Model Technical Summaries

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MODEL TECHNICAL SUMMARIES

DRAFT -- 8/27/91

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For each of the fourteen models participating in EMF 12, a standard-format model summary containing the key technical details is developed to assist us in interpreting model results. Of the first page is an outline of the standardized form used for each model, and following that are the model summaries themselves.

The table below summarizes the completeness of the process. Some model summaries are in various stages of completeness due to lack of documentation, or due to insufficient time since they entered the EMF process. Most unfinished model summaries, however, are very close to being done.

Model	Finished		Final review by modeler done
	No	Yes	
CETA	X		
DGEM		X	
ERM	X		
FOSSIL2	X		
GEMINI	X		
GLOBAL 2100		X	
GLOBAL MACRO-ENERGY	X		
GREEN	X		
GOULDER		X	
IEA EDS	X		
MARKAL	X		
MINTZER	X		
RUTHERFORD	X		
T-GAS		X	

MODEL NAME - Modeler

I) GENERAL

Type
Perfect foresight
Time horizons and number of periods
Data time frame, benchmark year
Documentation used

II) FOCUS

Why does this model exist?
What are some of its salient features relevent to the global warming debate?
etc.

III) DEMAND

Regional aggregation
Sectoral aggregation
Consumer behavior
Exogenous inputs
Feedstocks
Energy/macroeconomic linkages
Price elasticities
Other (non-price driven) energy efficiency improvements
Energy-using capital dynamics
Explicit conservation technologies

IV) SUPPLY

Choice of supply fuel/technology mix
Energy imports/exports
International oil price
Primary fossil energy
Primary nonfossil energy
Secondary liquids
Secondary gasses
Secondary solids
Conventional electricity
Advanced electricity (not currently economical)
Supply technology change

V) ENVIRONMENTAL

Emissions
Emissions to concentrations
Concentrations to potential or realized temperature change
Economic impacts of atmospheric change

ENERGY SUPPLY NETWORK DIAGRAM

CETA - Peck/Teisberg

I) GENERAL

Type:	intertemporal non-linear optimization
Perfect foresight:	yes
Time horizon/periods	2200 X 10
Data time frame/b.m.:	1990 bm, parameterized
Documentation used:	2/91: "CETA: . . ."
	3/91: overheads from EMF 12 meeting presentation

II) FOCUS

This model is conceptiually similar to GLOBAL 2100, but it has a single consumer, and a single global energy sector and macroeconomic production function in capital, labor, and electric and nonelectric energy. It has a detailed treatment of emissions (with CO2 only endogenous), and a warming-related damage function. When not running EMF scenarios, its focus is the optimal level of Carbon emissions, given different assumptions about the economic damages due to the level and rate of the warming. The implicit carbon tax time path (reduction time profile) equates the marginal cost of the reduction to the marginal benefit (avoided cost) of the reduction. Can also do exogenous taxes/limits. The model has minimal supply disaggregation, but has several Carbon-free technologies.

III) DEMAND

Regional aggregation:	global
Sectoral aggregation:	macroeconomy
Consumer behavior:	a representative consumer maximizes the sum of discounted utility (the log of aggregate global consumption); utility discount rate is 3%; optimization equates marginal benefit of consumption, investment, energy expenditure, and emissions reduction
Other exogenous inputs:	potential GDP growth rates based on assumed labor supply and labor productivity growth
Feedstocks:	included in energy demand from benchmark, but allowance subtracted out for oil/gas aggregate used as feedstocks when determining total energy sector emissions
Energy/macro. link:	global CES macroeconomic production function (nested Cobb-Douglas capital/labor and nonelectric/electric bundles); putty-clay specification in that there is no ex-ante possibilities for substitution, subst. possibilities only in current period's input bundle, which is a function of present and future relative prices; output divided between consumption, investment, energy costs, and warming-induced costs
Price elasticities:	elasticities of substitution between value-added (K/L) and energy (E/NE): .3, measured at secondary energy production; unit elasticities in Cobb-Douglass, with value shares from benchmarking: capital .276 and electric energy .33
Other EEI:	energy efficiency enters production function explicitly as coefficient on the Cobb-Douglas subproduction function for energy service; efficiency improvement rate is .25% annually; labor

	productivity enters production function directly through labor "efficiency unit" specification, which causes additional indirect EEI
Energy-using capital:	homogenous and vintaged, with disembodied efficiency changes represented by EEI parameter
Explicit conserv. tech.:	-

IV) SUPPLY

Choice of supply mix:	implicitly least-cost, results from utility maximization subject to supply sector constraints
Energy imports/exports:	-
International oil price:	endogenous (implicit)
Primary fossil energy:	oil/gas aggregate QUESTION: SAME AS GLOBAL 2100 coal assumed inexhaustible
Primary non-fossil energy:	none modeled explicitly, implcit in non-fossil secondary energy specifications
Secondary liquids:	synfuel available 2010 with cost parameter capacity QUESTION max intro rate QUESTION renewables (like ethanol from biomass) available 2000 with cost parameter capacity QUESTION max intro rate QUESTION
Secondary solids:	coal cost parameter maximum use growth rate tied to GNP growth rate
Secondary gasses:	nonelectric backstop (like electrolysis of hydrogen) available 2010 with cost parameter capacity QUESTION max intro rate QUESTION
Conventional electricity:	oil/gas composite cost and heat rate parameters capacity QUESTION QUESTION coal cost and heat rate parameterized capacity QUESTION QUESTION nuclear cost and heat rate parameters capacity QUESTION QUESTION hydro (included geothermal and existing renewables) QUESTION QUESTION
Advanced electric:	coal available 2000 with cost and heat rate parameters usage decline rate bounded at 95%

oil/gas composite
available 2000 with cost and heat rate parameters
QUESTION
QUESTION
electric backstop
available 2010 with cost and heat rate parameters
QUESTION
QUESTION

Supply tech. change: disembodied efficiency improvements implicit in the single EEI parameter; also new supply technologies

IV) ENVIRONMENTAL

Emissions: CO_2 via fuel coefficients less allowance for non-energy sector use of carbon-based fuels -- global energy sector
N_2O, CH_4, CFC's, and CO_2 (from land conversion) -- global exogenous

Emis. to conc. change: three models used for CO_2: QUESTION: WHICH
1. "depreciation model" -- constant rate of removal for entire stock (0.004 annual);
2. "half-n-half" -- half removed immediately, half stays forever;
3. "three parameters" -- fraction removed immediately, anthropogenic and nonanthropogenic flows, and constant annual rate of removal of existing stock

others:
constant rates of removal

Conc. to temp. change: CO_2: pot. temp change $\propto$ ln (conc.)
CH4, N20: pot. temp change $\propto$ $(\text{conc.})^{0.5}$
CFC's: pot. temp change $\propto$ conc
actual temp change $\approx 0.02\ (\Delta T_{pot,t-1} - \Delta T_{act,t-1})$

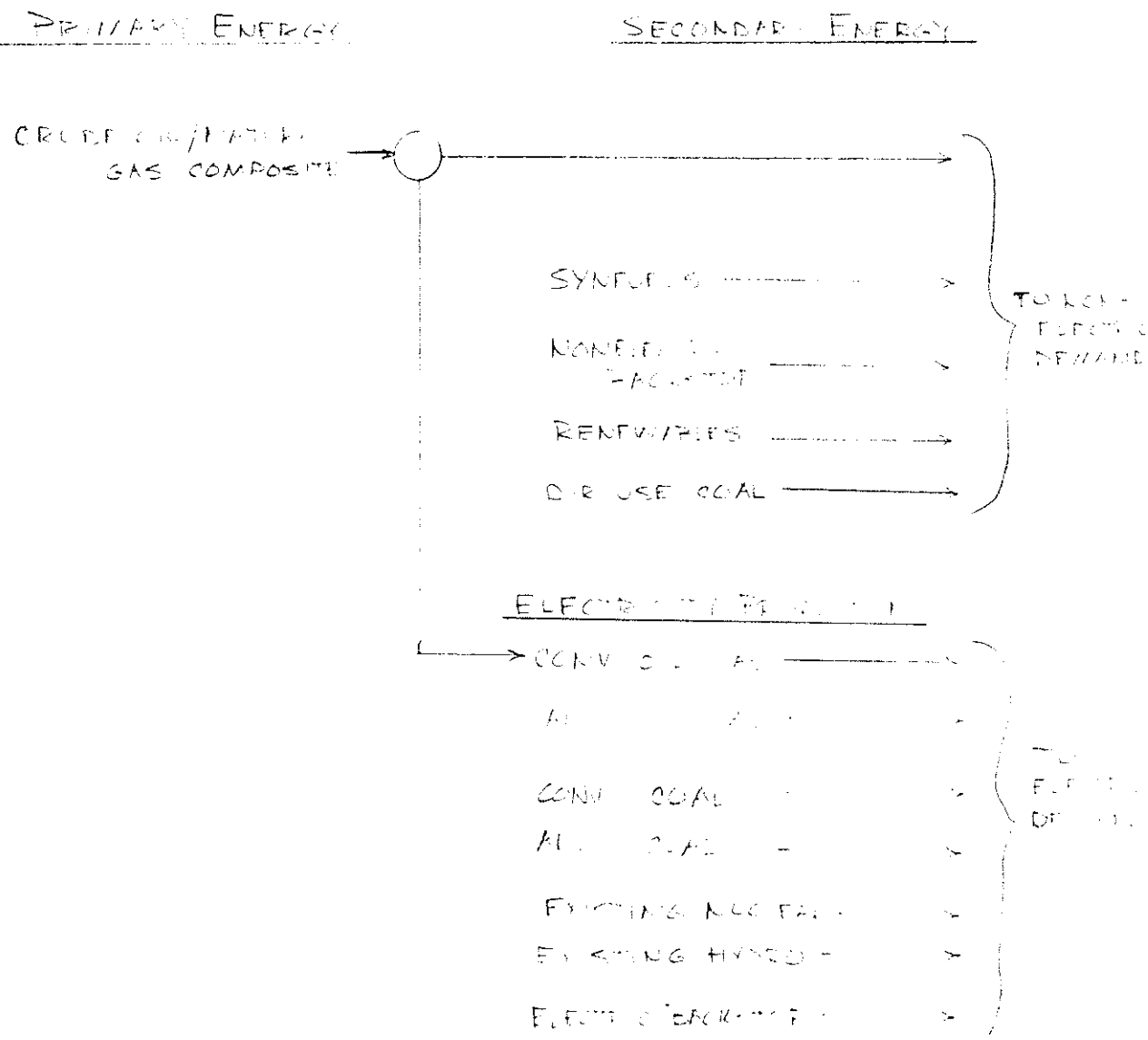
Warming damages (not used when running EMF scenarios):
"level only"
$D_L(t) = \alpha\ T(t)^{\beta}$
where α such that 2% GWP lost at 3 degrees C. incr.
$\beta = 3$ (nonlinear damages)

level and rate
$D_L(t) = \alpha\ T(t)^{\beta}$
where α such that 1% GWP lost at 3 degrees C. incr.
$\beta = 3$ (nonlinear damages)
$D_R(t) = \gamma\ \mu\ \Delta T(t)^{\lambda} + (1 - \mu)\ D_R(t - 1)$
where $\lambda = 4$, $\mu = .1$, $\gamma = 4\%$ GWP at .2 degrees C./decade
(results in geometrically-declining weights on past rates of temp change)
QUESTION: INLCUDED IN OUTPUT DIVISION/EMF SCENARIOS

CETA ENERGY SUPPLY NETWORK

(DOES NOT INCLUDE TRANSMISSION OR TRANSFER ARROWS)

○ = MARKET



DGEM - Jorgensen/Wilcoxen

I) GENERAL

Type:	intertemporal general equilibrium of US with ROW sector
Perfect foresight:	yes
Time horizon/periods:	2050 x 1
Data time frame/bm:	1947-1985
Documentation used:	7/90: "Global Change, Energy Prices. . ."
	7/89: "Environmental Regulation . . ."
	1/90: "Productivity Trends . . ."

II) FOCUS

DGEM has econometrically-estimated translog cost and expenditure functions for 35 industries (including 5 energy supply sectors) and 672 households. It also has a US governmental sector and an aggregate ROW sector. This disaggregation allows for looking at the distributional impacts of environmental policies on different sectors of the US economy. Moreover, the model includes endogenous rates of productivity change and economic growth, so it has an internally-consistent treatment of macroeconomic impacts. It calculates GDP loss from policies, and can consider the effects of various C-tax revene recycling schemes. It can not do technology-oriented policies, only taxes and emissions limits.

The disaggregation also allows for price-induced shifts in the composition of goods away from energy-intensive ones, but allows for no non price-driven sector/product shift, technical change, or productivity improvements. Capital is also perfectly mobile in each time period, althought the rate of investment is endogenous. Energy resources are in effect inexhaustible, and no depletion effects of the cost function are included. No C-based synfuels are allowed, and no C-free energy supply options exist.

III) DEMAND

Regional aggregation:	USA, ROW
Sectoral aggregation:	US: industry (35, approx by 2-digit SIC code, includes 5 energy supply sectors), households (672), government; ROW single sector
Consumer behavior:	agents intertemporal optimizers
	industry: econometrically-estimated constant returns to scale (CRTS) translog cost function parameters, gives price-sensitive factor demands (per unit output) which incorporate both price elasticity and price-driven productivity improvements (see below)
	consumers: intertemporal utility over consumption and leisure allocates time endowment between labor and leisure and determines savings and consumption expenditures in the 35 industries; time endowment includes no labor-augmenting tech. progress
Exogenous inputs:	project to 2050, 2050 levels to 2100 to allow steady-state: cohort population projections give time endowment of household sector; gov't fiscal data; various trade data
Feedstocks:	included in various industries' factor demands
Energy/macro. link:	intertemporal general equilibrium

Price elasticities:	implicit in estimated factor demands
Other EEI:	rate of productivity growth endogenous, function of relative input prices, but separate from price elasticities; no autonomous sector/product shift or productivity/technical change
Energy-using capital:	homogeneous, perfectly mobile among sectors in each time period
Explicit conserv. tech.:	-

IV) SUPPLY

Choice of supply mix:	intertemporal general equilibrium
Energy imports/exports:	endogenous given price
International oil price:	exogenous
Primary fossil energy:	oil/gas aggregate and coal modeled as other sectors, so implicitly inexhaustible and no stock depletion effects on cost of extraction
Primary nonfossil energy:	none included in model
Secondary liquids:	refined crude CRTS translog factor demands; costs endogenous price-driven productivity improvements capacity endogenous, with perfectly mobile capital stock
Secondary solids:	coal can be demanded as input to production functions
Secondary gasses:	gas utility sector CRTS translog factor demands; costs endogenous price-driven productivity improvements capacity endogenous, with perfectly mobile capital stock
Conventional electricity:	electric utility sector CRTS translog factor demands; costs endogenous price-driven productivity improvements capacity endogenous, with perfectly mobile capital stock
Advanced electricity:	none explicit
Supply tech. change:	rate of productivity growth endogenous in supply sectors as with all other sectors

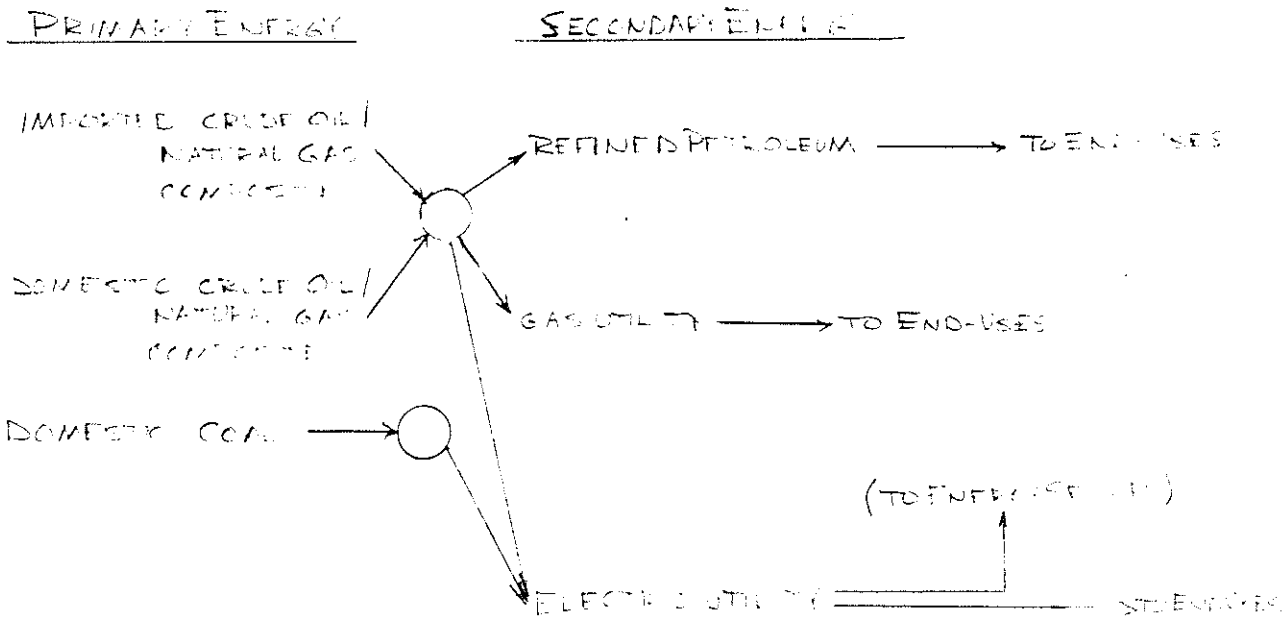
V) ENVIRONMENTAL

Emissions:	Carbon emissions via coefficients, with wieghts for oil/gas aggregate coming from base year and are assumed fixed -- US and ROW

DGEM ENERGY SUPPLY NETWORK

(DOES NOT INCLUDE TRANSMISSION OR TRANSPORT ACTIVITIES)

○ = MARKET



ERM - Edmonds/Reilly

I) GENERAL

Type:	intertemporal generalized equilibrium of global fuel markets
Perfect foresight:	no (recursive)
Time horizon/periods:	1975 - 2095 x 15
Data time frame/bm:	parameterized, 1975 bm for market share algorithms
Documentation used:	85: "Global Energy . . ."
	5/90: "Estimating MC ..."
	3/91: "ERM Contributions to OECD ..."

II) FOCUS

The model is intended to look at the long-term dynamics of global CO2 emissions. It has a relatively rich representation of global primary and secondary fuel markets. There are three demand subsectors in each of the three OECD regions, and a single aggregate sector in each of the nine other world regions. Demands are price and income elastic, but do not explicitly model consumer technology/fuel choice: the fuel shares in the various markets are determined by logit fuel share algorithms. Behavioral equations for fossil primary resources are price-inelastic.

The model can calculate GNP loss over base case through single-period feedbacks, but there is no intertemporal linkage so GNP loss in one period does not affect investment and thus future GNP growth rates.

III) DEMAND

Regional aggregation:	USA, OECD Europe, OECD Pacific, USSR/EE, China and Asian cent.-planned economies, Mideast, Africa, Latin America, and SE Asia
Sectoral aggregation:	3 OECD: residential/commercial, transport, industry; others: single sector/region
Consumer behavior:	baseline end-use energy services demand for each sector/region based on baseline GNP and population, both "cost" and income elastic (see below); fuel mix meeting modified end-use demand is determined by logit market share algorithm, based on benchmark year's market share and current year's relative prices
Exogenous inputs:	income determined by GNP and population projections
Feedstocks:	included in industry demand, but subtracted out to determine emissions, with mix of solids, liquids, gasses assumed constant and total amount used as feedstocks assumed to grow at rate of GNP growth
Energy/macro. link:	baseline GNP -- and hence income -- is modified by regional GNP feedback elasticity related to own region's total cost of energy services, C, $GNP_{actual} = (GNP_{base})\ C^{\varepsilon}$
Price elasticities:	end-use service demand has region- and sector-specific end service cost and income elasticities; for res/comm and trans demand $d = C^{a}\ I^{b}\ P,$ where the superscripts are elasticities, C is the total end-use energy services costs, I is a per capita GNP index (using adjusted

GNP_{actual} from above), and P is a population index; for industry demand

$$d = C^a I^b GNP,$$

where GNP is adjusted GNP_{actual}

Other EEI: to reflect technical advance, but not sector shift, a region- and sector-specific demand-side energy efficiency improvement parameter (eei) reduces fuel needed to meet services demand at 1%/yr after 1990 (in 1990 various rates of 0 - 5%)

$$F = (c\ S\ d) / (eei),$$

where F is sector fuel demand, c is Leontieff process coefficient (fuel needed per unit of service for a given fuel), S is fuel share from logit algorithm (see below), and d is sector's total energy services demand

Energy-using capital: -

Explicit conserv. tech.: -

IV) SUPPLY

Choice of supply mix: global fuel market equilibrium for primary and secondary fuels; region-specific prices derived from world market prices include effects of transportation and net taxes; in OECD regions, electric energy price is sector-specific:

primary resources

see below

conversion

transformation into prerefined and refinedsecondary energy with Leontieff cost function (energy and "other" costs)

market allocation

all market shares determined by logit market share algorithm, so demand in given year based on benchmark year's market shares and current year's relative prices

Energy imports/exports: QUESTION: WHICH FUELS ARE TRADED AND WHAT ARE THE CONSTRAINTS?

International oil price: endogenous for all traded fuels

Primary fossil energy: Mideast crude oil supply is exogenously-determined

conventional oil and gas supply from regions outside of Mideast

price-inelastic function: $q(t) = f(t)(1-f(t))bR$, where R is ultimate resource base, f(t) is fraction cumulative depletion which is logistic function of time,

$$f(t) = \exp(a + bt)/(1 + \exp(a + bt)),$$

where a and b are parameters

conventional coal, and unconventional natural gas and crude oil

treated as "backstop" with price defined as

$$p(t) = a(t) \exp(c\ q(t) / b\ q_{ref}(t))$$

a is minimum entry price (decreases over time for unconventional fuels to reflect technical change), b and c are parameters, and reference quantity q_{ref} is determined by assumed exogenously-set long-run growth rate; this distinguishes short-run and long-run supply functions NEED DATA POINTS

Primary non-fossil energy: solar and nuclear

supply function modelled as for coal, above, with technical change assumed
NEED DATA POINTS

biomass
QUESTION ON ASSUMED RESOURCE BASE AND SHARE FUNCTIONS

Secondary - all:

solids liquefaction - prerefined product
solids gassification - prerefined product
solid refining
gas refining
liquids refining
costs Leontieff with fuel and "other" costs, included scale factor on fuel cost to reflect price/avg cost differential
no additional supply-side technical progress assumed
capacity endogenous

Conventional electricity:

liquids
gasses
solids
solar
nuclear
costs leontieff with fuel and "other" costs
no additional supply-side technical progress assumed
capacity endogenous

hydro (includes wind and geothermal)
costs and capcacity exogenously seT
QUESTION ON DATA

Advanced electricity: none explicit

Supply tech. change: supply technology change treated as lowering the entry price, a, over time of the "backstop" technologies: unconv oil and gas, coal, solar, and nuclear

$$a = a_1^{(1-t/T)} a_2^{(t/T)}$$

where a_1 is initial value, a_2 is time T (equilibrium) value

V) ENVIRONMENTAL

Emissions: CO2, CH4, N2O via coefficient, less allowance for feedstocks -- each region's energy sector, including carbonate rock mining (shale)

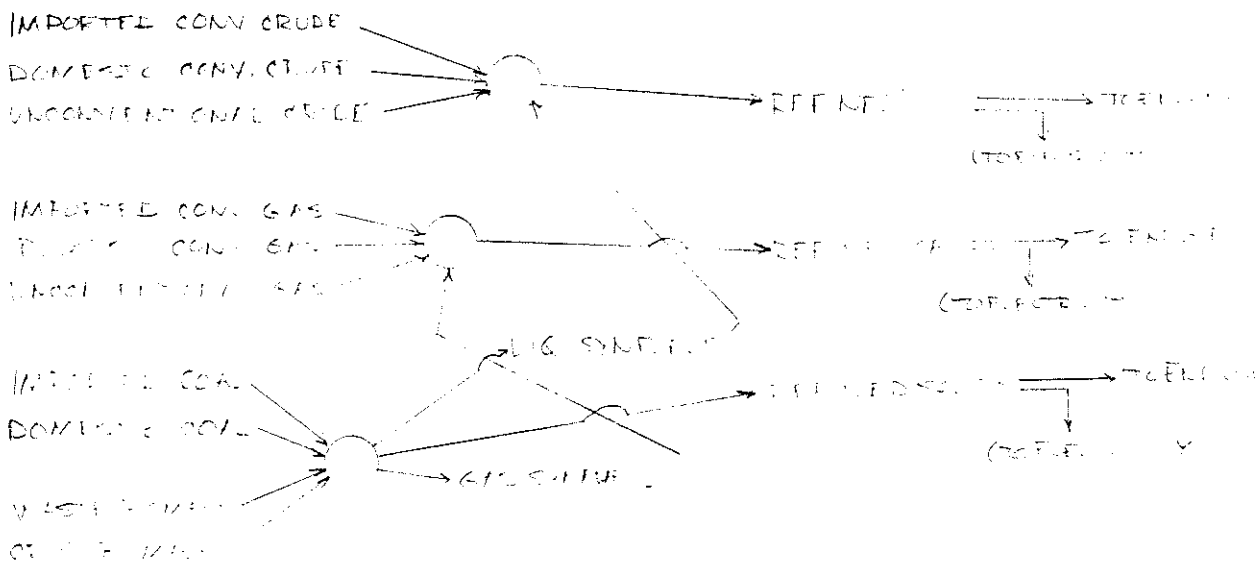
ERM ENERGY S[illegible] NETWORK

(DOES NOT INCLUDE TRANSM[illegible])

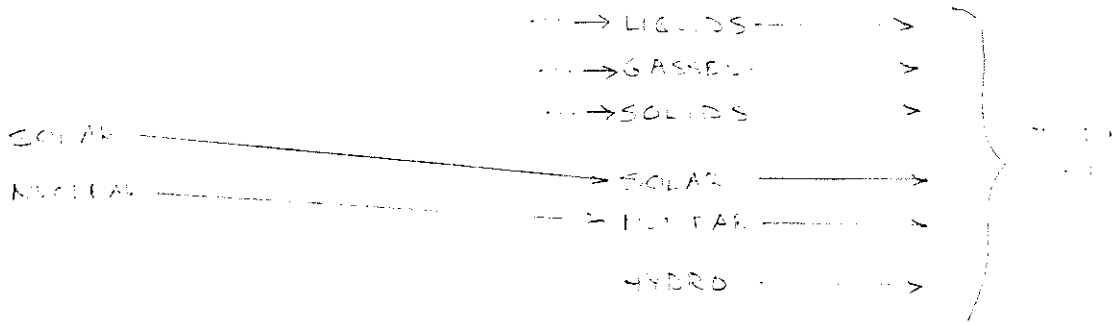
◯ = MARKET

PRIMARY ENERGY

SECONDARY ENERGY



FINAL [illegible]



FOSSIL2 - AES

I) GENERAL

Type:	intertemporal generalized equilibrium (US energy markets)
Perfect foresight:	QUESTION WHAT IS "IMPERFECT EXPECTATIONS"
Time horizon/periods:	2030 x 1
Data time frame/bm:	parameterized
Documentation used:	7/90: "Overview of Fossil 2"

II) FOCUS

Model is heavily focused on US energy supply and demand technologies which will likely be available over the medium term (to 2030). It explicitly models consumer and supplier cost minimizing choices, thus can model supply-side or demand side policies, including either tax/financial incentives or "command and control" type policies. It has simple GNP feedback mechanism on energy demand; however, it is assumed that current lost output does not affect future GNP growth rates.

III) DEMAND

Regional aggregation:	USA
Sectoral aggregation:	industrial (4) steam, process heat, machine drive/electrolytic processes, feedstocks residential (4) space heat, cooling, thermal, appliances/lighting commercial (4) same as above transportation (4) light duty vehicles, trucks, air travel, misc freight
Consumer behavior:	reference demand path for end-use energy services, which is sensitive to current-period price and GNP changes; each subsector minimizes energy service cost by choosing combination of fuels and end-use/conservation technologies ("high" discount rates are used to emulate actual behavior)
Exogenous inputs:	residential building and commercial sqft, and appliance level projections determine baseline energy services demand; total baseline industry output "indices" determine industrial energy service demands before accounting for non-price driven energy efficiency improvements; transportation sector inputs from other models: baseline service demands, efficiencies, and vehicle stocks, etc.; levels for seven dispersed renewables (not including solar) meet end-use demand directly
Feedstocks:	feedstocks included in demand by fuel type, level specified is consistent with assumed industry production/product mix levels QUESTION ARE THEY INCLUDED IN REPORTED EMISSIONS
Energy/macro. link:	feedback to GNP affects baseline end-use demand paths QUESTION WHAT ARE THE EQUATIONS

Price elasticities:	single period price response changes utilization of existing capital stock in each subsector, based on total fuel bills as fractions of disposable income QUESTION WHAT ARE THE FUNCTIONS, DOES THIS ALSO AFFECT GNP SINCE LESS OUTPUT; also long-term (lagged) price response in transportation sector adjusts efficiency levels if prices deviate from reference price inputs
Other EEI:	some function QUESTION FUNCTIONAL FORM AND PARAMETER VALUES in industrial sector changeS energy intensity over time to reflect sector/product mix shift and process changes; efficient end-use technologies chosen either when cost-effective or through mandate (non-price)
Energy-using capital:	stock vintaged because of changing efficiencies and fuel-use characteristics over time QUESTION EXOGENOUS TURNOVER OR ECONOMIC DECISION; thus aggregate efficiency is dependent on mix of vintages and turnover rate
Explicit conserv. tech.:	sub-sector and fuel specific supply curves of conservation technologies (marginal cost of demand reduction), with level chosen through cost minimization; change over time to reflect assumed new technologies availability and price

IV) SUPPLY

Choice of supply mix:	US energy market equilibrium resource extraction see below conversion technologies that maximize individual supply industry's profit and meet demand or conform to regulatory measures (utilities) market allocation market shares ferom logit market share algorithm
Imports/exports:	maximum import capacity by source; Alaska oil/gas production/pipeline capacity minimum and maximum; natural gas and oil imports are assumed marginal supply QUESTION WHAT ARE LIMITS IF ANY
International oil price:	exogenous reference price/demand path, with price adjusted via "supply elasticity" if demand changes relative to reference case QUESTION WHAT IS SUPPLY ELASTICITY
Supply constraints:	construction lags; capacity limits endogenous; hydropower, some of other minor renewables' levels determined exogenously
Primary fossil energy:	Hotelling suppliers; also discovery/depletion treated explicitly; resource base, find rates, stock depletion effects on marginal cost of extraction curve INCOMPLETE
Primary nonfossil energy:	INCOMPLETE
Secondary liquids	
Secondary gasses	
Secondary solids	
Conventional electricity:	general explicit modelling of capacity expansion, life extension, operation, and rate setting for utilities and NUGs; model distinguishes between base/intermediate/peak demands with annualized load duration curve; NUG least-cost mix

fills market share determined by utilities' "avoided cost," lowest cost baseload technology; each year, 5-year ahead forecast of load done by "extrapolation" is split into peak/intermediate/base components to derive needed generation requirements, and thus new capacity needs, to which is added a reserve margin; price determined from regulated cost process which determines average cost of electricity production

pulverized coal
atmospheric fluidized bed
pressurized fliudized bed
IGCC
coal ISTIG
coal-based fuel cells
life extended coal
repowered AFB
repowered IGCC
oil/gas steam
gas combined cycle
steam-injected gas turbines
combustion turbines
gas-based fuel cells
life-extended oil/gas steam
light water reactors
advanced light water reactors
new nuclear reactors
photovoltaics
solar thermal
solar/ISTIG
geothermal
biomass
wind electric
wind/ISTIG
hydroelectric
pumped/other storage

costs are fuel costs, OM, capital cost, and "avoided cost" payments to NUGs
QUESTION, COSTS OR OPERATING PARAMETERS CHANGE
QUESTION WHICH ARE NOT CURRENTLY AVAILABLE
WHAT ARE CAPACITY CONSTRAINTS, IF ANY EXOGENOUS
LIFE CYCLE EXOGENOUS?
WHAT DOES "EXPLICITLY LIFE EXTEND" MEAN

NUG electricity:

IPP/cogenerators reduce industrial demand directly
small power producers

biomass
geothermal
hydroelectric
municipal solid waste
solar thermal
wind electric

Advanced electricity:

QUESTION FROM ABOVE WHICH ARE "NEW"

Supply tech. change:

new technologies enter market when cost-effective QUESTION DO COSTS/EFFICIENCY PARAMETERS CHANGE OVER TIME FOR ANY TECHNOLOGIES

V) ENVIRONMENTAL

Emissions:	CO_2 via coefficient by fuel and end-use
	CH_4 via coefficient for coal mining/NG distribution
	NO_x, SO_2 via coefficient by fuel and technology where appropriate

GEMINI - DFI/EPA

I) GENERAL

Type:	intertemporal generalized equilibrium of US energy markets
Perfect foresight:	yes
Time horizon/periods:	2030 x 5
Data time frame/bm:	parameterized
Documentation used:	10/90: "Status Report . . ."
	2/91: sections of updated documentation received
	8/91: completed questionnaire and technology appendix received

II) FOCUS

GEMINI concentrates on the energy supply and demand technologies which will likely be available over the medium term, and on the economic decisions which govern the technology/fuel mix used to meet demand. It can thus analyze how portfolios of various tax and financial incentives and/or "command and control" type policies for efficient technologies and renewable fuels affect service demand levels and tech./fuel market penetration, and hence Carbon emissions. It is not assumed that macroeconmic affects such as GNP loss affect energy demand; only lagged price elasticities are used to modify the reference demand paths.

The model has a detailed atmospheric submodel which determines potential and actual temperature changes, given a comprehensive set of emissions projections, some of which are exogenous.

III) DEMAND

Regional aggregation:	USA
Sectoral aggregation:	agriculture (1) industrial (5) direct heat, indirect heat, electromechanical, feedstocks, metallurgical coal residential (5) space heating and cooling, water heating, lighting, appliances, other gas commercial (4) space heating and cooling, lighting, other electric, other gas transportation (4) auto, air, rail, truck and ship
Consumer behavior:	for each (non-agriculture) subsector there are exogenously-specified price/demand paths for end-use energy services, around which price changes cause demand shifts through lagged elasticities; consumers minimize costs through choosing mix of available demand technologies, including alternative efficient technologies as well as the standard conventional ones; agriculture sector has energy-using production function with exogenous demand for its homogeneous product

Exogenous inputs: GNP, population, housing stocks, commercial floor space and other projections determine reference price/quantity paths

Feedstocks: subcategory of industry demands (but Carbon assumed "fixed" in products over life of the model)

Energy/macro. link: macroeconomic projections help determine reference demand paths; otherwise macroeconomic effects of energy sector events are assumed not to impact services demand levels

Price elasticities: a sector's energy services demand level has lagged price elasticity:

$$\frac{Q(t)}{Q_{ref(t)}} = \left[\frac{Q(t-1)}{Q_{ref(t-1)}}\right]^{\alpha}\left[\frac{p(t)}{p_{ref(t)}}\right]^{\beta}$$

where long-run elasticity = $\beta/(1-\alpha)$, with α = lag parameter

Other EEI: efficient demand technologies explicitly modelled, chosen either through optimizing behavior (price-driven) or by mandate (non-price driven); evolutionary efficiency changes represented as capital cost reductions or efficiency parameter improvements in some demand technologies; sector/product shift and non energy-related efficiency improvements implicit in reference p/q paths

Energy-using capital: vintage structure for demand-side energy-using capital with different operating parameters; explicit modelling of retiring and adding capital stock through optimizing behavior or mandate; "useful life" parameters are not fixed life, but operating costs begin to rise more steeply; thus aggregate efficiency is dependent on vintage mix

Explicit conserv. tech.: choice among efficient demand-side tech's, such as efficient residential water heaters, and higher housing/commercial building thermal integrity -- inspired by either cost minimization or non-fiscal regulations

IV) SUPPLY

Choice of supply mix: US energy market equilibrium: optimizing agents linked in a process network (resource extraction, conversion, trans., market allocation, end-use demand):

resource extraction

see below

conversion

implicitly cost minimizers using Leontief technology, with both evolutionary tech progress and cumulative use ("breakdown") changing the coefficients; also entirely new processes; capacity utilization, addition and capital retiremant endogenous, so aggregate efficiency depends on mix of vintages and technologies

transport/transmission

efficiency parameters to determine trans. losses plus capital charge to pay for equipment

market allocation

long-run supply market share model allocates demand for commodity among competing suppliers according to relative prices, with actual share dynamics modeled as:

$$S_{actual(t)} = \gamma S_{longrun(t)} + (1-\gamma) S_{actual(t-1)}$$

Energy imports/exports: crude oil import level determined by market share algorithm

International oil price: price path exogenous and fixed

Note on supply tech. costs: Leontief cost function for all processes: total cost = total capital charge plus unit oper./maint. plus unit fuel costs (for conversion processes only); capital charge is fixed "specific capital cost" times capital charge rate, which is endogenous function of future costs, prices, and output levels; fuel cost is unit price divided by efficiency; hydroelectric is fixed quantity, so costs irrelevant

Primary fossil energy: gulf coast crude, other domestic crude, imports, conv. and uncontentional natural gas, and eastern and western coal:
each industry is intertemporal profit maximizer with Leontief tech., *given* previous periods' cumulative depletion: price equals marginal cost of extraction plus opportunity cost (which *does* depends partially on current period's output); physical depletability modeled as extraction rate is less than maximum rate

$$q(t) \leq \delta \left[1 - \sum_{\tau=0}^{t-1} q(\tau) \right],$$

where δ is exogenously-specified maximum production to reserves ratio; economic depletability modeled as operating cost increasing with new capacity (new reserves) and operating costs of extraction in given field increasing with *previous* periods' cumulative depletion; evolutionary technical progress decreases specific capital cost

Primary non-fossil energy: solar, wind, geotherm., ag, non-ag, and waste (ind. ht. and elec.)
biomass, wood
exogenous increasing MC curves, treated as "fuel cost"
DATA NOT AVAILABLE
nuclear
exogenous constant price supply, treated as "fuel cost"
photovoltaics
"infinite" supply at constant price, treated as "fuel cost"

Secondary liquids: coal liquefaction
Leontief costs endogenous, OM costs increase after 25 years
no technical progress assumed
90% availability, endogenous capacity level and utilization
refined crude
Leontief costs endogenous, OM costs increase after 25 years
no technical progress assumed
90% availability, endogenous capacity level and utilization
ethanol from biomass
methanol from natural gas
Leontief costs endogenous, OM costs increase after 25 years
technical progress assumed
80%/90% avail., endogenous capacity level and utilization
methanol from coal
available 2010, costs more before
Leontief costs endogenous, OM costs increase after 25 years
technical progress assumed
90% availability, endogenous capacity level and utilization

Secondary solids: direct-use coal for industrial heat
direct-use biomass for industrial heat
wood for residential space heat
all characteristics of end-use technologies

Secondary gasses: direct-use natural gas

	both conventional and advanced end-use technologies
	coal gasification
	Leontief costs endogenous, OM costs increase after 25 years
	no technical progress assumed
	90% availability, endogenous capacity level and utilization
Conventional electric:	refined liquids
	natural gas
	Leontief costs endogenous, OM costs increase after 30 years
	no technical progress assumed
	80% availability, endogenous capacity level and utilization
	coal
	Leontief costs endogenous, OM costs increase after 40 years
	technical progress assumed
	71% availability, endogenous capacity level and utilization
	nuclear
	Leontief costs endogenous, OM costs increase after 35 years
	no technical progress assumed
	65% availability, endogenous capacity level and utilization
	hydro
	all potential hydroelectric potential used to meet demand
	3.21 Quads in 1990 up to 3.51 in 2030
Advanced electric:	coal
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed
	75% availability, endogenous capacity level and utilization
	natural gas
	available 1995, costs more before
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed
	79% availability, endogenous capacity level and utilization
	nuclear
	available 2050, costs more before (assumed no new nuclear)
	crop biomass
	waste biomass
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed
	80% availability, endogenous capacity level and utilization
	solar
	available 2000, costs more before
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed
	30% availability, endogenous capacity level and utilization
	wind
	Leontief costs endogenous, OM costs increase after 20 years
	technical progress assumed
	30% availability, endogenous capacity level and utilization
	photovoltaics
	available 2000, costs more before
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed
	30% availability, endogenous capacity level and utilization
	geothermal
	Leontief costs endogenous, OM costs increase after 30 years
	technical progress assumed

Supply tech. change:	80% availability, endogenous capacity level and utilization gradual capital cost reduction and/or efficiency improvements modeled through exogenous rate parameter for transition from present to ultimate levels (may be identical if no technical change assumed), based on various technology change forecasts; also entirely new processes are represented; aggregate rate of tech. change depends on endogenously-chosen vintage mix and rate of turnover and installation

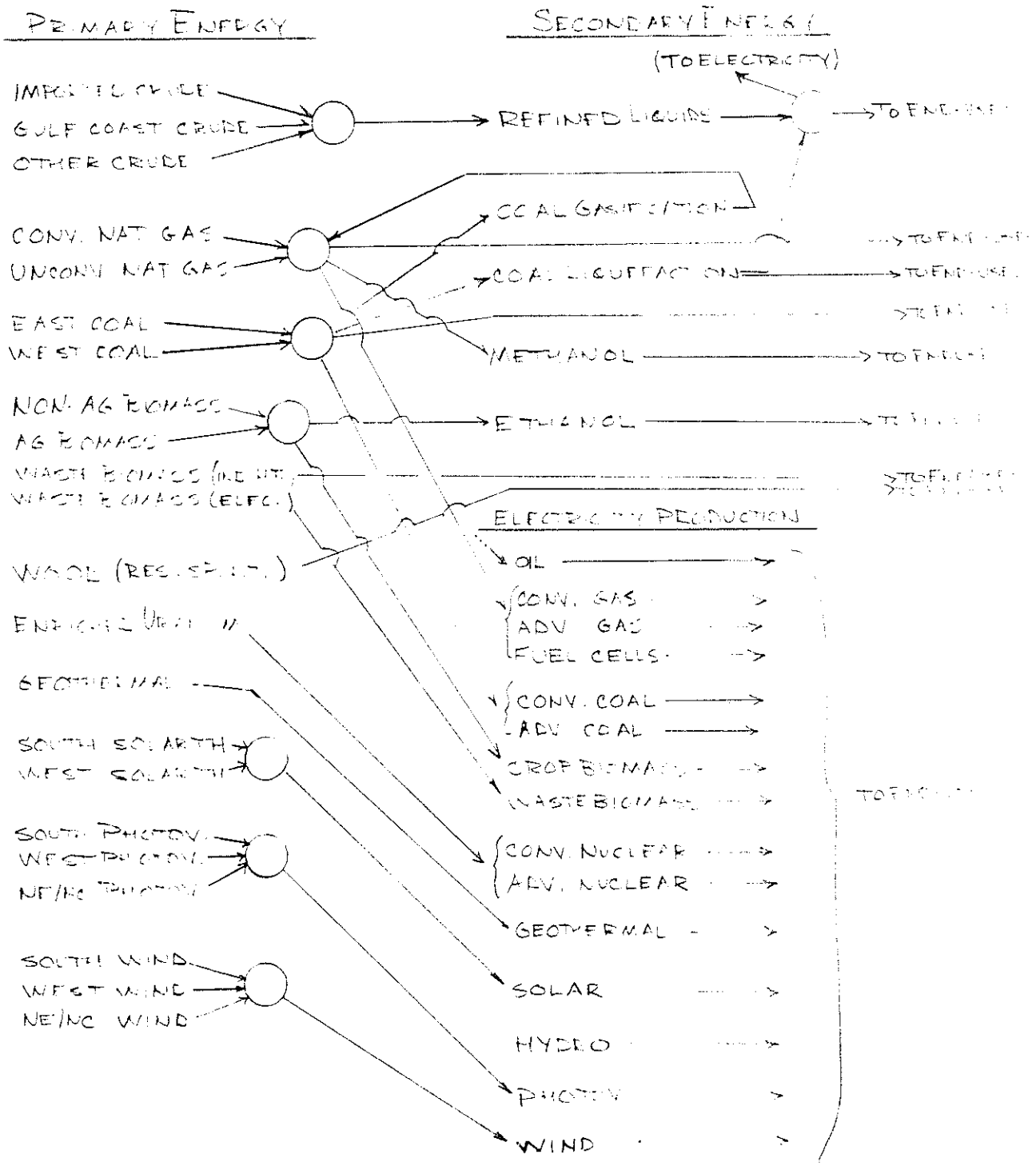
V) ENVIRONMENTAL

Emissions:	CO_2, CH_4, N_2O via fuel/technology coefficients -- US energy N_2O exogenous -- US agriculture CO_2, CH_4, N_2O exogenous -- ROW CFCs, HCFCs exogenous -- US and ROW
Emissions to atm conc:	global atmospheric concentrations, by gas: $c(t) = [1 - 1/r][c(t-1) - v] + \gamma e(t-1))$ where c(t) is concentration at time t, r is atmospheric residence time, v is pre-industrial steady-state level, γ is emission-to-concentration conversion factor, and e is aggregate annual emissions
Atm conc to temp inc:	radiative forcing, CO_2 equivalents: CO_2: $\Delta RF = 6.3 \times \ln\left[\frac{C}{C_0}\right]$, for $C < 1000$ ppmv CO_2 CH_4: $\Delta RF = 0.036 \times (\sqrt{M} - \sqrt{M_0}) - F(M, M_0, N_0)$, for $M < 5$ ppmv CH_4 (F is function -- see GEMINI documentation) N_2O, CFCs, HCFCs: see GEMINI documentation potential temp change: $\Delta P(t) = \alpha \Delta RF(t)$ actual temp change, by gas: lagged -- see GEMINI documentation
Concentration feedbacks:	CO_2 on agricultural productivity is possible

GEMINI ENERGY SUPPLY NETWORK

(DOES NOT INCLUDE TRANSMISSION OR TRANSPORT ACTIVITIES)

○ = MARKET



GLOBAL 2100 - Manne/Richels

I) GENERAL

Type:	parallel intertemporal nonlinear optimization
Perfect foresight:	yes
Time horizon/periods:	2100 x 10
Data time frame/bm:	1990 benchmark, parameterized
Documentation used:	2/90: "Global CO_2 Emission Reductions. . ."
	2/90: "Global 2100: an Almost Consistent Model. . ."
	11/90: "Buying Greenhouse Insurance"
	11/90: "A Decomposition Procedure for CO_2 Trade . . ."
	11/90: "Estimating the Energy Conserv. Parameters . . ."
	2/91: "Three Scenarios for Reducing Carbon Emissions"
	8/91: "Buying Greenhouse Insurance . . ."

II) FOCUS

GLOBAL 2100 is intended to analyze the long-run GDP costs of CO_2 emissions limits. Both exogenously-set tax and emissions limits policies can be treated. The model is based on parallel optimizations in five major global regions, with the only internationally-traded commodity being crude oil. In each region, there is a utility-maximizing representative consumer, a macroeconomic production function in capital, labor and nonelectric and electric energy, and a moderately rich representation of the energy supply sector.

The model is thus suited to analyze how the costs of the carbon limits change under alternative assumptions about supply technology availability, easier substitution between energy and other inputs, and non price-related energy efficiency improvements. In extended forms, the model can also be used to determine the price of internationally-traded emissions rights, and can also be used in a decision analytic framework to estimate optimal "hedging" strategies and the value of information on key uncertainties.

III) DEMAND

Regional aggregation:	USA, O-OECD, USSR, China, ROW
Sectoral aggregation:	macroeconomy
Consumer behavior:	representative consumer in each region maximizes the sum of discounted utility (log of region's aggregate consumption), with the utility discount rate being consistent with the assumed potential economic growth rates; the optimization determines the consumption/ investment decision
Exogenous inputs:	regional potential GDP growth rates based on assumed (inelastic) labor supply and per capita productivity growth; labor is measured in "efficiency units" in production function
Feedstocks:	implicitly included in nonelectric energy demand, but allowance is made for oil and gas quantities used as feedstocks because carbon emissions limit is for energy sector only
Energy/macro. link:	region-specific CES macroeconomic production function with 2 nested Cobb-Douglas functions of capital/labor and nonelectric/electric energy; "putty-clay" in that each period's mix

be deferred; constant marginal cost for hi and lo-cost oil and natural gas supplies includes OM, fuel cost and, for hi-cost, a capital charge since they are not available until 2010 -- costs include all costs between extraction and use at either electricity production or nonelectric direct use

Primary non-fossil energy: none explicitly modeled as primary resources; implicit in nonfossil supply technology specifications

Secondary liquids: synfuel
- available 2010 with cost parameter
- capacity 1 EXAJ in 2010 for all regions
- max intro rate 15% exceeded at quadratically-incr. MC

renewables (like ethanol from biomass)
- available 2000 with cost parameter
- capacity 5 EXAJ in 2000 for all regions, then 10 EXAJ
- max intro rate 15% exceeded at quadratically-incr. MC

Secondary solids: coal
- cost parameter
- maximum use growth rate tied to GNP growth rate

Secondary gasses: nonelectric backstop (like electrolysis of hydrogen)
- available 2010 with cost parameter
- capacity 1 EXAJ in 2010 for all regions
- max intro rate 15% exceeded at quadratically-incr. MC

Conventional electricity: fuel oil

natural gas
- cost and heat rate parameters
- capacity constraints to 2000 (US, OOECD, China) or 2030 (USSR, ROW), and 0 thereafter
- can be exceeded at quadratically-increasing MC

coal
- cost and heat rate parameterized
- capacity constraints to 2020/2030 in all countires, 0 after
- can be exceeded at quadratically-increasing MC

nuclear
- cost and heat rate parameters
- US/OOECD capacities .562/.847 TKWH to 2010, then halved in 2020, then 0 thereafter, can be exceeded at quadratically-increading MC
- USSR capacity .131 to 2000, then down to .033 in 2030, then 0 thereafter, can be exceeded at quadratically-increasing MC

hydro (included geothermal and existing renewables)
- capacities US .19 TKWH, OOECD .835 to 2050 then .934, USSR .134, China .099, ROW .39, TOTAL 2.539/2.638, exceeded at quadratically-increasing MC

Advanced electric: coal
- available 2000 with cost and heat rate parameters
- usage decline rate bounded at 95%

natural gas
- available 2000 with cost and heat rate parameters
- capacity .2 TKWH in 2000 to 1000 after for all regions
- usage decline rate bounded at 95%, can be exceeded at quadratically-increasing MC

advanced low-cost (Carbon free)

advanced high-cost (Carbon free)

of inputs are function of current and future prices, while the mix in all previous vintages is fixed; aggregate output divided between consumption, investment, and energy costs; non-energy capital cost and investment fully endogenous, while energy sector capital costs fixed; labor supply exogenous and inelastic

Price elasticities: for current vintage of inputs: elasticities of substitution between value-added (K/L) and energy (E/NE): .4 USA/O-OECD, .3 others, measured at secondary energy prod; Cobb-Douglas value shares from benchmarking for different regions

Other EEI: accounts for all non-price mechanisms of energy efficiency improvements: parameter applied to both non-electric and electric aggregate energy services demand to determine actual supply needed:

$$\text{actual supply} = \text{service demand} \prod_{\tau=0}^{t-1} (1-eei_\tau)^{10}$$

for t = 2000, 2010, . . ., 2100;

annual rates:

USA/O-OECD:	.5% to 2100
USSR:	.25% to .5% by .05% in 2050, .5% to 2100
China:	1.0% to .5% by .05% in 2050, .5% to 2100
ROW	0.0% to .5% by .05% in 2050, .5% to 2100;

labor productivity also enters production function directly through "efficiency unit" specification of labor force, causes additional indirect EEI

Energy-using capital: non-energy sector stock homogenous, but distinguished by vintage; total productive capital is sum of depreciated previous periods' installed capital, plus current investment; efficiency improvemnts are disembodied and fully accounted for in EEI parameter

Explicit conserv. tech.: -

IV) SUPPLY

Choice of supply mix: meet endogenous electric and nonelectric demands after EEI parameter applied; implicitly least-cost since utility maximizing

Energy imports/exports: crude oil trade endogenous to balance interregional supply and demand; ROW (includes OPEC) assumed marginal supplier; US and OECD oil imports upper bounded at 1000 EXAJ to 2030; ROW exports upper bounded at 1000 EXAJ always, with USSR and CHINA have small upper bounds to 2030 6.6-1.0 and 0.6, respectively

International oil price: ROW sets price, others price takers: price balances interregional oil supply/demand

Note on supply costs: all costs are total unit-cost parameter and include levelized capital charge (for not currently available technologies only), OM, and fuel costs (for all but existing oil- and gas-fired electric plants, which have separate fuel costs); oil/gas price differential to reflect imperfect substituability for nonelectric use of gas

Primary fossil energy: low- and high-cost crude oil

low- and high-cost natural gas

production/proven remaining reserves ratio is fixed; reserve additions are upper bounded by a fraction of the remaining undiscovered resources, so reserve additions can

available 2010 with cost and heat rate parameters
capacities .1 TKWH or .2 (OOECD adv. lo-cost) in 2010, 100 therafter for all rwgions
max intro rate 15% exceeded at quadratically-incr. MC

Supply tech. change: the single EEI parameter (see above) includes disembodied supply efficiency improvements which are not price-related; also advanced technologies employed in least-cost mix subject to introduction rate and capacity constraints (thus price driven)

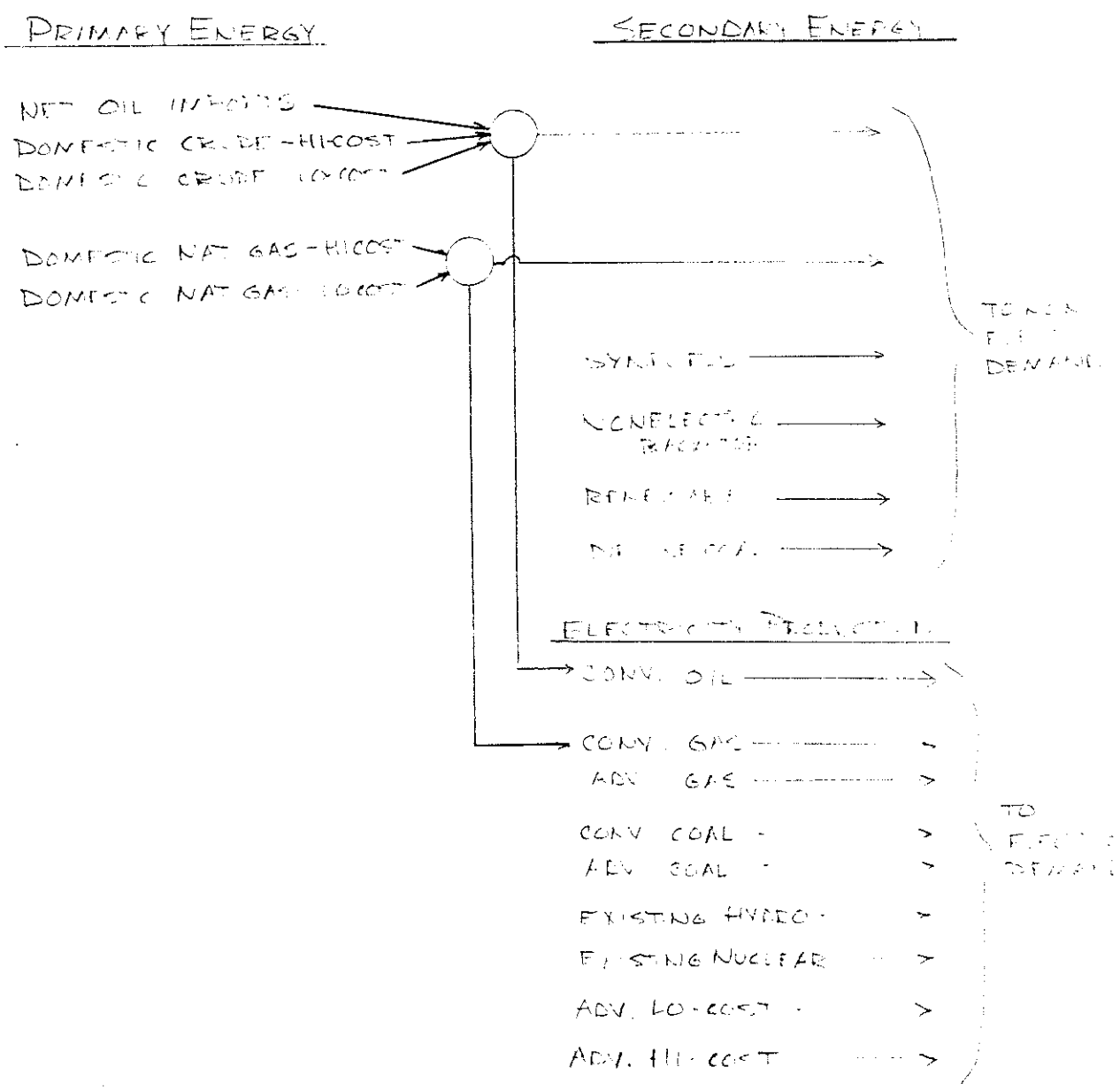
V) ENVIRONMENTAL

Emissions: CO_2 via fuel coefficients, less allowance for non-energy sector use of carbon-based fuels (feedstocks) -- each region's energy sector

GLOBAL 2100 ENERGY SUPPLY NETWORK

(DOES NOT INCLUDE TRANSMISSION OR OTHER SUPPLY ACTIVITIES)

○ = MARKET



Global Macro-Energy - ICF

I) GENERAL

Type:	intertemporal generalized equilibrium of global energy markets
Perfect foresight:	no (recursive)
Time horizon/periods:	1985 - 2100 x 25 ? QUESTION
Data time frame/bm:	parameterized, 1985 b.m.
Documentation used:	10/88: "Global Macro-Energy Model, Summary Paper"

II) FOCUS

Model focuses on global energy markets, with moderately-rich detail on supply side. Tracks capital vintages on both supply and demand side, but turnover rate is exogenous.

III) DEMAND

Regional aggregation: USA, OECD West, OECD Asia, cent.-planned Europe, cent-planned Asia, Middle East, Africa, Latin America, SE Asia

Sectoral aggregation:
residential (4)
space heating, AC, water heating, and appliances
commercial (6)
space heating, AC, water heating, cooking, lighting, and refrig
transportation (3)
rail, road, air
industrial (3)
steel, cement kilns, boilers

Consumer behavior:
end-use energy demand by region and sector
res/comm and transportation sectors

$$d(t) = d(0) * \Delta C(t)^{\alpha} * \Delta I(t)^{\beta} * \Delta P(t)$$

industrial sectors

$$d(t) = d(0) * \Delta C(t)^{\gamma} * \Delta G(t)^{\delta}$$

where C is cost of energy services, P is population, I is income, based on GNP forecasts, and G is GNP; changes are over base year levels; superscripts are elasticities;
costs are dependent on aggregate nonfuel costs and efficiencies of energy-using capital stock, as well as on fuel shares and prices of secondary fuels

Exogenous inputs:	population, GNP assumptions, elasticities, etc.
Feedstocks:	in industrial demand QUESTION included in emisions
Energy/macro. link:	-
Price elasticities:	see above
Other EEI:	no autonomous sector/product shift; demand technology efficiency improvements are totally embodied in capital stock, see below
Energy-using capital:	fuel and sector-specific vintage structure to calculate efficiencies and non-fuel costs of energy-using equipment; straightline depreciation with fixed useful life; new equipment cost and efficiency parameters exogenously specified QUESTION EQUATIONS

Explicit conserv. tech.: -

IV) SUPPLY

Choice of supply mix: global energy market equilibrium: regional process-network representation of energy supply: primary resources, transmission, refining, distribution, conversion, and global market allocation with regional price differences to reflect transport, taxes, etc.

primary resources

see below

transport, distribution

costs region and sector specific

market equilibrium

fuel share weights in a given market determined by relative prices, substitution elasticities, and base year fuel share weights for electricity, which are used to represent existing "inertia" in capital stock, but which are noneffectual after 40 years QUESTION HOW

for electricity:

fuel weight = (base weight) x $(\text{cost})^{\alpha}$

fuel share = (weight) / (sum of weights (excluding hydro))

for synfuel feedstocks, share of coal and biomass allocated to synprocess type:

share = ((cost of production for given process) / (cost of coal or biomas feedstock))$^{\beta}$

amount allocated = (share) / sum of shares for syngas, synoil, solid use) x (coal or biomass production)

Energy imports/exports: endogenous in traded fuels
oil: Middle East to US
coal: US to Japan, Europe
Gas: Europe to US

International oil price: endogenous

Primary fossil energy: crude oil
natural gas liquids
natural gas
coal

recoverable resources are fraction of total reserves; economic reserves are a fraction of recoverable resources which is determined by where the market price equals the MC of extraction curve, which can change over time to reflect technical progress; production is determined by fixed production to reserves ratio; reserve additions ration is also fixed

Primary non-fossil energy: commercial biomass

incr. MC of supply curve NEED DATA POINTS

Secondary liquids: synliquids from coal
synliquids from biomass

costs are non-fuel costs plus fuel costs divided by efficiency

QUESTION TECHNICAL CHANGE

Secondary gasses:
syngas from coal
syngas from biomass
same as synliquids above

Secondary solids:
coal or biomass not used for synfuels or electricity depends on market share algorithms

Conventional electricity:
liquids
gasses
coal
costs are non-fuel costs plus fuel price divided by conversion efficiency parameters
nuclear
cost is exogenous parameter with various adjustment factors to allow for technical progres or other factors affecting uclear generation costs; political factors can be included by adjusting fuel share weights EQUATIONS AND COSTS
solar
exogenous cost parameter, plus costs for backup and storage costs decline over time to reflect technological progress EQUATIONS AND COSTS
hydro
production is logistic function of time times fraction of technically feasible resources that will ultimately be produced; used to meet demand directly NEED DATA POINTS AND COSTS

Advanced electricity:
none explicitly modeled, implicit in capital stock assumptions underlying supply technical change

Supply tech. change:
for electricity production, straightline depreciation of existing capital stock overe fixed useful life; new capacity meets excess demand over existing capacity; new capacity has new operating parameters and costs which are exogenously specified QUESTION HOW RELATED TO ABOVE TECHNICAL CHANGE STUFF
for primary resource QUESTION

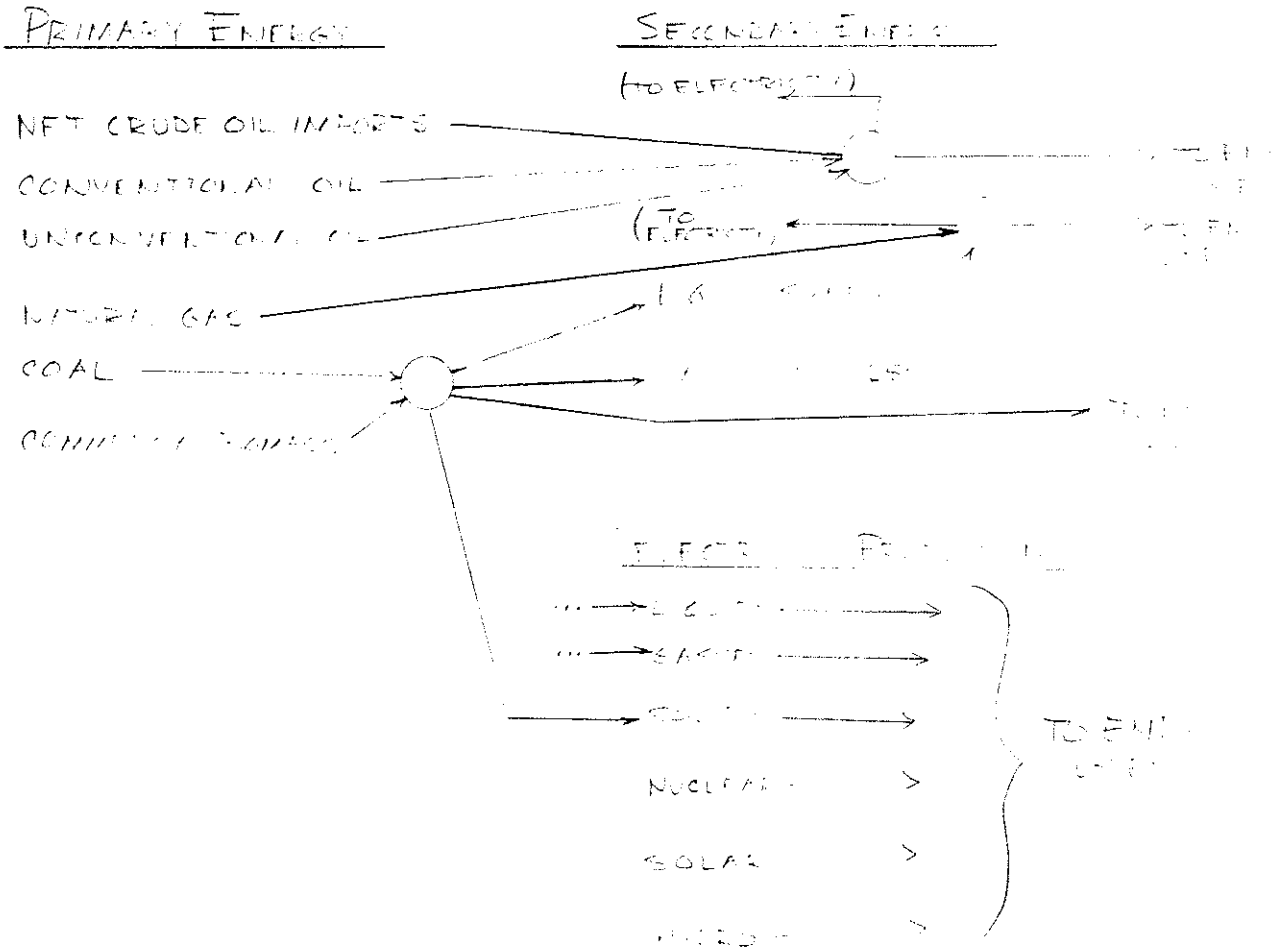
V) ENVIRONMENTAL

Emissions:
CO2, N2O, CH4, CO, NxO via fuel/technology coefficients -- each region and sector

GLOBAL MACRO ENERGY SUPPLY NET[illegible]

(DOES NOT INCLUDE TRANSPORT OR [illegible])

○ = MARKET



GOULDER - Goulder

I) GENERAL

Type:	intertemporal general equilibrium of U.S. economy
Perfect foresight:	yes
Time horizon/periods:	2065 x 1
Data time frame/bm:	benchmarked 1990; CES production function parameters derived from Jorgensen-Wilcoxen translog parameters
Documentation used:	3/91: "Second-Best Taxation . . ." 6/91: "Effects of C Taxes . . . with Prior Tax Distortions . . ." 7/91: "Effects of a Growing C Tax . . ." 8/91: completed questionnaire received

II) FOCUS

The model is designed to examine industry and economy-wide effects of Carbon limits and other energy/environmental policy issues. It considers the short-run adjustment dynamics as well as the approach to long-run equilibrium. It measures welfare costs in terms of either GDP losses or "equivalent variation." It has considerable detail on how taxes affect industry investment incentives and profitability. Therefore, the model can analyze how costs differ according to the manner in which Carbon tax revenues are recycled, and according to the nature of the existing tax distortions in the economy. It does not address the benefits of avoided emissions or any distributional impacts on consumers.

A dissaggregated production sector allows price-induced change in composition of goods purchased away from fossil-fuel intensive industries. Only "autonomous" productivity improvement comes about from "Harrod-neutral" technical progress embodied in labor. Production function approach to modeling energy industries: coal mining, crude oil/natural gas, petroleum refining, synfuels production, and electricity and gas service industries. Model explicitly models resource stock effects for crude oil/gas and has carbon-based "backstop" synfuel technology with endogenous rates of introduction. Does not allow for any non-carbon energy sources, such as nuclear.

III) DEMAND

Regional aggregation:	U.S., ROW
Sectoral aggregation:	US: 13 industries (included 6 energy supply sectors), single household, government sector ROW: aggregate sector
Consumer behavior:	consumers: infinitely-lived representative consumer with perfect foresight maximizes discounted utility of full consumption

$$U_t = \sum_{s=t}^{\infty} (1 + \omega)^{t-s} (\sigma/\sigma-1)\ C_s^{(\sigma-1/\sigma)}$$

where σ is intertemporal elasticity of substitution and full consumption C is CES in goods and services G and leisure L

$$C_s = [G_s^{(v-1/v)} + \delta^{1/v} L_s^{(v-1/v)}]^{(v/v-1)}$$

where G is Cobb-Douglas in 17 specific consumption goods; the aggregate time endowment in efficiency units is exogenous and grows at g = 2%; labor supply endogenous, and labor is perfectly mobile

industries:

17 final consumption goods produced with Leontief tech. from 13 primary and intermediate industries' goods; each industry (except combined crude/nat. gas, see below) produces single output with nested CES production function (f,g,and h are CES form) as equity maximizer,

$$Y = f(g(K,L), h(E,M)) - \phi(I/K)I$$

where the last term is a capital adjustment factor; E is CES energy aggregate, met with coal, crude/nat. gas/synfuel, refined petroleum, electricity, or gas utilitiy, while M is CES materials composite; non-energy, foreign-produced intermediate and consumer goods are impefect substitutes, with foreign price fixed and exchange rate determined by assumption of zero trade balance in each period

Other exogenous inputs: growth in nominal wages (steady-state inflation rate) of 4%; overall government expenditure is exogenous and increases at constant rate equal to the steady-state growth rate of the model (g = 2%); model includes complete specification of tax structure; deficit/GNP ratio strictly constant in long-run

Feedstocks: implicitly included in various demand categories

Energy/macro. link: intertemporal general equilibrium

Price elasticities: implicit in CES production functions and consumer demand functions; can have substitution at several levels (see below)

Other EEI: all embodied in labor's Harrod-neutral technical change; aggregate time endowment efficiency units grows at 2%: sum of pop. growth rate and prod. improvement rate

Energy-using capital: capital is sector specific, so adjustment lags and costs are endogenous; cost of capital is endogenous, with investment determined by firm's objective of equity maximization; adjustment costs determined by $\phi(I/K)I$ term, where I is investment (see below for prod. function); adjustment cost function per unit investment is convex in I/K and has the form

$$\begin{cases} 1/2\ \beta\ (I/K - \delta)^2/(I/K), & \text{if } I/K > \delta \quad \text{(depreciation rate)} \\ 0, & \text{otherwise} \end{cases}$$

Explicit conserv. tech.: -

IV) SUPPLY

Choice of supply mix: intertemporal general equilibrium

International oil price: price exogenous and fixed

Energy imports/exports: imported oil/gas composite is marginal supply (perfect substitute for domestic)

Primary fossil energy: domestic oil/gas aggregate

intertemporal equity maximizers: resource stock depletion increases MC through production function for crude oil/nat gas

$$Y = (\gamma(Z))f(g(K,L), h(E,M)) - \phi(I/K)I$$

where $\gamma(Z)$ is monotone decreasing in cumulative extraction Z,

$$\gamma(Z) = \gamma_0 - (Z/Z^*)^2$$

with $\gamma_0 = 1$ and $Z^* = 450$ bbl; relative demand for oil and gas are assumed constant at benchmark year's ratio

coal

assumed inexhaustible, modeled as other industries

Primary non-fossil energy: no non-fossil energy sources are included in model

Secondary liquids: refined crude

nested CES; costs endogenous

no explicit technical change

capacity endogenous, with capital stock imperfectly mobile

synfuels (coal)

available 2010

nested CES; costs endogenous

no explicit technical change

capacity endogenous, with capital stock accumulation allowed to begin in 2010, and imperfectly mobile

Secondary solids: coal

can be demanded as input to production functions

Secondary gasses: gas utility

nested CES; cost endogenous

no explicit technical change

capacity endogenous

Conventional electricity: electric utility sector

nested CES; cost endogenous

no explicit technical change

capacity endogenous

Advanced electricity: none

Supply tech. change: none, except indirectly in labor productivity change.

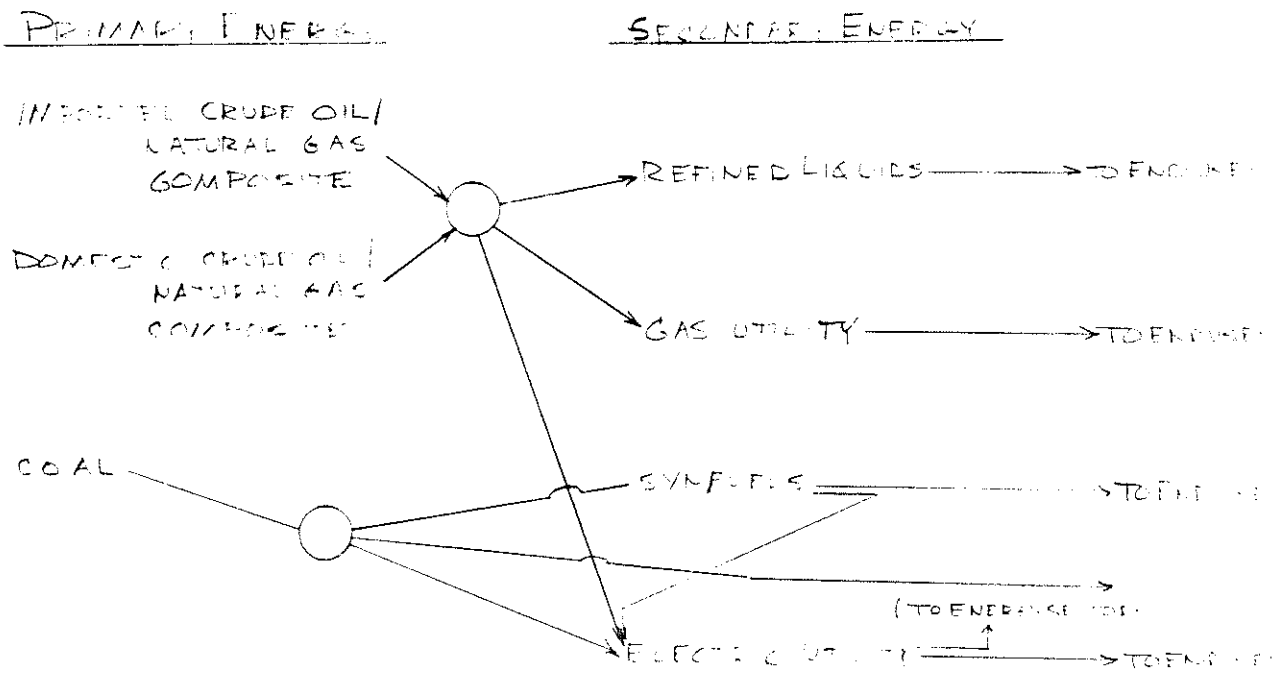
V) ENVIRONMENTAL

Emissions: CO2 via coefficients for coal, crude oil/gas aggregate, with weights for aggregate coming from benchmark year and assumed constant -- US total emissions

GOULDER ENERGY SUPPLY NETWORK

(DOES NOT INCLUDE TRANSMISSION OR TRANSPORT ACTIVITIES)

◯ = MARKET



GREEN - OECD

I) GENERAL

Type:	intertemporal global general equilibrium, with focus on energy markets
Perfect foresight:	no (recursive)
Time horizon/periods:	1985 - 2020 x 5
Data time frame/bm:	1985 benchmark, parameterized
Documentation used:	3/91: "Three Scenarios with Green . . ."
	7/91: ". . . A Technical Manual"

II) FOCUS

Model looks at the economy-wide and global impacts of Carbon limits. Its disaggregated and global nature allow it to analyze various trade issues, including Carbon rights trading, and to analyze tax recycling issues by specifying that marginal tax rates change to maintain governmental revenue neutrality. It can thus also allow for price-induced shifts away from Carbon-intensive goods. It includes six energy supply sectors, plus a carbon-free source of energy.

III) DEMAND

Regional aggregation: North America, European OECD, Pacific OECD, USSR, China, Energy-exporting LDC's, ROW

Sectoral aggregation: production sectors

agriculture, coal mining, crude oil, natural gas, refined oil, electricity and gas/water distribution, energy-intensive industries, other (non-energy-intensive) industries

consumption expenditure aggregates

food, beverages, and tobacco; fuel and power; transport and communication; other goods and services

Consumer behavior: producers and consumers are single-period optimizers, except ROW which is represented by import/export equations

consumers

total income determined by (1) income from labor and capital, (2) rents from fixed factors (see below), and (3) gov't transfer payments net of taxes; income optimally allocated between consumption and savings, and consumption between 4 types of consumption goods, using "extended linear expenditure system;" total net savings = household savings plus foreign trade balance plus net governemt savings = new capital investment; the "price" of savings set arbitrarily to weighted average of consumption goods' prices

producers

new capital investment level in given period is determined solely by savings decisions of consumer since markets clear for "old capital" (see below); total new investment in a given sector is equal to its demanded share of new capital plus

"old" capital from other sectors; putty-puty specification since capital stock adjusts to its long-run optimal level immediately for all sectors in each period, thus zero profit; Leontief transition matrix determines mix of intermediate and primary goods are needed to produce consumption goods; two industrial sectors, two utilities, and agriculture share common nested CES production function:
(1) Leontief (3 intermediate good, KLEF bundle)
(2) each intermediate good (either 2 industry and agriculture) is CES (imported, domestic)
(3) KLEF is CES (labor, KEF bundle)
(4) KEF bundle is CES (energy bundle, KF bundle)
(5) energy bundle is CES (coal, nat. gas, crude, refined petroleum, electricity), while each is CES (domestic imports)
(6) KF bundle is leontief (capital, "fixed factor"), where "fixed factor" is carbon free resource for electricity sector, land for agriculture sector, and nothing in (2) industrial sectors

government

collects income, Carbon, and indirect taxes on intermediate goods, outputs, and consumption expenditures; so revenues endogenous, with expenditures fixed ratio of GNP; carbon tax income/expenditures automatically change marginal tax rate to maintain revenue neutrality

Exogenous inputs: upward-sloping constant elsticity of supply curve for land, fixed factor in agriculture sector; GDP rates and rates of technical progress calibrate model dynamics

Feedstocks: in energy-intensive industry demand QUESTION INCLUDED IN EMISSIONS

Energy/macro link: general equilibrium

Price elasticities: parameters in CES production functions; Leontief inelastic

Other EEI: region- and sector-specific rates of Harrod-neutral technical progress for energy bundle which, along with assumed GDP ghrowth rates, imply rates of technical progress for capital/fixed factor bundle, as well as labor QUESTION ON VALUES; no autonomous sector shift bewteen energy-intensive and non-energy intensive industries, but product shift within sectors is implicit in EEI parameter

Capital stock: sector specific and vintaged -- "old" and "new", but otherwise homogenous; sector-specific supply elasticities for old capital reflecting imperfect malleability across sectors; since stock adjusts fully in each period to optimal level, disinvestment occurs when demand for capital is less than depreciated old capital; net investment can come from "old" or "new" caspital since assumed homogeneous

Explicit conserv. tech: -

IV) SUPPLY

Choice of supply mix: general equilibrium

Energy imports/exports:	equilibrium conditioned on exogenous crude oil price
International oil price:	exogenous, to represent OPEC action
Primary fossil energy:	natural gas
	crude oil
	Leontief (K, L, non-energy intermediate goods, fixed factor, fuels), where fixed factor is oil for oil and gas for gas
	production fixed ratio of proven reserves
	reserve additions fixed ratio of remaining undiscovered resources
	price-sensitive through constant elasticity change in either ratio QUESTION WHICH ONE FOR EMF SCENARIOS AND DATA
	coal
	production leontief as above, where fixed factor is coal
	constant elsticity of supply, finite but large VALUE
Primary nonfossil energy:	carbon-free resource
	constant elasticity of supply QUESTION DATA !!
	fixed factor in electricity sector
Secondary liquids:	refined oil
	Leontieff as above, but with no fixed factor
Secondary gasses:	gas utility sector (includes water distribution)
	nested CES (as described in demand section), but with no fixed factor
Secondary solids:	direct-use coal demanded as per production functions and transition matrix
Conventional electricity:	electric utility sector
	nested CES (as described in demand section above)
	fixed factor is carbon-free resource
Advanced electricity:	none modeled explicitly
Supply technology change:	disembodied efficiency improvements handled solely in single technical progress parameter (described in demand section)

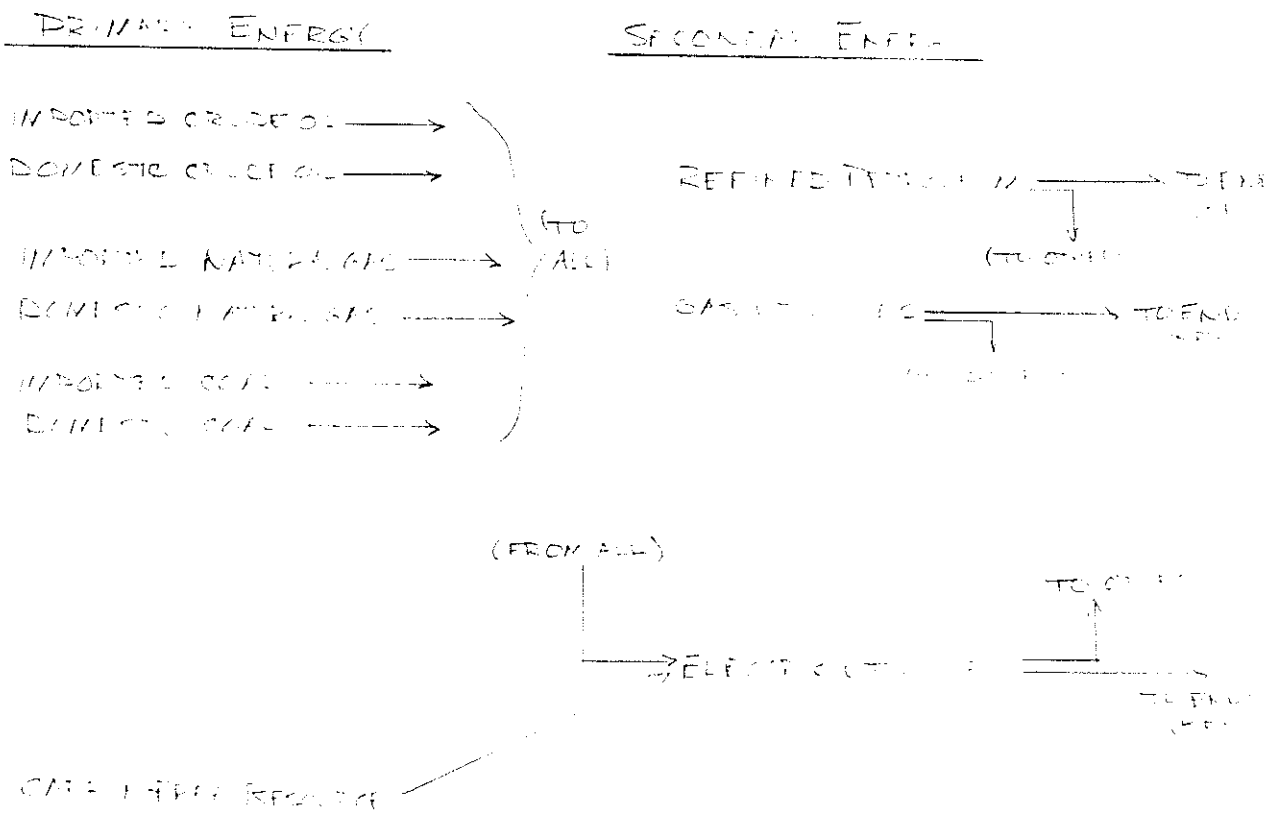
V) ENVIRONMENTAL

Emissions:	Carbon via coefficients -- each global region

GREEN ENERGY SUPPLY SECTOR

(DOES NOT INCLUDE TRANSMISSION OR DISTRIBUTION)

○ = MARKET



EDS MODEL - IEA

I) GENERAL

Type:	QUESTION
Perfect foresight:	-
Time horizon/periods:	2005 x 1
Data time frame/bm:	1965 - 1989
Documentation used:	3/91: completed outline 8/91: completed questionnaire

II) FOCUS

The model attempts to determine energy demand for various fuels, and hence Carbon emissions, in several global regions based on the historical relationships between energy demand and various explanatory variables, including GDP, population, relative prices, and some other technical inputs. The end is to determine the levels of region-specific Carbon taxes necessary to achieve given emisions targets. QUESTION: HOW DOES THIS MODEL WORK???

III) DEMAND

Regional aggregation:	North America, Europe, OECD Pacific, USSR, China, Africa, Asia, Latin America, Middle East
Sectoral aggregation:	oil gasoline, transportation, diesel,, heating oil, kerosine, heavy fuel oil, bunkers, other coal and gas power generation and "other" (aggregation of residential, industrial, and other sectors)
Consumer behavior:	demand for each subsector modeled as function of exogenous economic and technical projections
Other exogenous inputs:	GDP, population, relative prices, and various technical inputs such as structure and conversion efficiencies in electricity sector
Feedstocks:	implicit in demands QUESTION: INCLUDED?
Energy/macro. link:	no feedback from oil price on GDP; industrial structure also not affected by changes in energy prices
Price elasticities:	implicit in regressions: region-, and fuel-specific
Other EEI:	specific to demand category: time trend with estimated coefficient, exogenously-specified parameters to capture technical change or consumption pattern shifts (such as cars per household or miles driven)
Energy-using capital:	-
Explicit conserv. tech:	-

IV) SUPPLY

Choice of supply mix:	meets endogenous demand; interfual competition determined by relative fuel and capital costs QUESTION HOW SUPPLY AND MARKETS MODELED ??

International oil price:	exogenous and fixed
Energy imports/exports:	endogenous to balance interregional supply/demand of fuels; ME treated as marginal supplier of oil
Primary fossil energy:	QUESTION
Primary nonfossil energy:	QUESTION
Secondary - all:	none modeled explicitly
Conventional electricity:	QUESTION
Advaned electricity:	none
Exhaustible resources:	price-sensitive, resource-based non-OPEC oil and OECD gas QUESTION
Supply tech. change:	exogenous specification of increasing conversion efficiency in power generation

V) ENVIRONMENTAL

Emissions:	CO2 via coefficients for coal, crude oil, natural gas

T-GAS (Trace Gas Accounting System) - Alliance/BU/UNH

I) GENERAL

Type:	regression model of country- and end-use sector-specific fuel intensity (fuel use per unit output)
Perfect foresight:	-
Time horizon/periods:	2010 x 1
Data time frame/bm:	1971 - 1985
Documentation used:	6/90: "TGAS . . ."

II) FOCUS

Model is intended to provide country-specific CO2 emissions forecasts. It consists of a set of regression equations for each country and sector, which forecast fuel intensity and then emissions based on exogenous economic projections and electric utility data. The model can not endogenously handle any policl scenarious, , but can be linked with macro models, such as LINK.

III) DEMAND

Regional aggregation:	14 countries: OECD (USA, UK, BRD, Japan, Italy, France), Non-OECD (Brazil, China, Hungary, India, Mexico, Poland, South Korea, USSR)
Sectoral aggregation:	industrial, transportation, residential, commercial, agriculture, other
Consumer behavior:	econometric response function: country/sector-specific fuel intensity (fuel use / output) for coal, gas, oil, electricity, and heat (and motor fuels for transportation sector) based on exogenous economic forecasts; thus implicitly constant retunrs to scale
Exogenous inputs:	fuel prices, sector value-added/GDP ratio ("product mix," but actually "sector mix," since assumed homogenous product within sector), GDP/capita ("economic development"), time, dummy variables to capture past special circumstances (not forecasted), some variables lagged
Feedstocks:	in industry demand, but not included in energy sector emission levels
Energy/macro. link:	exogenous forecasts; can be linked with , for example, LINK model to do macroeconomic feedbacks exogenously
Price elasticities:	historical factor and interfuel substitutability implicit in regressions
Other EEI:	historical EEI implicit in regressions through non-price explanatory variables; technical change, sector shift, and economic maturation
Energy-using capital:	-
Explicit conserv. tech.:	-

IV) SUPPLY

Choice of supply mix:	electricity demand primary fossil fuels demand endogenous; derived primary fossil and nonfossil demand from electricity

	production based on exogenous country-specific fuel mix and conversion efficiency data; supply meets demand plus own-use and distribution losses (which are also country specific)
International oil price:	exogenous and fixed
Energy imports/exports:	-
Primary fossil energy:	oil gas coal supply derived from electricity sector parameters and direct demand own-use and distribution losses implicit in model
Primary nonfossil energy:	nuclear solar supply derived from electric sector parameters
Secondary - all:	none explicit
Conventional electric:	public utilities sector fuel use determined by exogenous parameters reflecting fuel mix and conversion efficiency characterestics
Advanced electric:	none explicitly modeled
Supply tech. change:	historical pattern of supply technology change implicit in regressions; can specify exogenous parameters to reflect changing makeup of a country's utility sector

V) ENVIRONMENTAL

Emissions:	CO_2 via country- and fuel-specific coefficients, which also reflect utility process data -- each sector and country

T-GAS Energy Sub[illegible]

(Does not include [illegible])