Q:(L0)$(NOT UNEMPE)
        E:PL$UNEMPE            Q:(L0/(1-U0))$UNEMPE
        E:PL$UNEMPE            Q:(-L0/(1-U0))$UNEMPE           R:UNEMP$UNEMPE
        E:PPR           Q:R0
        E:PFX           Q:BOP0
        E:PMK                   Q:ks_s
        E:RKN                   Q:ks_n
        E:PG            Q:(GDEF)
```

```
*==============================================================================
* Reporting Variables
*==============================================================================

$REPORT:
*Production
        V:DOM(SEC)        O:PD(SEC)         PROD:Y(SEC)
        V:EXP(SEC)        O:PE(SEC)         PROD:Y(SEC)

        V:ENN(SEC)        O:PEN(SEC)        PROD:ENER(SEC)
        V:ELL(SEC)        I:PD("ELE")       PROD:ENER(SEC)
        V:PETM(SEC)       I:PD("PET")       PROD:ENER(SEC)

        V:VAL(SEC)        O:PVA(SEC)        PROD:VA(SEC)
        V:DL(SEC)         I:PL                      PROD:INCOME(SEC)
        V:DP(SEC)         I:PPR             PROD:INCOME(SEC)
        V:DK(SEC)         I:PMK             PROD:VA(SEC)

        V:IOD(ROW,SEC)            I:PI(SEC)         PROD:Y(SEC)

*Households and Visitors
        V:CDD(ENFD)       I:PD(ENFD)        PROD:C
        V:CCD(ROW)        I:PD(ROW)         PROD:CC
        V:CMD             I:PM              PROD:CC
        V:VDD(SEC)        I:PD(SEC)         PROD:V
        V:VMD             I:PM              PROD:V

*Welfare of Agents
        V:WRA             W:RA
        V:WG          W:GOV
        V:WV          W:VIS

*Government
        V:GDD(SEC)        I:PD(SEC)         PROD:G
        V:FGDD(SEC)       I:PD(SEC)         PROD:FG
        V:MGDD(SEC)       I:PD(SEC)         PROD:MG

*Investment
        V:INDD(SEC)       I:PD(SEC)         PROD:INVT
        V:I               D:PINV            DEMAND:RA

*Exports
        V:EXD(SEC)        I:PE(SEC)         PROD:X(SEC)

*==============================================================================
* Auxiliary constraints determine replacement tax rates
*==============================================================================

*$CONSTRAINT:TAU_LUMP$FIXG
*       G =E= 1;

*$CONSTRAINT:TAU_LO$FIXG
*       1 =E= G;

$CONSTRAINT:UNEMP$UNEMPE
* Nominal Wage cannot decline
```

```
*        PL =G= 1;
* Real Wage cannot decline
       PL =G= PC;


$OFFTEXT
$SYSINCLUDE MPSGESET ENERGY

*==========================================================================================
* Solve Benchmark Case  - Replication check
*==========================================================================================

ENERGY.ITERLIM = 0;
$INCLUDE ENERGY.GEN

* Fix exchange rate as the numeraire
PFX.FX = 1;

* Set initial values
PD.L(SEC) = 1 ;
PI.L(SEC) = 1 ;
PE.L(SEC) = 1 ;
PEVA.L(SNP) = 1 ;
PEN.L(SNP) = 1 ;
PVA.L(SEC) = 1 ;
PM.L = 1 ;
PL.L = 1 ;
PPR.L = 1 ;
PMK.L = 1 ;
RKN.L = 1 ;
PC.L = 1 ;
PG.L = 1 ;
PFX.L = 1 ;
PINV.L = 1 ;
PV.L = 1 ;
PFC.L = 1 ;
UNEMP.L$UNEMPE = U0 ;
kn.l = ks_n;

*TAU_LUMP.LO$FIXG        = 0;
*TAU_LUMP.L$FIXG         = 1;

*TAU_LO.LO$FIXG          = 0;
*TAU_LO.L$FIXG           = 1;

* Check homogeneity
*PFX.FX = 2 ;

SOLVE ENERGY USING MCP;

Display pd.l, pi.l ;

*$ontext
* Check whether Walras Law holds:

scalar   walras ;
```

```
     walras = sum(sec,DL.L(sec)) - sum(sec,LD0(sec)) ;

display  walras ;
*$offtext

Display UNEMP.L ;

*$exit

*===========================================================================
* Define Report Parameters
*===========================================================================

PARAMETER
       DynDat(*,SC)            Dynamics - labor capital BOP
       PEX(SEC,SC)             Price export
       PDM(SEC,SC)             Price domestic output
       PVD(SEC,SC)             Cost of value added
       PRK(SEC,SC)             Nominal cost of capital
       XX(SEC,SC)              Sector exports
       DD(SEC,SC)              Sector domestic output
       YY(SEC,SC)              Sector output value
       VV(SEC,SC)              Sector value added
       II(SEC,SC)              Sector industry demand
       VS(IND,SC)              Visitor demand at current prices

       HH(IND,SC)              Household demand at current prices
       IPCT(SEC,SC)            Industry demand percentage change
       HPCT(IND,SC)            Household expenditures percentage change
       VPCT(IND,SC)            Visitor expenditures percentage change
       XPCT(SEC,SC)            Exports percentage change
       DPCT(SEC,SC)            Domestic output percent change
       LABOR(SEC,SC)           Sector Labor bill
       LABQT(SEC,SC)           Labor quantity
       LCTAG(SEC,SC)           Wage and Salary Job count
       PCTAG(SEC,SC)           Proprietor income job count
       PROP(SEC,SC)            Proprietor income
       PROQT(SEC,SC)           Proprietor quantity
       PRQPC(SEC,SC)           Proprietor quantity percentage change

       LABPC(SEC,SC)           Sector Labor percentage chg
       OUTPCT(SEC,SC)          Sector Output percentage chg
       OUTLVL(SEC,SC)          Sector Output value
       VWEL(SC)                Visitor welfare
       VW(SC)            Aggregate Visitor welfare
       PVE(SC)           Aggregate visitor consumption bundle
       GWEL(SC)                Gov welfare (should be unchanged)
       DVL(SC)                 Domestic 0utput value
       XVL(SC)                 Export value
       VVL(SC)                 Total output dom and exported
       YVL(SC)                 Domestic output value
       DQ(SC)            Domestic output quantity
       XQ(SC)            Export quantity
       YQ(SC)            Total production quantity
       DQTY(SEC,SC)            Domestic output quantity
```

```
        XQTY(SEC,SC)              Export quantity
        YQTY(SEC,SC)              Total production quantity
        IQTY(SEC,SC)              Industry demand quantity
        VSQTY(IND,SC)             Visitor demand prices constant
        VSTQTY(IND,SC)            Visitor demand by types prices constant
        VQ(IND,SC)
        VSQT(SEC,SC)              Visitor demand by sector 2005 prices
        HQTY(IND,SC)              Household demand prices constant
        VQTY(SEC,SC)              Value added prices constant
        YQPCT(SEC,SC)             Output percentage change prices constant
        DQPCT(SEC,SC)             Domestic output percent change prices constant
        XQPCT(SEC,SC)             Exports  percent change prices constant
        IQPCT(SEC,SC)             Industry demand percent change prices constant
        HQPCT(IND,SC)             Household demand percent change prices constant
        VSQPCT(IND,SC)            Visitor demand percentage change prices constant
        IOQPCT(ROW,SEC,SC)        IO demand percent change price constant
        SUMMARY(*,SC)             Macro summary % chg since 1997
        MACRO(*,SC)               Macro summary levels
        MACROPCT(*,SC)            Macro summary percent chg since 1997 bmk
        JOBS(SC)                  Total number of jobs
        IIODD(ROW,SEC,SC)        Interindustry Dd current prices
        IODD(ROW,SEC,SC)         Interindustry Dd constant prices
        GG(SEC,SC)                State and Local Government Dd current prices
        FGG(SEC,SC)               Federal Government Dd current prices
        INN(SEC,SC)               Investment and inventories Dd current prices
        GQTY(SEC,SC)              State and Local Government Dd constant prices
        FGQTY(SEC,SC)             Federal Government Dd constant prices
        INQTY(SEC,SC)             Investment and inventories Dd constant prices
        GET(SC)                   General Excise tax collections
        GETS(SC,SEC)              General Excise tax collections
        RealOut(SEC,SC)           Real Output
        NomOut(SEC,SC)            Nominal Output
        EffPar(SC)                Efficiency Parameter;

EffPar(SC) = (1-0.0401) ;

*===========================================================================
* Begin Loop for Dynamics
*===========================================================================

Loop(SC,

IMSHK = CRUDEINDEX(SC,"%case%");
*  );
DISPLAY IMSHK  ;
*$exit

EFFP = EffPar(SC) ;

*EFFP = (1-0.0401) ;
*Source:www.eia.doe.gov/emeu/efficiency/recs_tables_list.htm
*number calculated from residential energy intensities, 1978:2005
*provided in 4-year intervals, calculated to be 0.0079 for one year, leads to
*estimate of 0.0401 for 5-years
*Alternative Source: www.eia.doe.gov/emeu/efficiency/eefig_ch7.htm#figure72
*shows a 1% yearly gain
```

```
* Fix exchange rate as numeraire
PFX.FX = 1 ;

* Set initial values
PD.L(SEC) = 1 ;
PI.L(SEC) = 1 ;
PE.L(SEC) = 1 ;
PEVA.L(SNP) = 1 ;
PEN.L(SNP) = 1 ;
PVA.L(SEC) = 1 ;
PM.L = 1 ;
PL.L = 1 ;
PPR.L = 1 ;
PMK.L = 1 ;
RKN.L = 1 ;
PC.L = 1 ;
PG.L = 1 ;
PFX.L = 1 ;
PINV.L = 1 ;
PV.L = 1 ;
PFC.L = 1 ;
UNEMP.L$UNEMPE = U0 ;
kn.l = ks_n;

* Run simulation
ENERGY.ITERLIM = 3000;
$INCLUDE ENERGY.GEN
SOLVE ENERGY USING MCP;

*==========================================================================
* Report simulation results
*==========================================================================

*      Report only solved cases:
IF (ENERGY.MODELSTAT EQ 1,

*  Report price effects
       PEX(SEC,SC) = 100 * (PE.L(SEC)  - 1) ;
       PDM(SEC,SC) = 100 * (PD.L(SEC)  - 1) ;
       PVD(SEC,SC) = 100 * (PVA.L(SEC) - 1) ;

*  Report labor market effects
       LABOR(SEC,SC) = PL.L * DL.L(SEC) *  1000 ;
       PROP(SEC,SC) = PPR.L * DP.L(SEC) *  1000 ;

       LABQT(SEC,SC) = DL.L(SEC) * 1000 ;
       PROQT(SEC,SC) = DP.L(SEC) * 1000 ;

       LABPC(SEC,SC)$LABQT(SEC,"base") = LABQT(SEC,SC)/LABQT(SEC,"base") ;
       PRQPC(SEC,SC)$PROQT(SEC,"base") = PROQT(SEC,SC)/PROQT(SEC,"base") ;

       LCTAG(SEC,SC) = JOBCT("WSJ",SEC) * (LABPC(SEC,SC)) ;
       PCTAG(SEC,SC) = JOBCT("PRJ",SEC) * (PRQPC(SEC,SC)) ;

DISPLAY LABQT, PROQT, labpc, prqpc, LCTAG, PCTAG ;
```

```
*  REPORT IN VALUE TERMS ($ AT CURRENT PRICES)
      XX(SEC,SC) = PE.L(SEC) * EXP.L(SEC) * 1000 ;
      DD(SEC,SC) = PD.L(SEC) * DOM.L(SEC) * 1000 ;
      YY(SEC,SC) = XX(SEC,SC) + DD(SEC,SC) ;
      VV(SEC,SC) = PVA.L(SEC) * VAL.L(SEC) * 1000 ;

      II(SEC,SC) = SUM(ROW, PD.L(SEC) * IOD.L(ROW,SEC) *1000) ;

      HH(ENFD,SC) = (PD.L(ENFD) * CDD.L(ENFD))*1000 ;
      HH(ROW,SC) = (PD.L(ROW)*CCD.L(ROW))*1000 ;
      HH("IMP",SC) = PM.L    * CMD.L * 1000 ;

      VS(SEC,SC) = PD.L(SEC) * (VDD.L(SEC))* 1000 ;
      VS("IMP",SC) = PM.L    * VMD.L* 1000 ;

      GG(SEC,SC) = PD.L(SEC)*GDD.L(SEC)*1000;
      FGG(SEC,SC) = PD.L(SEC)*FGDD.L(SEC)*1000;
      INN(SEC,SC) = PD.L(SEC)*INDD.L(SEC)*1000;

      GET(SC) = SUM(SEC, (DD(SEC,SC)+XX(SEC,SC))*TY0(SEC));
      GETS(SC,SEC) = (DD(SEC,SC) + XX(SEC,SC))*TY0(SEC) ;

      IIODD(ROW,SEC,SC) = PD.L(SEC) * IOD.L(ROW,SEC)*1000;

      YVL(SC) = SUM(SEC, YY(SEC,SC));
      DVL(SC) = SUM(SEC, DD(SEC,SC));
      XVL(SC) = SUM(SEC, XX(SEC,SC));
      VVL(SC) = SUM(SEC, VV(SEC,SC));

*  REPORT IN QUANTITY TERMS (CONSTANT 1997 PRICES)
      DQTY(SEC,SC) = DOM.L(SEC) * 1000 ;
      XQTY(SEC,SC) = EXP.L(SEC) * 1000;
      VQTY(SEC,SC) = VAL.L(SEC) * 1000;
      YQTY(SEC,SC) = DQTY(SEC,SC) + XQTY(SEC,SC);

      IQTY(ROW,SC) = SUM(SEC, IOD.L(ROW,SEC) * 1000);

      VSQTY(SEC,SC) = VDD.L(SEC)* 1000;
      VSQTY("IMP",SC) = VMD.L* 1000;

      VSTQTY(SEC,SC) = VDD.L(SEC)* 1000 ;
      VSTQTY("IMP",SC) = VMD.L* 1000 ;

      HQTY(ENFD,SC) = CDD.L(ENFD)* 1000 ;
      HQTY(ROW,SC) = CCD.L(ROW)* 1000 ;
      HQTY("IMP",SC) = CMD.L* 1000 ;

      GQTY(SEC,SC) = GDD.L(SEC)*1000 ;
      FGQTY(SEC,SC) = FGDD.L(SEC)*1000 ;
      INQTY(SEC,SC) = INDD.L(SEC)*1000 ;

*       IODD(SC,SEC,SECC)          = IOD.L(SECC,SEC)*1000;

      DQ(SC) = SUM(SEC, DQTY(SEC,SC)) ;
```

```
        XQ(SC) = SUM(SEC, XQTY(SEC,SC)) ;
        YQ(SC) = SUM(SEC, YQTY(SEC,SC)) ;

        LABQT(SEC,SC) = DL.L(SEC) *1000 ;

*  Welfare of agents

        VWEL(SC) = WV.L ;
        GWEL(SC) = WG.L ;
        VW(SC) = VWEL(SC)*CV0 ;
*         PVE(SC) = (PV.L*VWEL(SC))/(VWEL(SC)) ;

*  Price Indices
*         SUMMARY("VPI",SC) = 100*(PVE(SC)) ;
        SUMMARY("CPI",SC) = (PC.L - 1) ;
        SUMMARY("VPI",SC) = (PV.L-1) ;
*         SUMMARY("CPI",SC) = 100*(PC.L - 1) ;
*         SUMMARY("VPI",SC) = 100*(PV.L-1) ;

*  Macroeconomic indicators, on level basis

        MACRO("LBF",SC) = JOBS0 ;
        MACRO("UNP",SC) = JOBS0*UNEMP.L$UNEMPE ;
        MACRO("EWP",SC) = MACRO("LBF",SC)+MACRO("UNP",SC)$UNEMPE ;
* "EWP" stands for "Eligible Working Population
        MACRO("VEN",SC) = 1000*(CV0) ;
        MACRO("VER",SC) = 1000*(CV0/PV.L) ;
        MACRO("HSN",SC) = SUM(IND, HH(IND,SC)) ;
        MACRO("HSR",SC) = SUM(IND, HQTY(IND,SC)) ;
        MACRO("HSP",SC) = 1000*(SUM(IND, HQTY(IND,SC))/(MACRO("EWP",SC))) ;
*         MACRO("HSP",SC) = 1000*(SUM(IND, HQTY(IND,SC))/(MACRO("LBF",SC))) ;
        MACRO("CPI",SC) = 1+SUMMARY("CPI",SC) ;
        MACRO("VPI",SC) = 1+SUMMARY("VPI",SC) ;
        MACRO("WSN",SC) = 1000*L0 * PL.L ;
        MACRO("WSR",SC) = 1000*L0 * PL.L/PC.L ;
        MACRO("WSP",SC) = 1000000*(L0/EMP0) * (PL.L/PC.L) ;
        MACRO("WPN",SC) = 1000*(L0/EMP0)*(PL.L) ;
        MACRO("PRN",SC) = 1000*(SUM(SEC, PR0(SEC)))*PPR.L ;
        MACRO("PRR",SC) = 1000*(SUM(SEC, PR0(SEC)))*PPR.L/PC.L ;
        MACRO("PRP",SC) = 1000000*(R0/OWN0)*PPR.L/PC.L ;
        MACRO("OTN",SC) = YVL(SC) ;
        MACRO("OTR",SC) = YVL(SC)/PC.L ;
        MACRO("GSN",SC) = (VVL(SC) + GET(SC)) ;
        MACRO("GSR",SC) = (VVL(SC) + GET(SC))/PC.L ;


       realout(SEC,SC) = YY(SEC,SC)/PC.L;
        nomout(SEC,SC)  = YY(SEC,SC);


*  END Loop for solved cases
 );

DynDat("ks_s",sc) = ks_s;
DynDat("ks_n",sc) = ks_n;
DynDat("lab",sc) = l0;
```

```
DynDat("bop",sc) = bop0;
DynDat("i.l",sc) = i.l;

*==========================================================================================
* Advance labor, capital, balance of payments, visitor expenditures to next time period, including update of jobs
*==========================================================================================

ks_s = (1-dep0) * (ks_s + kn.l);
ks_n = (ret0 + dep0) * i.l;

L0 = (1 + GRW0)**(ord(SC)) * LBaseYr ;
R0 = (1+GRW0)**(ord(SC))*PRBaseYr ;
BOP0 = (1+GRW0)**(ord(SC)) * BOPBaseYr ;

CV0 = (1 + GRW0)**(ord(SC)) * VisBaseYr ;
VD0(IND) = (1+GRW0)**(ord(SC))*VisConsBaseYr(IND) ;

EMP0 = (1 + GRW0)**(ord(SC)) * EmpBaseYr*(1-UNEMP.L$UNEMPE) ;
OWN0 = (1 + GRW0)**(ord(SC)) * OWNBaseYr ;
*OWN0 = (1 + GRW0)**(ord(SC)) * OWNBaseYr*(1-UNEMP.L$UNEMPE) ;
*EMP0 = (1 + GRW0)**(ord(SC)) * EmpBaseYr ;
*OWN0 = (1 + GRW0)**(ord(SC)) * OWNBaseYr ;
JOBS0 = EMP0 + OWN0 ;


Display DynDat;

* Report the simulation results
DISPLAY MACRO;

*  Display results with constant 2005 prices
DISPLAY DQTY, XQTY, YQTY, LABQT, VSQTY, HQTY;

*  Display results in value terms (current prices)
DISPLAY XX, DD, YY, LABOR, VV, II, HH, VS;

* Display price changes
DISPLAY PEX, PDM, PVD;

DISPLAY  walras ;

* END Loop
);

*$exit

*==========================================================================================
* Report Simulation Results
*==========================================================================================
$LIBINCLUDE XLEXPORT MACRO      RESULTS.XLS B1:M20
$LIBINCLUDE XLEXPORT DQTY       RESULTS.XLS B22:M88
$LIBINCLUDE XLEXPORT DD         RESULTS.XLS P22:AA88
$LIBINCLUDE XLEXPORT XQTY       RESULTS.XLS B90:M156
$LIBINCLUDE XLEXPORT XX         RESULTS.XLS P90:AA156
$LIBINCLUDE XLEXPORT YQTY       RESULTS.XLS B158:M224
$LIBINCLUDE XLEXPORT YY         RESULTS.XLS P158:AA224
```

```
$LIBINCLUDE XLEXPORT LABQT      RESULTS.XLS B226:M293
$LIBINCLUDE XLEXPORT LABOR      RESULTS.XLS P226:AA293
$LIBINCLUDE XLEXPORT VSQTY      RESULTS.XLS B295:M362
$LIBINCLUDE XLEXPORT VS         RESULTS.XLS P295:AA362
$LIBINCLUDE XLEXPORT HQTY       RESULTS.XLS B364:M431
$LIBINCLUDE XLEXPORT HH         RESULTS.XLS P364:AA431
$LIBINCLUDE XLEXPORT PDM        RESULTS.XLS B433:M499
$LIBINCLUDE XLEXPORT LCTAG      RESULTS.XLS B501:M567
$LIBINCLUDE XLEXPORT PCTAG      RESULTS.XLS P501:AA567

*$exit
*==========================================================================================
* Aggregate Results for Compact Reporting Purposes
*==========================================================================================
SET AGGR Labels for Aggregated Sectors/
     PET, ELE, AGR, FRT, CON, OMN, AIR, WTR,
     TRN, RTL, REA, OSV, FGT, SGT /,

     MAP(SEC,AGGR)/
     PET.PET
     ELE.ELE
     (SUG,VEG,MAC,PNE,FLO,CRO,ANI,AQU,FIS,SAG).AGR
     LOG. FRT
     (HOU,BLD,CON).CON
     (MNG,MAI,FOO,BEV,CLO,OMN).OMN
     AIR.AIR
     WAT.WTR
     (TRU,BUS,SCE,COU).TRN
     (WHL,RTL).RTL
     (REA,REN).REA
     (GAS,STO,PUB,MOV,BRO,TEL,WEB,OIS,CRE,INS,FNI,LEG,ARC,COM,ELS,OPS,MAN,
     TRV,ADM,WAS,UNI,EDU,HLT,HOS,NUR,SOC,ART,HOT,EAT,REP,LAU,ORG).OSV
     FGO.FGT
     STG.SGT   /;

Parameter
     DOMOUTR(AGGR,SC)
     DOMOUTN(AGGR,SC)
     EXR(AGGR,SC)
     EXN(AGGR,SC)
     OUTR(AGGR,SC)
     OUTN(AGGR,SC)
     WAGER(AGGR,SC)
     WAGEN(AGGR,SC)
     VISPENDR(AGGR,SC)
     VISPENDN(AGGR,SC)
     RESPENDR(AGGR,SC)
     RESPENDN(AGGR,SC)
     PRICE(AGGR,SC)
     EMPL(AGGR,SC)
     OWNER(AGGR,SC);


DOMOUTR(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),DQTY(SEC,SC)) ;
DOMOUTN(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),DD(SEC,SC)) ;
EXR(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),XQTY(SEC,SC)) ;
```

```
EXN(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),XX(SEC,SC)) ;
OUTR(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),YQTY(SEC,SC)) ;
OUTN(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),YY(SEC,SC)) ;
WAGER(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),LABQT(SEC,SC)) ;
WAGEN(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),LABOR(SEC,SC)) ;
VISPENDR(AGGR,SC)= SUM(SEC$MAP(SEC,AGGR),VSQTY(SEC,SC)) ;
VISPENDN(AGGR,SC)= SUM(SEC$MAP(SEC,AGGR),VS(SEC,SC)) ;
RESPENDR(AGGR,SC)= SUM(SEC$MAP(SEC,AGGR),HQTY(SEC,SC)) ;
RESPENDN(AGGR,SC)= SUM(SEC$MAP(SEC,AGGR),HH(SEC,SC)) ;
PRICE(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),PDM(SEC,SC)) ;
EMPL(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),LCTAG(SEC,SC)) ;
OWNER(AGGR,SC) = SUM(SEC$MAP(SEC,AGGR),PCTAG(SEC,SC)) ;

*==============================================================================
* Report Aggregated Results
*==============================================================================
$LIBINCLUDE XLEXPORT MACRO        RESULTS_AGG.XLS B1:H20
$LIBINCLUDE XLEXPORT DOMOUTR      RESULTS_AGG.XLS B22:H36
$LIBINCLUDE XLEXPORT DOMOUTN      RESULTS_AGG.XLS K22:Q36
$LIBINCLUDE XLEXPORT EXR          RESULTS_AGG.XLS B38:H52
$LIBINCLUDE XLEXPORT EXN          RESULTS_AGG.XLS K38:Q52
$LIBINCLUDE XLEXPORT OUTR         RESULTS_AGG.XLS B54:H68
$LIBINCLUDE XLEXPORT OUTN         RESULTS_AGG.XLS K54:Q68
$LIBINCLUDE XLEXPORT WAGER        RESULTS_AGG.XLS B70:H84
$LIBINCLUDE XLEXPORT WAGEN        RESULTS_AGG.XLS K70:Q84
$LIBINCLUDE XLEXPORT VISPENDR     RESULTS_AGG.XLS B86:H101
$LIBINCLUDE XLEXPORT VISPENDN     RESULTS_AGG.XLS K86:Q101
$LIBINCLUDE XLEXPORT RESPENDR     RESULTS_AGG.XLS B103:H118
$LIBINCLUDE XLEXPORT RESPENDN     RESULTS_AGG.XLS K103:Q118
$LIBINCLUDE XLEXPORT PRICE        RESULTS_AGG.XLS B120:H134
$LIBINCLUDE XLEXPORT EMPL         RESULTS_AGG.XLS B136:H150
$LIBINCLUDE XLEXPORT OWNER        RESULTS_AGG.XLS K136:Q150

*==============================================================================
* Pau!
*==============================================================================
```

3. Code to solve multiple Oil Price Scenarios

"run.bat"

```
set case=%1
call gams hawaii o=%case%.lst --case=%case%

copy RESULTS.XLS RESULTS_%case%.XLS
copy RESULTS_AGG.XLS RESULTS_AGG_%case%.XLS
```

"runall.bat"

```
path=%path%;c:\program files\gams22.9
call run med
call run low
call run high
call run none
```

Appendix II. HELM Code

```
$ontext
Electricity sector model

ADAGE model representation
  (1) Minimize Total Generation Costs subject to:
  (2) Total Generation per period + Net Imports => Demand
  (3) Capacity => Peak Demand * (1+ Reserve Margin)
  (5) Generation by Type <= Maximum Availability (capacity factor)
  (6) Generation by Type => Minimum Availability
  (7) Fuel Consumption <= Fuel Supply by Type
  (8) Capacityt = Capacityt-1 + Build_Capacityt (time period t)
  (9) Retrofitst = Retrofitst-1 + Build_Retrofitst
  (11) Emissions <= Emission Cap – Net Emissions Banking
Souce:  ema-model-doc

Minimize Total Generation Costs {PV over time}
= (Fixed O&M + Variable O&M + Fuel costs) {existing plants}
+ (Capital costs + Fixed O&M + Variable O&M + Fuel costs) {new plants}
+ (Capital costs + Fixed O&M + Variable O&M) {retrofits}
+ Transmission Costs
+ Environmental Taxes

(1a) Fuel Cost = Generation (kWh) * Heat Rate (btu/kWh) * Fuel Price ($/MMBtu)
Construction costs for building new capacity are based on EIA (AEO 2008) data. Total
capital costs are the sum over the payback period (or book life, assumed to be 30 years) of
the discounted present value of the annualized capital costs. These annual costs are equal
to the size of the new unit times the total overnight construction cost (adjusted for
regional cost differences) times the annual capital charge rate.
(1b) Total Capital Cost = åPayback period PV [Capacity (kW) * Cost ($/kW) * Capital Charge Rate]
Capital charge rate = 13%
Payback period taken to be 30 years
Discount rate = 6%

In breaking up load over the year, want to account for daily peak, shoulder, and off-peak.  Also, need to account
for periods of greatest and minimal wind and periods of no sun and sun.  The capacity factor for wind and solar should vary
according to the time periods.  Need to determine how much seasonal variability there is with wind and solar to figure out
how many load blocks are needed.  May need to map times to seasons or particular months depending on variability.  Need
to recognize blocks in a particular period so that maintenance makes sense.

$offtext

$if not set forecast    $set forecast base

Sets
        b  "load blocks - 3 day types X 4 seasons X 7 different hour blocks"      /b1*b84/
        t                  Time (solution years)   /2010, 2015, 2020, 2025, 2030/
        p                  "Pools generally one per island, but may want 2 for Big Island" /Oahu, Hawaii, Maui, Kauai/
        g                  generators /
*       Oahu units
                AES             AES coal unit
                Hon             Honolulu 1 and 2 - LSFO
```

Waiau-ST	Waiau - LSFO
Waiau-CT	Waiau - Diesel
Kahe-ST	Kahe LSFO
DG	Distributed generation
Kalaeloa	Kalaeloa - Diesel
Hpower	H-Power
CIP	Cambell industrial park unit
O-Wind	New Oahu wind
O-BioFuel1	New Oahu Biofuel unit
O-BioFuel2	New Oahu Biofuel unit
O-LFG	New Oahu Land fill gas
O-NewCoal	New Oahu coal unit

* Hawaii Island units
Apollo
DG-HELCO
Hamakua
Hawi
Kanoelehua
Keahole
Keahole-Solar
Lalamilo
H-Hydro
Puna-MSFO
Puna-Diesel
PGV
Shipman-MSFO
WHHill
Waimea

H-Geo1
H-Geo2
H-Wind
H-BioFuel1
H-BioFuel2
H-BioFuel3
H-MSW

* KIUC units
Kapaia
K-Hydro
Kaumakani-Wood
Kaumakani-Oil
Slr-PioneerHwy
PA1
PA2
PA3
PA4
PA-Steam

K-Wind
K-BioFuel1
K-BioFuel2
K-BioFuel3
K-MSW

```
*       MECO units
        HCS
        Kaheawa
        Kahului1
        Kahului2
        Maalaea1
        Maalaea2
        Maalaea3
        Maalaea4
        MikiBasin
        Palaau
        Palaau-Solar

        M-Wind
        M-BioFuel1
        M-BioFuel2
        M-BioFuel3
        M-MSW
                /


        ng(g)   New generators /
                CIP
                O-Wind
                O-BioFuel1
                O-BioFuel2
                O-LFG
                O-NewCoal

                H-Geo1
                H-Geo2
                H-Wind
                H-BioFuel1
                H-BioFuel2
                H-BioFuel3
                H-MSW

                K-Wind
                K-BioFuel1
                K-BioFuel2
                K-BioFuel3
                K-MSW

                M-Wind
                M-BioFuel1
                M-BioFuel2
                M-BioFuel3
                M-MSW
                /

*       Create sets for stacked bar graph
        coalg(g)        Coal units /AES,O-NewCoal/
        FDslg(g)        Diesel units /Waiau-CT, DG, Kalaeloa, DG-HELCO,
                        Kanoelehua, Keahole, Puna-Diesel, Waimea, Kapaia, PA1, PA2, PA3, PA4
                        Maalaea1, Maalaea2, Maalaea3, Maalaea4, MikiBasin, Palaau/
```

```
      FOilg(g)        Fuel oil units /Hon, Kahe-ST, Waiau-ST, Hamakua,Puna-MSFO,Shipman-MSFO,WHHill,Kaumakani-
Oil,PA-Steam,Kahului1 ,Kahului2/

      BDslg(g)        Biodiesel units /CIP/
      CPOlg(g)        CPO units /O-BioFuel1,O-BioFuel2, H-BioFuel1,H-BioFuel2,H-BioFuel3,K-BioFuel1,K-BioFuel2,K-
BioFuel3,M-BioFuel1,M-BioFuel2,M-BioFuel3/
      Windg(g)        Wind units /O-Wind,H-Wind,K-Wind,M-Wind,Apollo,Hawi, Lalamilo, Kaheawa/

      GeoTg(g)        Geothermal units /PGV,H-Geo1,H-Geo2/
      Wastg(g)        MSW units /Hpower,O-LFG,H-MSW, K-MSW, M-MSW/

      Solrg(g)        Solar units /Slr-PioneerHwy,Palaau-Solar,Keahole-Solar/
      Hydrg(g)        Hydro units /H-Hydro,K-Hydro/
      BioMg(g)        Biomass units /Kaumakani-Wood, HCS/


      f     Fuel /FDsl, LSFO, BDsl, CPO, Coal, MSFO
              RPLS          Repower LSFO fueled unit to burn CPO
              BioM    Biomass
              MSW     Municipal solid waste
              None    for PV and wind/

      oil(f)          Oil based fuels /FDsl, LSFO, MSFO/

      c               Customer classes /Res, Mil, Com, Trn/
*-later     rps     RPS pools      /HECO, KUIC/
      rps    RPS pools      /HECO/
      mapp2rps(p,rps)      mapping of power pools to RPS pool /Oahu.HECO/
;

Alias(b,bb);

Set mapIntf2g(f,g)     mapping of generator to initial fuel /
*     Unit   Fuel
Coal.AES
LSFO.Hon
LSFO.Waiau-ST
LSFO.Waiau-CT
LSFO. Kahe-ST
FDsl.DG
LSFO. Kalaeloa
MSW. Hpower
BDsl. CIP
None. O-Wind
Coal. O-NewCoal
CPO. O-BioFuel1
CPO. O-BioFuel2
None. O-LFG

None.Apollo
FDsl. DG-HELCO
MSFO. Hamakua
None.Hawi
FDsl. Kanoelehua
FDsl. Keahole
None. Keahole-Solar
```

```
None. Lalamilo
None. H-Hydro
MSFO. Puna-MSFO
FDsl.Puna-Diesel
None. PGV
MSFO. Shipman-MSFO
MSFO. WHHill
FDsl.Waimea

None.H-Geo1
None. H-Geo2
None. H-Wind
None. H-BioFuel1
None. H-BioFuel2
None. H-BioFuel3
MSW. H-MSW

*       KIUC
FDsl.Kapaia
None. K-Hydro
BioM. Kaumakani-Wood
MSFO. Kaumakani-Oil
None. Slr-PioneerHwy
FDsl. PA1
FDsl. PA2
FDsl. PA3
FDsl. PA4
MSFO. PA-Steam

None. K-Wind
None. K-BioFuel1
None. K-BioFuel2
None. K-BioFuel3
MSW. K-MSW

*       MECO
BioM. HCS
None. Kaheawa
MSFO. Kahului1
MSFO. Kahului2
FDsl. Maalaea1
FDsl. Maalaea2
FDsl. Maalaea3
FDsl. Maalaea4
FDsl. MikiBasin
FDsl. Palaau
None. Palaau-Solar

None. M-Wind
None. M-BioFuel1
None. M-BioFuel2
None. M-BioFuel3
MSW. M-MSW
/ ;

Set mapf2g(f,g)        mapping of generator to fuel /
```

* Unit Fuel
Coal. AES
LSFO. Hon
LSFO. Waiau-ST
LSFO. Waiau-CT
(CPO,LSFO). Kahe-ST
(BDsl,FDsl). DG
LSFO. Kalaeloa
MSW. Hpower
BDsl. CIP
None. O-Wind
Coal. O-NewCoal
CPO. O-BioFuel1
CPO. O-BioFuel2
None. O-LFG

None. Apollo
FDsl. DG-HELCO
MSFO. Hamakua
None. Hawi
FDsl. Kanoelehua
FDsl. Keahole
None. Keahole-Solar
None. Lalamilo
None. H-Hydro
MSFO. Puna-MSFO
FDsl. Puna-Diesel
None. PGV
MSFO. Shipman-MSFO
MSFO. WHHill
FDsl. Waimea

None. H-Geo1
None. H-Geo2
None. H-Wind
None. H-BioFuel1
None. H-BioFuel2
None. H-BioFuel3
MSW. H-MSW

* KIUC
FDsl. Kapaia
None. K-Hydro
BioM. Kaumakani-Wood
MSFO. Kaumakani-Oil
None. Slr-PioneerHwy
FDsl. PA1
FDsl. PA2
FDsl. PA3
FDsl. PA4
MSFO. PA-Steam

None. K-Wind
None. K-BioFuel1
None. K-BioFuel2
None. K-BioFuel3

```
MSW.  K-MSW

*      MECO
BioM. HCS
None. Kaheawa
MSFO. Kahului1
MSFO. Kahului2
FDsl. Maalaea1
FDsl. Maalaea2
FDsl. Maalaea3
FDsl. Maalaea4
FDsl. MikiBasin
FDsl. Palaau
None. Palaau-Solar

None.   M-Wind
None.   M-BioFuel1
None.   M-BioFuel2
None.   M-BioFuel3
MSW.  M-MSW
/ ;

Set mapg2p(g,p)        mapping of generator to pool /
*      Unit    Pool
AES.                   Oahu
Hon.                   Oahu
Waiau-ST.              Oahu
Waiau-CT.              Oahu
Kahe-ST.               Oahu
DG.                    Oahu
Kalaeloa.              Oahu
Hpower.                Oahu
CIP.                   Oahu
O-Wind.                Oahu
O-NewCoal.             Oahu
O-Biofuel1.            Oahu
O-Biofuel2.            Oahu
O-LFG.                 Oahu

*      Hawaii units
       Apollo          .Hawaii
       DG-HELCO        .Hawaii
       Hamakua         .Hawaii
       Hawi            .Hawaii
       Kanoelehua      .Hawaii
       Keahole         .Hawaii
       Keahole-Solar  .Hawaii
       Lalamilo        .Hawaii
       H-Hydro         .Hawaii
       Puna-MSFO       .Hawaii
       Puna-Diesel     .Hawaii
       PGV             .Hawaii
       Shipman-MSFO  .Hawaii
       WHHill          .Hawaii
       Waimea          .Hawaii
       H-Geo1          .Hawaii
```

```
        H-Geo2          .Hawaii
        H-Wind          .Hawaii
        H-BioFuel1      .Hawaii
        H-BioFuel2      .Hawaii
        H-BioFuel3      .Hawaii
        H-MSW           .Hawaii

*       KIUC
        Kapaia          .Kauai
        K-Hydro         .Kauai
        Kaumakani-Wood  .Kauai
        Kaumakani-Oil  .Kauai
        Slr-PioneerHwy  .Kauai
        PA1             .Kauai
        PA2             .Kauai
        PA3             .Kauai
        PA4             .Kauai
        PA-Steam        .Kauai
        K-Wind          .Kauai
        K-BioFuel1      .Kauai
        K-BioFuel2      .Kauai
        K-BioFuel3      .Kauai
        K-MSW           .Kauai

*       MECO
        HCS             .Maui
        Kaheawa         .Maui
        Kahului1        .Maui
        Kahului2        .Maui
        Maalaea1        .Maui
        Maalaea2        .Maui
        Maalaea3        .Maui
        Maalaea4        .Maui
        MikiBasin       .Maui
        Palaau          .Maui
        Palaau-Solar    .Maui
        M-Wind          .Maui
        M-BioFuel1      .Maui
        M-BioFuel2      .Maui
        M-BioFuel3      .Maui
        M-MSW           .Maui
/;

Parameter
        r               risk free rate of interest /0.05/
        DF(t)           Discount factor
        year0           First year for model /2010/
        year(t)         Years
        tint            Interval between model years /5/
;

year(t) = year0 + (ord(t)-1)*tint;
DF(t) = 1/(1+r)**(year(t)-year0)

*       System data
Set
```

```
        sn      season  /F, Sp, Su, W/
        dy      day     /1      M-Th
                         2      F
                         3      Sa-Su/
        hr      Hour    /
                        1 "- 12 a.m. - 5 a.m."
                        2 "- 7 a.m., 8 a.m., 10 p.m."
                        3 "- 10 a.m. - 6 p.m."
                        4 "- 7 p.m."
                        5 "- 8 p.m."
                        6 "- 9 a.m., 9 p.m."
                        7 "- 6 a.m., 11 p.m."
                        /
;

Table LoadBlock(sn,dy,hr,b,*)   84 load block data in MWh
*Island       Season   Day     Hour    Block
*Season    Day        Hour       Block  Hours  Oahu   Hawaii  Kauai   Maui
F      .    1     .    1     .    b1     306    216678  32351   13865   13865
F      .    2     .    1     .    b2     78     55457   8280    3549    3549
F      .    3     .    1     .    b3     156    109244  16311   6991    6991
F      .    1     .    2     .    b4     153    152078  22706   9732    9732
F      .    2     .    2     .    b5     39     38373   5729    2456    2456
F      .    3     .    2     .    b6     78     68408   10214   4377    4377
F      .    1     .    3     .    b7     459    525474  78456   33626   33626
F      .    2     .    3     .    b8     117    133166  19882   8521    8521
F      .    3     .    3     .    b9     234    246112  36746   15749   15749
F      .    1     .    4     .    b10    51     60940   9099    3900    3900
F      .    2     .    4     .    b11    13     14980   2237    959     959
F      .    3     .    4     .    b12    26     29376   4386    1880    1880
F      .    1     .    5     .    b13    51     58229   8694    3726    3726
F      .    2     .    5     .    b14    13     14214   2122    910     910
F      .    3     .    5     .    b15    26     28088   4194    1797    1797
F      .    1     .    6     .    b16    102    110175  16450   7050    7050
F      .    2     .    6     .    b17    26     27626   4125    1768    1768
F      .    3     .    6     .    b18    52     52019   7767    3329    3329
F      .    1     .    7     .    b19    102    88740   13249   5679    5679
F      .    2     .    7     .    b20    26     22665   3384    1450    1450
F      .    3     .    7     .    b21    52     41508   6197    2656    2656
Sp     .    1     .    1     .    b22    318    220227  32881   14093   14093
Sp     .    2     .    1     .    b23    78     54567   8147    3492    3492
Sp     .    3     .    1     .    b24    162    110982  16570   7102    7102
Sp     .    1     .    2     .    b25    159    156059  23301   9986    9986
Sp     .    2     .    2     .    b26    39     38107   5690    2439    2439
Sp     .    3     .    2     .    b27    81     69987   10449   4479    4479
Sp     .    1     .    3     .    b28    477    538857  80455   34482   34482
Sp     .    2     .    3     .    b29    117    131321  19607   8403    8403
Sp     .    3     .    3     .    b30    243    246694  36833   15786   15786
Sp     .    1     .    4     .    b31    53     59984   8956    3838    3838
Sp     .    2     .    4     .    b32    13     14166   2115    906     906
Sp     .    3     .    4     .    b33    27     28186   4208    1804    1804
Sp     .    1     .    5     .    b34    53     60389   9016    3864    3864
Sp     .    2     .    5     .    b35    13     14202   2120    909     909
Sp     .    3     .    5     .    b36    27     28646   4277    1833    1833
Sp     .    1     .    6     .    b37    106    113999  17021   7295    7295
Sp     .    2     .    6     .    b38    26     27494   4105    1759    1759
```

```
Sp  .  3  .  6  .  b39  54   53112  7930   3399   3399
Sp  .  1  .  7  .  b40  106  90100  13452  5766   5766
Sp  .  2  .  7  .  b41  26   22239  3320   1423   1423
Sp  .  3  .  7  .  b42  54   42138  6291   2696   2696
Su  .  1  .  1  .  b43  324  240893 35967  15415  15415
Su  .  2  .  1  .  b44  78   58171  8685   3722   3722
Su  .  3  .  1  .  b45  156  115107 17186  7366   7366
Su  .  1  .  2  .  b46  162  166317 24832  10643  10643
Su  .  2  .  2  .  b47  39   39898  5957   2553   2553
Su  .  3  .  2  .  b48  78   71295  10645  4562   4562
Su  .  1  .  3  .  b49  486  576481 86072  36890  36890
Su  .  2  .  3  .  b50  117  138641 20700  8872   8872
Su  .  3  .  3  .  b51  234  253468 37844  16220  16220
Su  .  1  .  4  .  b52  54   63484  9479   4062   4062
Su  .  2  .  4  .  b53  13   14781  2207   946    946
Su  .  3  .  4  .  b54  26   28527  4259   1825   1825
Su  .  1  .  5  .  b55  54   64337  9606   4117   4117
Su  .  2  .  5  .  b56  13   14868  2220   951    951
Su  .  3  .  5  .  b57  26   29081  4342   1861   1861
Su  .  1  .  6  .  b58  108  121744 18177  7791   7791
Su  .  2  .  6  .  b59  26   28861  4309   1847   1847
Su  .  3  .  6  .  b60  52   54041  8069   3458   3458
Su  .  1  .  7  .  b61  108  97087  14496  6213   6213
Su  .  2  .  7  .  b62  26   23491  3507   1503   1503
Su  .  3  .  7  .  b63  52   43284  6463   2770   2770
W   .  1  .  1  .  b64  300  194588 29053  12452  12452
W   .  2  .  1  .  b65  78   51235  7650   3279   3279
W   .  3  .  1  .  b66  156  101244 15116  6479   6479
W   .  1  .  2  .  b67  150  139495 20827  8926   8926
W   .  2  .  2  .  b68  39   36219  5408   2318   2318
W   .  3  .  2  .  b69  78   63809  9527   4083   4083
W   .  1  .  3  .  b70  450  477797 71338  30575  30575
W   .  2  .  3  .  b71  117  123465 18434  7901   7901
W   .  3  .  3  .  b72  234  227202 33923  14539  14539
W   .  1  .  4  .  b73  50   56884  8493   3640   3640
W   .  2  .  4  .  b74  13   14178  2117   907    907
W   .  3  .  4  .  b75  26   27569  4116   1764   1764
W   .  1  .  5  .  b76  50   54387  8120   3480   3480
W   .  2  .  5  .  b77  13   13537  2021   866    866
W   .  3  .  5  .  b78  26   26490  3955   1695   1695
W   .  1  .  6  .  b79  100  101239 15116  6478   6478
W   .  2  .  6  .  b80  26   25989  3880   1663   1663
W   .  3  .  6  .  b81  52   48572  7252   3108   3108
W   .  1  .  7  .  b82  100  80623  12037  5159   5159
W   .  2  .  7  .  b83  26   21120  3153   1351   1351
W   .  3  .  7  .  b84  52   38694  5777   2476   2476
;

Parameter BlkHr(b)     Thousands of hours in each load block
          ChkHr        Check number of hours;
BlkHr(b) = Sum((sn,dy,hr), LoadBlock(sn,dy,hr,b,"Hours"))/1000;
ChkHr = 8760/1000 - Sum(b, BlkHr(b));
Display BlkHr, ChkHr;

Table SystemLoad(*,*,*)     System load properties
*     Total Demand and demand by load block in GWh
```

```
*       Peak in GW
*       Source: HECO IRP-3?  Seem outdated given recent recession so load reduced
              2010    2015    2020    2025    2030
Oahu.Demand     8078.6  8413.7  8821.7  9435.3  9871.6
Oahu.Peak       1.39    1.46    1.54    1.65    1.74
Hawaii.     Peak    0.220   0.228   0.248   0.2685  0.2914
Hawaii.     Demand  1226.5  1271.5  1377.3  1488.2  1611.4
Kauai.  Peak    0.079   0.0835  0.0926  0.1035  0.1168
Kauai.  Demand  505     525     581     649     731
Maui.   Peak    0.2322  0.2447  0.2761  0.3061  0.3362
Maui.   Demand  1302.7  1369.1  1537.3  1709.6  1872.2
;

SystemLoad(p,b,t) = SystemLoad(p,"Demand",t) * Sum((sn,dy,hr), LoadBlock(sn,dy,hr,b,p))/ Sum((sn,dy,hr,bb),
LoadBlock(sn,dy,hr,bb,p));

Parameter
       PeakDemand(p,t)        Maximum load hours in year for pool p in GW
       ReserveMargin(p)        Reserve margin /
                       Oahu 0.15/
       Demand(c,p,*,t)        Demand by class and pool for each block in TWh
       AvgLoad(p,b,t)  Average load in GW
;

PeakDemand(p,t) = SystemLoad(p,"Peak",t);

*       Adjustment to load based on forecast
*       Real Electricity Sector Output ($2005 billion)  from H-CGE model and UHERO forecase
Table EleDmdNdx(*,*)    Electricity demand index from H-CGE
       None    Low     Base    High
2005    1.90    1.90    1.90    1.90
2010    2.16    2.05    2.05    2.05
2015    2.44    2.48    2.23    2.06
2020    2.76    2.85    2.47    2.20
2025    3.12    3.23    2.76    2.45
2030    3.52    3.63    3.07    2.73
;

*       Base system load off of UHERO forecast -- Assume 2005 load and peak grow at 1%/yr from 2005-2010
SystemLoad(p,b,t)$(year(t)>2010) = SystemLoad(p,b,"2010") *
EleDmdNdx(t,"%forecast%")/EleDmdNdx("2010","%forecast%") *
EleDmdNdx("2010","%forecast%")/EleDmdNdx("2010","Base");
PeakDemand(p,t)$(year(t)>2010) = PeakDemand(p,"2010") *
EleDmdNdx(t,"%forecast%")/EleDmdNdx("2010","%forecast%") *
EleDmdNdx("2010","%forecast%")/EleDmdNdx("2010","Base");;


Demand("Res",p,b,t)     = SystemLoad(p,b,t)/1000;
Demand("Res",p,"Tot",t)         = Sum(b,SystemLoad(p,b,t))/1000;
AvgLoad(p,b,t) = Demand("Res",p,b,t)/BlkHr(b)*1000;
Display Demand,AvgLoad, PeakDemand;
**$exit

Table FuelCost(f,*)     "Fuel costs in 2007$/MMBtu "
              2005    2010    2015    2020    2025    2030
FDsl            13.7
```

```
LSFO          7.4
MSFO           7.4
Coal         3.8     3.8     3.8     3.8     3.8     3.8
MSW           20
BDsl
CPO
BioM          15
;

Table OilForecast(*,*)  EIA forecasts for oil (index 2005=1)
*                        None policy assumes no change in oil prices from 2005
       None    Base    Low    High
2005    1       1       1       1
2006    1       1.221   1.221   1.221
2007    1       1.433   1.433   1.433
2008    1       1.932   1.932   1.932
2009    1       1.179   1.179   1.179
2010    1       1.406   1.406   1.406
2011    1       1.39    1.061   1.613
2012    1       1.522   1.004   1.958
2013    1       1.65    0.972   2.268
2014    1       1.749   0.946   2.62
2015    1       1.813   0.915   2.858
2016    1       1.88    0.906   3.097
2017    1       1.934   0.903   3.309
2018    1       1.994   0.894   3.471
2019    1       2.022   0.878   3.585
2020    1       2.048   0.871   3.67
2021    1       2.072   0.861   3.715
2022    1       2.098   0.86    3.76
2023    1       2.127   0.865   3.808
2024    1       2.152   0.86    3.836
2025    1       2.18    0.863   3.878
2026    1       2.198   0.866   3.916
2027    1       2.228   0.868   3.944
2028    1       2.259   0.87    3.981
2029    1       2.3     0.871   4.022
2030    1       2.326   0.874   4.051
2031    1       2.372   0.874   4.081
2032    1       2.409   0.871   4.111
2033    1       2.448   0.871   4.127
2034    1       2.49    0.874   4.145
2035    1       2.532   0.876   4.165
;

*       Tie oil fuel price forecasts to EIA
FuelCost(f,t)$(oil(f))  = FuelCost(f,"2005") * OilForecast(t,"%forecast%");
FuelCost("MSW",t)       = FuelCost("MSW","2005") * OilForecast(t,"%forecast%");
FuelCost("BioM",t)      = FuelCost("BioM","2005") * OilForecast(t,"%forecast%");

Table BioFuelForecast(*,*)      Biofuel forecast
*                              2007$s/MMBtu Source:  HECO IRP-4
                 2010    2015    2020    2025    2030
BDsl-None       30.4    24.2    19.2    18.3    18.3
BDsl-Low        30.4    16.7    15.0    15.0    15.0
BDsl-Base       30.4    24.2    19.2    18.3    18.3
```

```
BDsl-High      30.4   31.7   23.3   21.7   21.7
CPO-None       22.6   16.3   13.1   13.3   13.7
CPO-Low        22.6   11.3   10.7   11.2   11.8
CPO-Base       22.6   16.3   13.1   13.3   13.7
CPO-High       22.6   21.2   15.5   15.5   15.5
;

**FuelCost("CPO",t) = BioFuelForecast("CPO-%forecast%",t);
**FuelCost("BDsl",t) = BioFuelForecast("BDsl-%forecast%",t);
** Using high price biofuels for now since using base against base oil seems to produce unrealistic relationship
FuelCost("CPO",t) = BioFuelForecast("CPO-High",t);
FuelCost("BDsl",t) = BioFuelForecast("BDsl-High",t);

Display FuelCost;
*$exit

*       Define data for existing and new units
Table GenDat(g,*)       Generator Data for existing units
              Cap    FOM     VOM     HR      CapFac  MinGen  EFOR    derate  CapCost Rnw  YrOn
*             GW     ($/kW)  ($/MWh)        (MMBtu/MWh)     %       %
AES            0.200   50      3       10      0.9     0.2     8
Hon            0.1073  100     3       12.3    0.65    0.1     50
Waiau-ST       0.379   60      3       10.5    0.85            15
Waiau-CT       0.1018  60      3       20      0.5             80
Kahe-ST        0.6205  60      3       10      0.85            10
DG             0.0294  25      3       11      0.1             75
Kalaeloa       0.208   60      3       9.8     0.85            10
Hpower         0.046   75      3       10      0.85            15                  1

**Table NewGenDat(g,*)  Data for new generating units
*             Cap    FOM     VOM     HR      CapFac  MinGen  EFOR    derate  CapCost       Rnw  YrOn
*             GW     $/kW    $/MWh   MMBtu/MWh                               $/kW
CIP            0.110   40      3       9       0.75                          3000    0.8  2010
O-Wind         0.060   30      2               0.35                  0.8     2000    1
O-BioFuel1     0.500   80      7       10      0.75                          2500    0.8
O-BioFuel2     1.500   80      7       10      0.75                          4500    0.8
O-LFG          0.050   80      7       10      0.15                          6000    1
O-NewCoal      0.200   40      4       9       0.9     0.2                   4000

$ontext
VOM&FOM for wind and Geo taken from IRP on new wind units
Cap. Factors for Wind taken from IRP new units
HELCO   NetCapacity (MW)       Fixed O&M $/KwH       Variable O&M $/MWh       HeatRate       CapacityFactor
              Cap    FOM     VOM     HR      CapFac  MinGen  EFOR    derate CapCost Rnw
$offtext
Apollo         0.0205  11.1    1.7             0.41    0.0             0.8             1.0
DG-HELCO       0.0040  8.6     0.9     9.8     0.10    0.0
Hamakua        0.0600  53.5    1.2     8.5     0.85    0.0
Hawi           0.0106  11.1    1.7             0.41    0.0             0.8             1.0
Kanoelehua     0.0495  20.0    5.0     14.4    0.85            12.5
Keahole        0.0603  37.9    0.8     8.5     0.85    0.0
Keahole-Solar  0.0005  298.9   34.0            0.20    0.0             0.8             1.0
Lalamilo       0.0022  11.1    1.7             0.41    0.0             0.8             1.0
H-Hydro        0.0171  0.3     2.4             0.33    0.0             0.8             1.0
Puna-MSFO      0.0141  164.2   1.2     16.2    0.85            9.0
Puna-Diesel    0.0204  45.8    0.1     13.3    0.85            7.5
```

```
PGV            0.0300  5.5     22.5          0.85    0.0                        1.0
Shipman-MSFO    0.0144  158.9   2.4     17.0    0.85          10.0
WHHill          0.0337  20.5    0.9     13.3    0.85          25.0
Waimea          0.0083  20.5    0.9     10.8    0.85          7.5

H-Geo1          0.008   8.3     22.5          0.85    0.0                  5000.0  1.0  2015
H-Geo2          0.0300  8.3     22.5          0.85    0.0                  5000.0  1.0
H-Wind          0.0299  20.07   1.68          0.45              0.8    3700.0  1.0
H-BioFuel1      0.0350  3.6     8.3     9.8     0.60    0.0              2357.0  1.0
H-BioFuel2      0.0350  3.6     8.3     9.8     0.60    0.0     0.0     0.0     4500.0  1.0
H-BioFuel3      0.50    3.6     8.3     9.8     0.60    0.0     0.0     0.0     6000.0  1.0
H-MSW           0.0073  107.8   21.9    18.8    0.83                     4296.0  1.0

Kapaia          0.0266  0.0     1.4     8.2     0.85          14.0
K-Hydro                 0.0041  0.3     2.4           0.67    0.0          0.6
Kaumakani-Wood  0.0028  10.5    11.7    14.6    0.8     0.0
Kaumakani-Oil   0.0009  0.0     4.3     11.4    0.85    0.0
Slr-PioneerHwy  0.0002  298.9   34.0          0.2     0.0          0.8
PA1             0.0075  25.9    7.8     10.0    0.85    0.0
PA2             0.0304  25.9    7.8     8.6     0.85    0.0
PA3             0.0401  25.9    7.8     9.8     0.85    0.0
PA4             0.0034  25.9    7.8     10.0    0.85    0.0
PA-Steam        0.0090  25.9    1.6     14.2    0.85    0.0          0.5

K-Wind          0.0299  20.1    1.7     0.0     0.45    0.0     0.0     0.8     3700.0  1.0
K-BioFuel1      0.035   3.6     8.3     9.8     0.60    0.0     0.0     0.0     2357.0  1.0
K-BioFuel2      0.035   3.6     8.3     9.8     0.60    0.0     0.0     0.0     4500.0  1.0
K-BioFuel3      0.5     3.6     8.3     9.8     0.60    0.0     0.0     0.0     6000.0  1.0
K-MSW           0.0073  107.8   21.9    18.8    0.83    0.0     0.0     0.0     4296.0  1.0

*MECO   NetCapacity (MW)    Fixed O&M $/KwH     Variable O&M $/MWh     HeatRate     CapacityFactor
*           Cap         FOM     VOM         HR      CapFac   MinGen      EFOR    derate      CapCost  Rnw
HCS             0.0120  6.1     4.7     15.6    0.85          8.0
Kaheeawa        0.0300  11.1    1.7           0.41    0.0          0.8
Kahului1        0.0095  168.0   1.1     14.6    0.85          4.6
Kahului2        0.0229  159.8   1.1     12.1    0.85          14.1
Maalaea1        0.0125  24.4    7.8     9.2     0.85          12.5
Maalaea2        0.0492  34.4    7.8     9.2     0.85          25.6
Maalaea3        0.0330  18.9    7.8     9.2     0.85          15.0
Maalaea4        0.1136  67.2    0.5     9.2     0.85          70.6
MikiBasin       0.0104  25.9    7.8     10.3    0.85    0.6     4.7
Palaau          0.0152  25.9    7.8     10.1    0.85    0.6     5.3
Palaau-Solar    0.0022  298.9   34.0          0.2               0.8          1.0

M-Wind          0.0299  20.1    1.7     0.0     0.4     0.0     0.0     0.8     3700.0  1.0
M-BioFuel1      0.0350  3.6     8.3     9.8     0.6     0.0     0.0     0.0     2357.0  1.0
M-BioFuel2      0.0350  3.6     8.3     9.8     0.6     0.0     0.0     0.0     4500.0  1.0
M-BioFuel3      0.50    3.6     8.3     9.8     0.60    0.0     0.0     0.0     6000.0  1.0
M-MSW           0.0073  107.8   21.9    18.8    0.8     0.0     0.0     0.0     4296.0  1.0
;

Parameter
    MaxCap(g,t)         Maximum capacity in GW
    Cap0(g,f)       Initial capacity of existing units GW
    derate(g)       Derating of units against reserve margin
    FOM(g)          "Fixed O&M $/kW"
```

```
      VOM(g)               "Variable O&M  $/MWh"
      CapCost(g)           "Capital cost to build new units $/kW"
      MaxCapFac(g,b)       "Maximum Capacity factor - maximum utilization (%)"
      MinCapFac(g,b)       "Minimum Capacity factor - maximum utilization (%)"
      Heatrate(g,f)   "Heat rate of fossil and biofuel units (MMBtu/MWh)"
      MustBld(g)           "Year unit g must come on-line"
;
HeatRate(g,f)$(mapf2g(f,g)) = GenDat(g,"HR");
VOM(g)         = GenDat(g,"VOM");
FOM(g)         = GenDat(g,"FOM");
CapCost(g)     = GenDat(g,"CapCost");
MaxCap(g,t)    = GenDat(g,"Cap");
Cap0(g,f)$(mapIntf2g(f,g) and not ng(g)) = GenDat(g,"Cap");
derate(g)      = GenDat(g,"derate");

MaxCapFac(g,b)  = GenDat(g,"CapFac");
MinCapFac(g,b)  = GenDat(g,"MinGen");
MustBld(g)     = GenDat(g,"YrOn");
Display CapCost, Cap0, MaxCapFac, MinCapFac;
**$exit

*      Data inputs
Parameters
      RPSTgt(rps,t)   "Level of RPS - fraction"
      RPSCredit(g,f)  RPS credit
      EmisTgt(t)      "Emissions cap for CO2 (MMT CO2)"
*...
;

RPSTgt(rps,t) = 0;
RPSCredit(g,f)$mapf2g(f,g) = GenDat(g,"Rnw");
EmisTgt(t) = 0;

Parameter EmisRate(f)   "Emissions rate in metric tons of CO2/MMBtu" /
Coal    0.094
FDsl    0.073
BDsl    0.018
LSFO    0.073
MSFO    0.073
CPO     0.018
MSW     0.04
Biom    0.018
/;


Parameter
      TtlEmis         Total emissions MT CO2
      RPSLvl          RPS level      pct
      TotGen          Total generation (TWh)
      TotCap          Total capacity (GW)
      TrnLoss(p)            Transmission loss
;

TrnLoss(p) = 0.08;

*-------------------------------------------------------------
```

```
*      Model definition
Positive Variables
       Gen(g,f,b,t)    "Generation (TWh)"
       Cap(g,f,t)      "Capacity (GW) - May want to have additional index to allow for repowering of units or retrofitting to
burn alternate fuel"
       Bld(g,f,t)      "New construction GW"
       Ret(g,f,t)      "Retirements GW"
*      Rtr(g,f,t)      Retrofits
;

Variables
       z               Objective function value - cost of generation
;

Equations
       obj             "Objective function = DPV of Fuel cost + Var O&M + Fixed O&M + New Construction Cost in millions of
dollars"
*                      In next phase need to account for post-terminal year costs to correctly balance operating and capital costs
       c_Demand(p,b,t)        "Required demand to be met by island, load block, and year (TWh)"
       c_ResMar(p,t)   "Reserve margin requirement - capacity requirement for each island system (GW)"
       C_MinGen(g,b,t)        "Must run minimum generation - Minimum generation that must be produced from specific units
(TWh)"
       C_MaxGen(g,b,t)        "Maximum allowable generation - Maximum generation that can occur for each unit by time
period (TWh)"
       C_CapInt(g,f,t)        "Initial capacity - Defines initial capacity of each unit by fuel source"
       C_CapDyn(g,f,t)        "Equation of motion for evolution of capacity - Cap(t+1) = Cap(t) + Build(t+1) - Retire(t+1) in
GW"
       C_MaxCap(g,t)   "Maximum capacity for any given unit - Sets upper bound on capacity for any unit (GW).  Constraint
needed because some units"
*                      can burn multiple fuels
       C_RPSLvl(rps,t)        "RPS target -- can define different RPS pools -- Renewable energy requirement for a given
system or set of systems"
       C_EmisMx(t)     "Emissions target (millions of metric tons) -- Currently only for CO2 if add other pollutants need
additional index"
;

obj..   z =e= Sum(t, DF(t) * (
                  Sum((f,g,b)$mapf2g(f,g), FuelCost(f,t) * HeatRate(g,f) * Gen(g,f,b,t))
            +      Sum((f,g,b)$mapf2g(f,g), VOM(g) * Gen(g,f,b,t))
            +      Sum((f,g)$mapf2g(f,g),   FOM(g) * Cap(g,f,t))
            +      Sum((f,g)$mapf2g(f,g),   CapCost(g) * Bld(g,f,t)) ) )
;

c_Demand(p,b,t)..
       Sum((g,f)$(mapf2g(f,g) and mapg2p(g,p)), Gen(g,f,b,t))*(1-TrnLoss(p)) =G= Sum(c,Demand(c,p,b,t)) ;

c_ResMar(p,t)$PeakDemand(p,t)..
       Sum((f,g)$(mapf2g(f,g) and mapg2p(g,p)), Cap(g,f,t)*(1-derate(g))) =G= (1+ReserveMargin(p)) * PeakDemand(p,t);

C_MinGen(g,b,t)..
       Sum(f$mapf2g(f,g), Gen(g,f,b,t)) =G= MinCapFac(g,b)*BlkHr(b)*Sum(f,Cap(g,f,t));

C_MaxGen(g,b,t)..
       Sum(f$mapf2g(f,g), Gen(g,f,b,t)) =L= MaxCapFac(g,b)*BlkHr(b)*Sum(f,Cap(g,f,t));

C_CapInt(g,f,t)$(mapf2g(f,g) and ord(t) = 1)..
```

```
      Cap(g,f,t) =E= Cap0(g,f) + Bld(g,f,t)$CapCost(g) - Ret(g,f,t);

C_CapDyn(g,f,t)$(mapf2g(f,g) and ord(t) > 1)..
      Cap(g,f,t) =E= Cap(g,f,t-1)     + Bld(g,f,t)$CapCost(g) - Ret(g,f,t);

C_MaxCap(g,t)..
      Sum(f$mapf2g(f,g), Cap(g,f,t)) =L= MaxCap(g,t);

C_RPSLvl(rps,t)$RPSTgt(rps,t)..
      Sum((f,g,b,p)$(mapg2p(g,p) and mapp2rps(p,rps) and mapf2g(f,g)),
            RPSCredit(g,f)*Gen(g,f,b,t)) =G= RPSTgt(rps,t) * Sum((f,g,b)$mapf2g(f,g), Gen(g,f,b,t));

C_EmisMx(t)$EmisTgt(t)..
      Sum((f,g,b)$mapf2g(f,g), EmisRate(f)*HeatRate(g,f)*Gen(g,f,b,t)) =L= EmisTgt(t) ;


Model HIEle /all/;

Cap.fx(g,f,t)$(Not mapf2g(f,g)) = 0;
Gen.fx(g,f,b,t)$(Not mapf2g(f,g)) = 0;
Bld.fx(g,f,t)$(MustBld(g) = year(t) and mapIntf2g(f,g)) = GenDat(g,"Cap");
Bld.up(g,f,t)$(ng(g) and Not Bld.lo(g,f,t) and Year(t) < 2015 and mapIntf2g(f,g)) = 0;
Display Bld.up;

Solve HIEle using LP minimizing z;

*-----------------------------------------------------------------------------------------------------
*     Display results and summary statistics
Parameter CapUtil       Capacity utilization
      GenPool         Generation by pool
      GenbyType       Generation by type by pool
      NewBuilds       New builds
;

CapUtil(g,t)$Sum(f,Cap.l(g,f,t)) = Sum((f,b), Gen.l(g,f,b,t))/(8.760*Sum(f,Cap.l(g,f,t))) + EPS;
TtlEmis(t) = Sum((f,g,b)$mapf2g(f,g), EmisRate(f)*HeatRate(g,f)*Gen.l(g,f,b,t));
RPSLvl(rps,t) = Sum((f,g,b,p)$(mapg2p(g,p) and mapp2rps(p,rps) and mapf2g(f,g)),
            RPSCredit(g,f)*Gen.l(g,f,b,t)) / Sum((f,g,b)$mapf2g(f,g), Gen.l(g,f,b,t));
TotCap(p,t) = Sum((g,f)$(mapg2p(g,p) and mapf2g(f,g)), Cap.l(g,f,t));
GenPool(p,t) = Sum((g,f,b)$mapg2p(g,p), Gen.l(g,f,b,t));

Set type        Type of generation /
      Coal            Coal-fired
      FDsl            Diesel units
      FOil            Fuel oil units

      BDsl            Biodiesel units
      CPOl            CPO units
      Wind            Wind units

      Geo             Geothermal units
      Waste           MSW units

      Solar           Solar units
      Hydro           Hydro units
      BioM            Biomass units
```

```
/
   mapg2type(g,type) /
      (AES,O-NewCoal).Coal
      (Waiau-CT, DG, Kalaeloa, DG-HELCO,
      Kanoelehua, Keahole, Puna-Diesel, Waimea, Kapaia, PA1, PA2, PA3, PA4
      Maalaea1, Maalaea2, Maalaea3, Maalaea4, MikiBasin, Palaau).FDsl

      (Hon, Kahe-ST, Waiau-ST, Hamakua,Puna-MSFO,Shipman-MSFO,WHHill,Kaumakani-Oil,PA-Steam,Kahului1
,Kahului2).FOil

      CIP.BDsl
      (O-BioFuel1,O-BioFuel2, H-BioFuel1,H-BioFuel2   ,H-BioFuel3,K-BioFuel1,K-BioFuel2,K-BioFuel3,M-
BioFuel1,M-BioFuel2,M-BioFuel3).CPOl
      (O-Wind,H-Wind,K-Wind,M-Wind,Apollo,    Hawi, Lalamilo, Kaheawa).Wind

      (PGV,H-Geo1,H-Geo2).Geo
      (Hpower,O-LFG,H-MSW, K-MSW, M-MSW).Waste

      (Slr-PioneerHwy,Palaau-Solar,Keahole-Solar).Solar
      (H-Hydro,K-Hydro).Hydro
      (Kaumakani-Wood, HCS).BioM
/;

GenbyType(p,type,t) = Sum((f,b,g)$(mapg2p(g,p) and mapg2type(g,type)), Gen.l(g,f,b,t));
NewBuilds(g,t) = Sum(f, Bld.l(g,f,t));
Display TotCap, GenPool, GenbyType, NewBuilds;

Parameter ObjVal;
ObjVal("Fuel",g,t) = Sum((f,b)$mapf2g(f,g), FuelCost(f,t) * HeatRate(g,f) * Gen.l(g,f,b,t));
ObjVal("VOM",g,t) = Sum((f,b)$mapf2g(f,g), VOM(g) * Gen.l(g,f,b,t));
ObjVal("FOM",g,t) = Sum((f)$mapf2g(f,g),   FOM(g) * Cap.l(g,f,t));
ObjVal("CapCost",g,t) = Sum((f)$mapf2g(f,g),   CapCost(g) * Bld.l(g,f,t));

Display      CapUtil, ObjVal, EmisRate, Heatrate, TtlEmis
      RPSLvl, Cap.l, Bld.l, Ret.l
      Gen.l
;

file out /%forecast%.csv/; put out;
put "Total capacity by island (GW)" /
put "Island, Year, Capacity" /;
Loop((p,t),
   Put p.tl,",",t.tl,",",TotCap(p,t):10:4 /;
);

put //;
put "Generation by pool (TWh)" /
put "Island, Year, Generation" /;
Loop((p,t),
   Put p.tl,",",t.tl,",",GenPool(p,t):10:4 /;
);

put //;
put "Generation by type and by island (TWh)" /
put "Island, Type, Year, Generation" /;
Loop((p,type,t),
```

```
    Put p.tl,",",type.tl,",",t.tl,",",GenbyType(p,type,t):10:4 /;
);

put //;
put "New builds by type and by island (GW)" /
put "Unit, Year, Capacity" /;
Loop((g,t),
    Put g.tl,",",t.tl,",",NewBuilds(g,t):10:4 /;
);
```