PRELIMINARY
DRAFT
(Not to be Quoted)

TECHNICAL DETAILS FOR THE CORE SET OF MODELS PARTICIPATING IN EMF 12

WP 12.27

Ron Beaver

February 18, 1992

Energy Modeling Forum
Stanford University
Stanford, California

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Introduction

To facilitate comparison of the results from the fourteen different models participating in EMF 12, a standard-format model summary was prepared for each of the models. The summaries include as much information as is possible or reasonable. For some of the more complex models, for instance, the summaries would extend to many pages if all of the technical details were included; this is especially true of the technology-rich models. Conversely, there is little documentation available for several of the models.

However, the summaries do provide a reasonably complete view of the internal model workings, and allow for easy comparison across models. The model characteristics are divided into the natural groupings of general model structure, demand modeling, supply modeling, and environmental modeling. Also, there is an illustration depicting the energy supply network, excluding transmission or transport activities, for each model.

The fourteen models are listed in Table 1 on the next page. Following that is a listing of the different characteristics for comparison. Summaries for two models, MARKAL and MWC, are forthcoming.

CETA (Carbon Emissions Trajectory Assessment)	Stephen Peck Thomas Teisberg
CRTM (Carbon Rights Trade Model)	Thomas Rutherford
Jorgensen-Wilcoxen (neo-DGEM) (Dynamic General Equilibrium Model)	Dale Jorgenson Peter Wilcoxen
EDS (Energy Demand System)	Lakis Vouyoukis, Niko Kouvaritakis (IEA)
ERM (Edmonds-Reilly Model)	Jae Edmonds David Barns
FOSSIL2	Sharon Belanger, Roger Naill (AES)
GEMINI	Dave Cohan, Adriana Diener (DFI), Joel Scheraga (EPA)
GLOBAL 2100	Alan Manne Rich Richels
GLOBAL MACRO-ENERGY	Bill Pepper (ICF)
GOULDER	Larry Goulder
GREEN (GeneRal Equilibrium ENvironmental)	John Martin, Jean-Marc Burniaux (OECD)
MARKAL (MARKet ALlocation model)	Samuel Morris (BNL)
MWC (Model of Warming Commitment)	Irving Mintzer
T-GAS (Trace Gas Accounting System)	Bob Kaufmann

Table 1: The Core Models of EMF 12

Contents of Model Summary

MODEL NAME - modeler

I) GENERAL

Type
Perfect foresight
Time horizons and period lengths
Data time frame, benchmark year

II) FOCUS

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

III) DEMAND

Regional aggregation
Sectoral aggregation
Consumer behavior
Exogenous inputs
Energy-macroeconomic linkages
Price or substitution elasticities
Other (non price-driven) energy efficiency/intensity 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 available)
Supply technology change (not covered in specific technology)

V) ENVIRONMENTAL

Emissions (only carbon emissions are relevant to EMF scenarios)
Emissions to concentrations
Concentrations to potential or realized temperature change
Economic impacts of atmospheric change

ENERGY SUPPLY NETWORK DIAGRAM

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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: A Model for Carbon Emissions Trajectory Assessment" 3/91: overheads from EMF 12 meeting presentation 10/91: energy supply constraint data

II) FOCUS

This model is conceptiually similar to GLOBAL 2100, but it has a single representative consumer for the entire world, 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 only energy sector CO2 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 model's implicit carbon tax time path equates the marginal present value cost of the reduction to the marginal present value benefit (avoided cost) of the reduction. The model can also handle exogenous taxes or emissions limits. The model has minimal energy supply disaggregation, but includes 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), with a utility discount rate of 3%; optimization equates marginal benefit of consumption, investment, energy expenditure, and emissions reduction
Other exogenous inputs:	labor supply and labor productivity growth
Energy/macro. link:	global CES macroeconomic production function (nested Cobb-Douglas capital/labor and nonelectric/electric bundles); putty-putty specification since capital stock adjusts fuilly in each time period to long-run optimal level; output is 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, which is applies to entire input bundle since the inputs are not vintaged; labor productivity enters production function directly through labor "efficiency unit" specification, which includes both labor

	force growth and productivity growth, and this indirectly causes EEI
Energy-using capital:	homogenous and not vintaged
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 constant marginal cost of extraction, with overall resource limit
Primary non-fossil energy:	none modeled explicitly, implcit in non-fossil secondary energy specifications

Secondary liquids:	synfuel
	    available 2010 with cost parameter
	    capacity limit 5 EXAJ in 2010 only
	    max intro/decline rates 20%/yr and 5%/year
	renewables (like ethanol from biomass)
	    available 2000 with cost parameter
	    capacity 50 EXAJ in 2010 and thereafter

Secondary solids:	coal
	    cost parameter
	    capacity limit 42.28 EXAJ in 1990, 0 thereafter

Secondary gasses:	nonelectric backstop (e.g., electrolysis of hydrogen)
	    available 2010 with cost parameter
	    capacity limit 5 EXAJ in 2010 only

Conventional electricity:	oil/gas composite
	    cost and heat rate parameters
	    capacity limit 2.7 EXAJ in 1990 down to 0 in 2040
	coal
	    cost and heat rate parameterized
	    capacity limit 4 EXAJ in 1990 down to 0 in 2040
	nuclear
	    cost and heat rate parameters
	    capacity limit 1.5 EXAJ thru 2010, then down to 0 in 2040
	hydro (includes geothermal and existing renewables)
	    capacity limit of approx 1.7 EXAJ

Advanced electric:	coal
	    available 2000 with cost and heat rate parameters
	    max usage intro/decline rates of 20%/yr and 5%/yr
	oil/gas composite
	    available 2000 with cost and heat rate parameters
	    max usage intro/decline rates of 20%/yr and 5%/yr
	electric backstop
	    available 2010 with cost and heat rate parameters
	    capacity limit .6 EXAJ in 2010 then 500 EXAJ thereafter
	    max usage intro/decline rates of 20%/yr and 5%/yr

Supply tech. change: efficiency improvements of existing technologies implicit in the single EEI parameter; also new supply technologies, as described above.

IV) ENVIRONMENTAL

Emissions: energy sector CO_2 via fuel coefficients -- global energy sector

Deferral of emissions not allowed when running EMF scenarios

N_2O, CH_4, CFC's, and CO_2 (from land conversion) -- global exogenous

Emis. to conc. change: three models used for CO_2:

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)

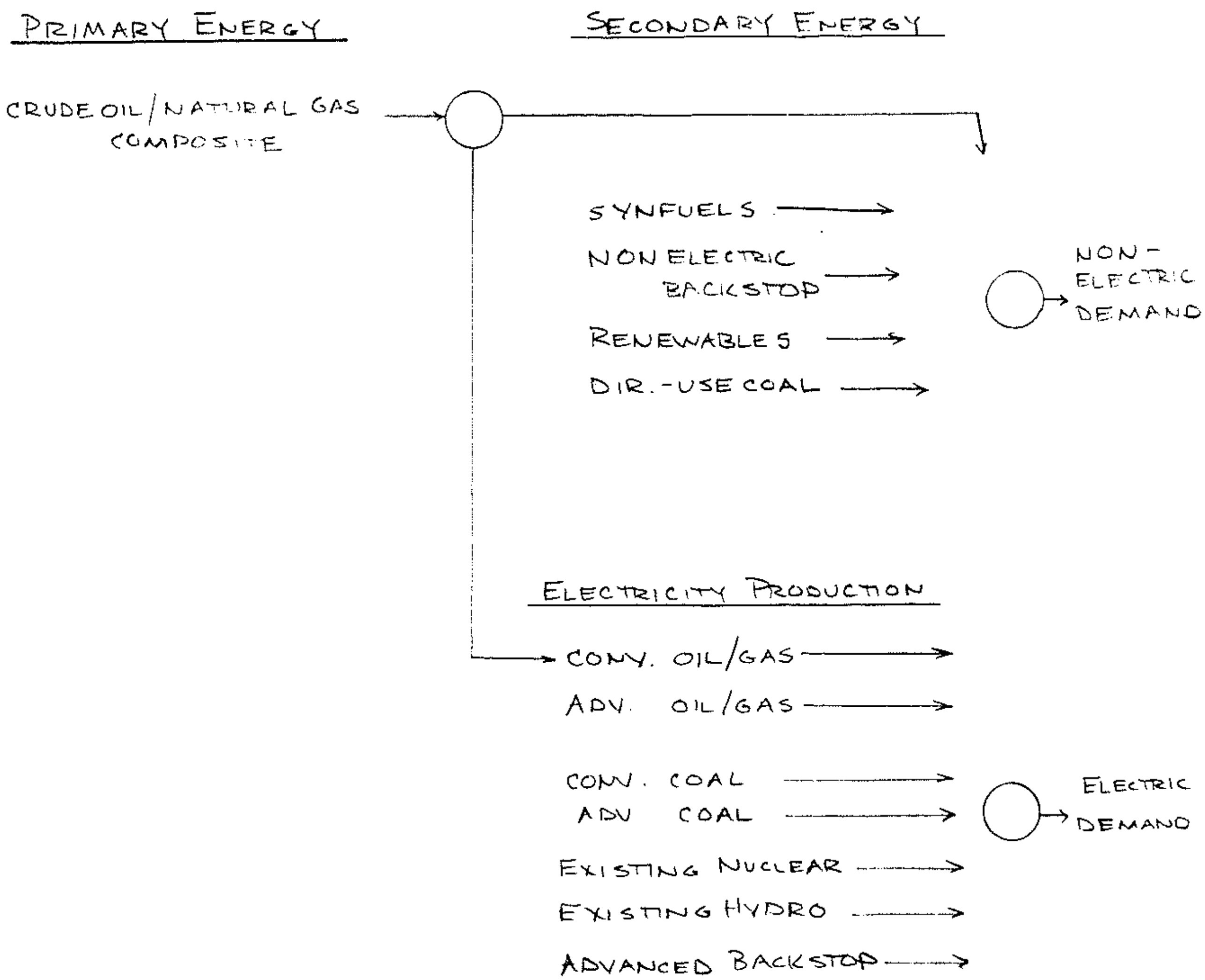
$D_R(t) = \gamma \mu\ \Delta T(t)^{\lambda} + (1 - \mu)\ D_R(t - 1)$

where $\lambda = 4$, $\mu = .1$, $\gamma = 4\%$ GWP at .2 degrees C/decade

(results in geometrically-declining weights on past rates of temp change)

CETA Energy Supply Network

◯ = MARKET



CRTM - Rutherford

I) GENERAL

Type:	recursive global general equilibrium
Perfect foresight:	no (recursive)
Time horizon/periods	2100 x 10
Data time frame/b.m.:	parameterized
Documentation used:	8/91: "The Welfare Effects of Fossil Carbon Restrictions: Results from a Recursively-dynamic Trade Model"

II) FOCUS

CRTM focuses on the economic effects of limits on carbon emissions, particularly the "carbon leakage" through international trade in nonenergy carbon-intensive goods. The model features five global regions, two non-energy goods, as well as the primary inputs of capital, labor, and non-electric and nonelectric energy. One of the nonenergy goods is basic intermediate materials, which is carbon intensive. The energy supply possibilities are varied and include both carbon and noncarbon sources. Carbon constraints are applied on a regional or international basis. The model does not include any benefits of reductions.

III) DEMAND

Regional aggregation: USA, O-OECD, USSR, China, ROW

Sectoral aggregation: basic materials, aggregate output, and energy supply sectors

Consumer behavior: production is modeled as putty-clay, i.e., there are no ex post substitution possilbilities; substitution only in current vintage's mix of inputs, which are based on current prices only; new vintage capital supply in each region determined by

$$K(t) = s\,D(t-1)$$

where D(t) is aggregate demand (investment plus savings, see below) in previous period, s is steady state savings rate

$$s = k(\gamma + \delta)$$

where k is capital/GDP ratio, γ is exogenous growth rate and δ is exogenous depreciation rate

- aggregate output produced with nested CES with composite energy, basic materials, and value-added aggregate inputs.
- value-added aggregate is Cobb-Douglas in capital and labor.
- energy composite is Cobb-Douglas in electric and nonelectric.

basic materials is Cobb-Douglas in primary energy and "other" composite, which in turn is CES in aggregate output and composite energy.

- aggregate output good, basic intermediate materials good, and crude oil are internationally traded; regional markets exist for capital, labor, primary energy (oil and gas) and secondary energy (electric and nonelectric)
- aggregate output divided between consumption, investment, net exports, and energy and materials costs

Other exogenous inputs: -

Energy/macro. link: static global general equilibrium

Price elasticities: substitution elasticities unity in Cobb-Douglas, sector/region specific in CES production functions

Other EEI: none

Energy-using capital: putty-clay representation, so "old" vintages immobile

Explicit conserv. tech.: -

IV) SUPPLY

Choice of supply mix: equilibrium result of cost-minimizing agents

Energy imports/exports: endogenous, according to ROW (OPEC) price setting

International oil price: ROW (OPEC) modeled as price setter, reducing exports to maintain target price when possible

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 be deferred; when hi-cost reserves first are exploited is endogenously determined, but production profile is fixed thereafter, and follows double exponential profile;
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

natural gas

available 2000 with cost and heat rate parameters
capacity .2 TKWH in 2000 to 1000 after for all regions
max intro rate 15% exceeded at quadratically-incr. MC

advanced low-cost (Carbon free)

advanced high-cost (Carbon free)

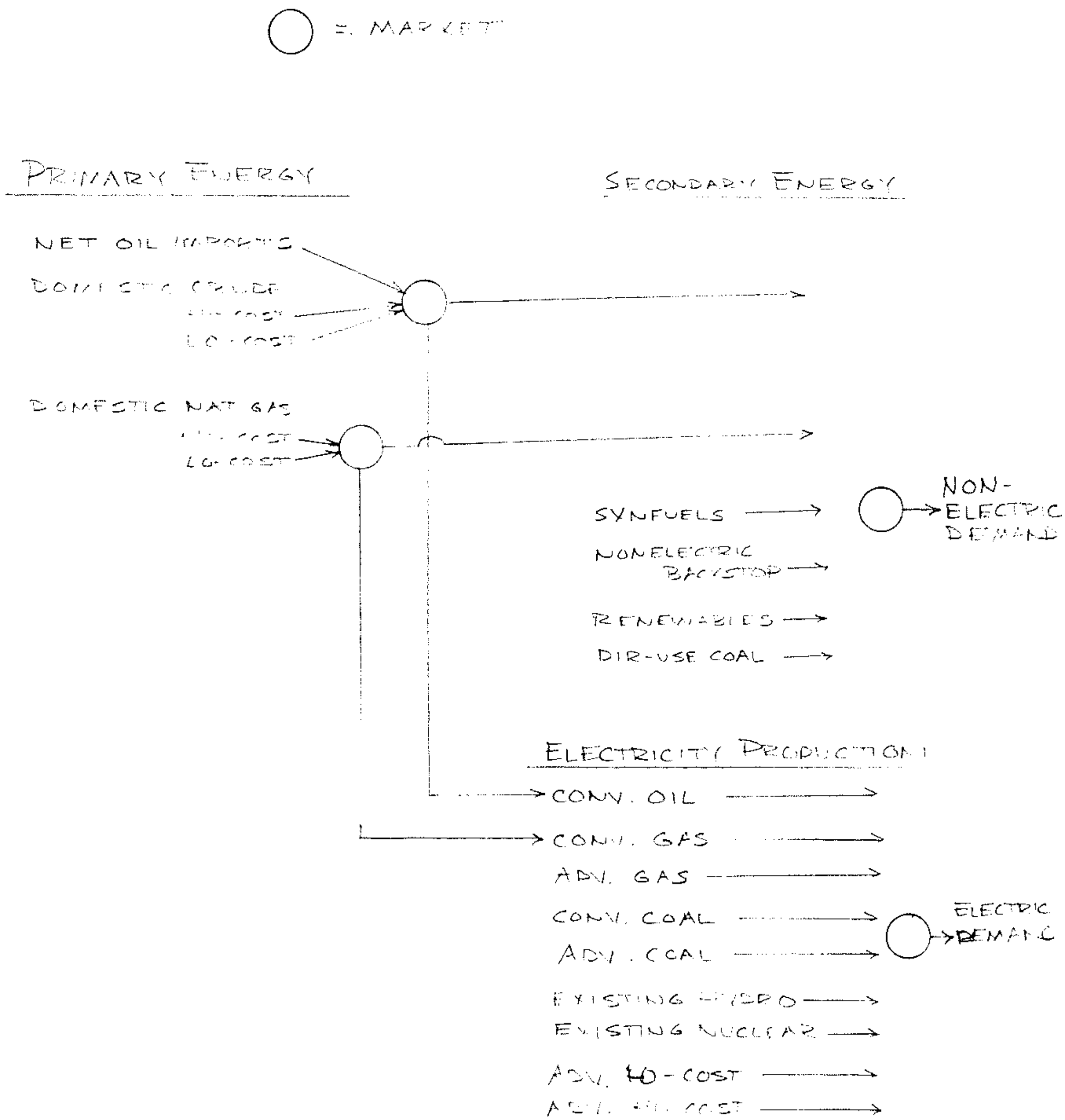
available 2010 with cost and heat rate parameters
capacities .1 TKWH or .2 (OOECD adv. lo-cost) in 2010, 100 therafter for all rwgions
max intro rate 15% exceeded at quadratically-incr. MC

Supply tech. change: none

IV) ENVIRONMENTAL

Emissions: energy sector CO_2 via fuel coefficients -- regional energy sectors
Deferral of emissions not allowed

CRTM ENERGY SUPPLY NETWORK



DGEM - Jorgensen/Wilcoxen

I) GENERAL

Type:	intertemporal general equilibrium of US with aggregate 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, and US Economic Growth" 7/89: "Environmental Regulation and US Economic Growth" 1/90: "Productivity Trends and the Cost of Reducing CO2 Emissions"

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 carbon-tax revenue recycling schemes. It can not do energy 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. Capital is perfectly mobile in each time period, although the rate of investment is endogenous. Energy resources are in effect inexhaustible, and no depletion effects are included in the cost function. No carbon-based synfuels and no carbon-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) nonhomothetic translog cost function

$$\ln C = \alpha_0 + \alpha^T \mathbf{P} + (0.5)\mathbf{P}^T \mathbf{B} \mathbf{P} + \gamma g(t) + (0.5)\delta g(t)^2 + \varepsilon^T \mathbf{P} g(t)$$

where $\mathbf{P}^T = [\ln p_1 \ \ln p_2 \ldots \ln p_n]$

$\mathbf{B} = \mathbf{B}^T = [\beta_1 \ \beta_2 \ldots \beta_n]$

(locally concave over historical period's prices)

$\alpha^T \mathbf{1} = 1$to preserve share sum to unity

$\mathbf{B1} = \mathbf{0}$, $\varepsilon^T \mathbf{1} = 0$ for HD 1 in prices

$g(t) = A/(1 + \exp(-\mu(t-\tau)))$,

where A, μ, τ are estimated parameters in logistic technical change function (see below)

thus cost shares are

$$\mathbf{w}^T = \mathbf{a}^T + \mathbf{P}^T\mathbf{B} + \varepsilon^T g(t)$$

(with $\mathbf{B} = \mathbf{0}$, $\varepsilon^T = \mathbf{0}$, homotheticity and no factor bias, respectively, but generally not)

consumers: nonhomothetic translog utility functions (similar to above), 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; nonhomotheticity allows for income effects, and also there are logistic non-price driven shifts in expenditure shares (see below)

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

Energy/macro. link: intertemporal general equilibrium

Price elasticities: **B** gives share elasticities, excluding technical change (see below)

Other EEI: rate of factor use per unit output endogenous: consumption driven shifts independent of prices through non-homotheticity and expenditure share shifts over time; in industry, with price changes set to zero, and primes denoting time derivitives, for j = 1, 2, . . ., n:

$$w_j' = \varepsilon_j g(t)'$$

with total factor productivity being

$$(\ln C)' = [\gamma + \delta g(t) + \varepsilon^T \mathbf{P}]g(t)'$$

first term is Hick's-neutral technical change, second reflects increasing/decreasing rate of technical change over time (due to logistic function), and third term reflects that as factors with high rates of productivity improvement go up/down in price, overall cost reduction will slow/accelerate due to substitution away/towards that factor; these drive autonomous sector shift as well; note that $g(t)'$ goes to zero near end of model horizon

- this model assumes that whatever mechanism is driving productivity improvements (economic maturation, R and D) continues into the future, and that industry-specific rates of technical change may vary significantly from aggregate rate

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 fixed price

International oil price: exogenous

Primary fossil energy: oil/gas aggregate, coal

modeled as other sectors, so implicitly inexhaustible and stock depletion does not affect cost of extraction

Primary nonfossil energy: none included in model

Secondary liquids: refined crude

CRTS translog factor demands; costs endogenous

productivity modelled as above

capacity endogenous, with perfectly mobile capital stock

Secondary solids: coal

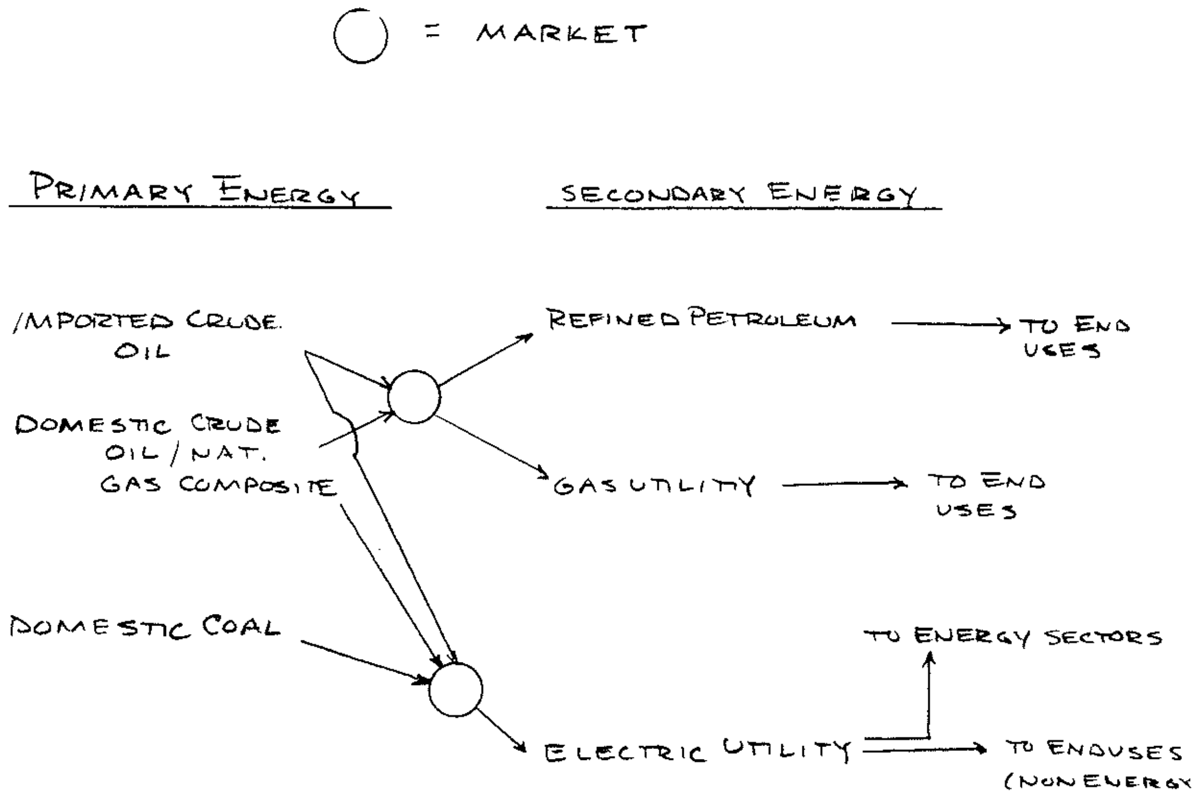
can be demanded as input to production functions

Secondary gasses:	gas utility sector CRTS translog factor demands; costs endogenous productivity modelled as above capacity endogenous, with perfectly mobile capital stock
Conventional electricity:	electric utility sector CRTS translog factor demands; costs endogenous productivity modelled as above 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 deferral of not allowed

DGEM ENERGY SUPPLY NETWORK



Energy Demand System (EDS) - IEA

I) GENERAL

Type:	recursive generalized equilibrium of global fuel markets
Perfect foresight:	no (recursive)
Time horizon/periods:	2005 x 1
Data time frame/bm:	most parameters econometrically-estimated, 1965 - 1989
Documentation used:	3/91: completed questionnaire 12/91: "Model Structure and Key Assumptions"

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. Several adjustment parameters supplement the historically-based regressions, but the detailed econometric model allows examination of the transition period, from 1990 to 2005, for coping with carbon limits. There are quite detailed representations of energy markets in OECD regions. and there are no macroeconomic feedbacks from energy price changes.

III) DEMAND

Regional aggregation:	North America, Europe, OECD Pacific, USSR, Eastern Europe, China, Africa, Asia, Latin America, Middle East
Sectoral aggregation:	industrial other industrial coke (coal only) transportation commercial/residential
Consumer behavior:	exogenous asumptions on GDP and polpulation converted into activity variables, which, along with equilibrium prices and various exogenous technical data determine final end-user fuel demands
Other exogenous inputs:	GDP, population, and various technical inputs such as structure and conversion efficiencies in electricity sector, and heating days, for example
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; sensitive to both own price (separate upward and downward price elasticities), and substitute fuel price
Other EEI:	specific to demand category: time trend with estimated coefficient, or exogenously-specified parameters to capture technical change or consumption pattern shifts (such as cars per household or miles driven) not captured by historical trends
Energy-using capital:	-
Explicit conserv. tech:	-

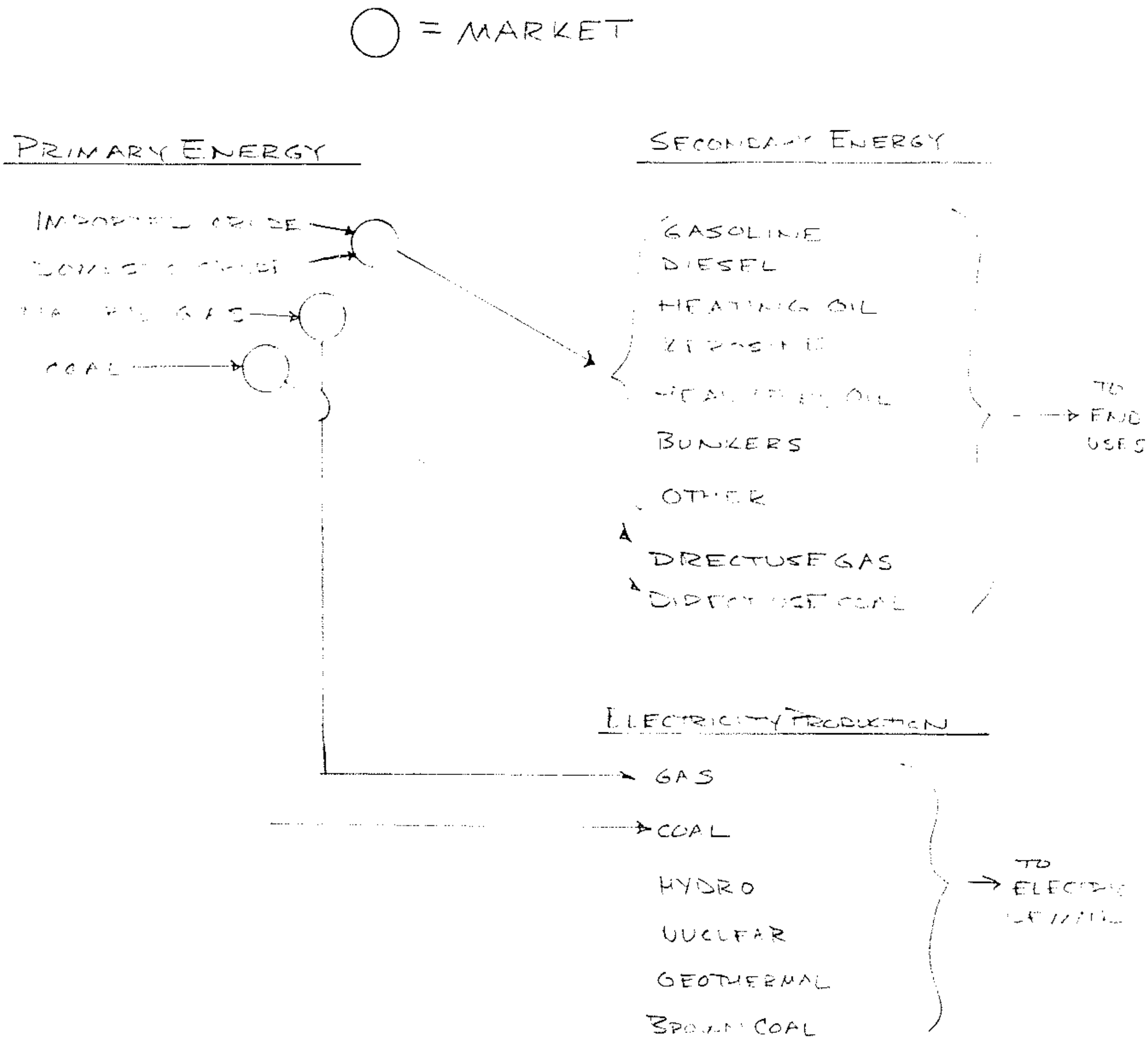
IV) SUPPLY

Choice of supply mix:	energy market equilibrium; interfual competition determined by relative fuel and capital costs China specified exogenously
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:	oil, natural gas, coal price sensitive, given assumptions about discovery rates, reserves, and other relevant data
Primary nonfossil energy:	none explicit
Secondary liquids:	gasoline diesel heating oil kerosine heavy fuel oil bunkers other
Secondary gasses:	direct-use gas
Secondary solids:	direct-use coal
Conventional electricity:	nuclear hydroelectric geothermal brown coal levels set exogenously, reduce demand directly gas coal fuel and capital costs exogenously-specified increasing conversion efficiency
Advaned electricity:	none explicit

V) ENVIRONMENTAL

Emissions:	CO_2 via coefficients for coal, crude oil, natural gas no defferal of emissions rights allowed

EDS ENERGY SUPPLY NETWORK



ERM - Edmonds/Reilly

I) GENERAL

Type:	recursive 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 logit market share algorithms
Documentation used:	85: "Global Energy: Assessing the Future" 5/90: "Estimating the MC of reducing Global Fossil Fuel CO2 Emissions" 3/91: "ERM Contributions to OECD CO2 Modelling Program" 11/91: technical appendix with model revisions

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 twelve world regions. Demands are price and income elastic, but do not explicitly model consumer technology/fuel choice, as the fuel shares in the various markets are determined by logit fuel share algorithms.

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: residential/commercial, transport, industry

Consumer behavior: end-use energy services demand for each sector/region based on GNP and population levels, and are both "cost" and income elastic (see below); the fuel mix meeting the adjusted end-use demand is determined by a logit market share algorithm which is based on the benchmark year's market shares and the current year's relative prices

Exogenous inputs: -

Energy/macro. link: *reference* GNP is determined from the previous period's *actual* GNP and the exogenous fixed GNP growth rates; in turn, this reference GNP -- and hence income -- is modified by regional GNP feedback elasticity related to own region's contemporaneous total cost of energy services, C,

$$GNP_{actual} = (GNP_{reference})\, C^{\varepsilon}$$

Price elasticities: end-use service demand has region- and sector-specific cost and income elasticities for end-use service demands; 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 as determined by prices and fuel share mix resulting from Logit share algorithm, I is a per capita GNP index (using adjusted GNP_{actual} from above), and P is a population index; for industry demand

$$d = C^a \, I^b \, GNP_{actual}$$

Other EEI:	to reflect technical advance and sector shift, a region- and sector-specific demand-side energy intensity 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 for a given fuel, 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 refined secondary energy with Leontieff technolocy (linear cost function in energy and levelized nonenergy 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:	liquids (conv and syn oil perfect subst), gasses (conv and syngas perfect subst), solids (coal and biomass perfect subst); no limits in EMF runs
International oil price:	endogenous for all traded fuel forms, regional price differentials include effect of transportation costs
Primary fossil energy:	conventional crude oil, natural gas, and coal, and unconventional oil each regions total resource base divided into five grades, with minimum and maximum "technical" extraction costs for each type; unit cost of extraction increases linearly with total depletion in each grade; result is piecewise linear, continuous, and increasing supply function in cumulative (all gardes) depletion; the actual extraction costs equals the "technical" plus the "environmental" (nongreenhouse-related) costs (in any), divided by a technical change index which reduces costs over time; annual production found by setting regional price equal to marginal actual cost of *cumulative* supply, and subtracting previous period's cumulative supply, *thus price must increase over time*; supply can expand at the maximum at the rate of GDP growth (exogenous) without constraint, and at higher rates constrained by $$q(t) = q(t-1)\ [Y(t)/Y(t-1)]\ [p(t)/p(t-1)]^r$$
Primary non-fossil energy:	nuclear

similar to above, except depletion dependent on endogenous determination of nuclear capacity installed, which in turn depends on total costs of production, including uranium costs

solar

treated as backstop technology, with price declining logistically over time to represent technical change

biomass - urban and ag waste

five grades of biomass in overall resource base determined by GDP level; upward sloping total supply curve results from specified supply curves for each grade

biomass - plantation

resource base specified exogenously, with production set at 80% of maximum

Secondary - all:

solids liquefaction - prerefined product
solids gassification - prerefined product
solid refining
gas refining
liquids refining

costs linear (Leontieff technology) with fuel and levelized nonenergy costs, included scale factor on fuel cost to reflect price/avg cost differential
no additional supply-side technical progress assumed
no capacity limits

Conventional electricity:

liquids
gasses
solids
solar
nuclear

costs linear (Leontieff technology) with fuel and levelized nonenergy costs
no additional supply-side technical progress assumed
capacity endogenous

hydro (includes wind and geothermal)

production exogenous through logistic equation

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

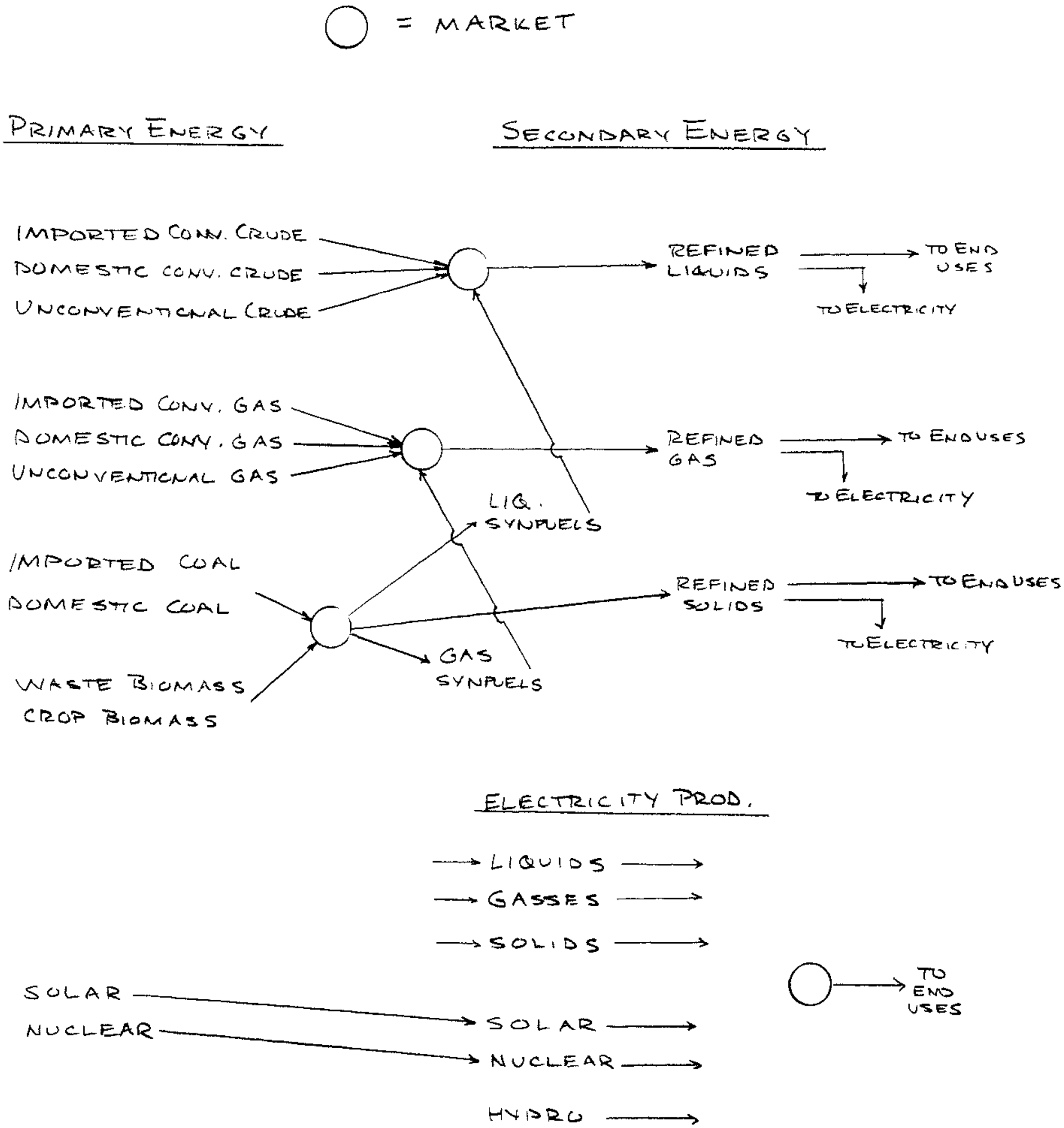
$$a = a_1^{(1-t/T)} a_2^{(t/T)}$$

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

V) ENVIRONMENTAL

Emissions: CO_2, CH_4, N_2O via coefficient, less allowance for feedstocks -- each region's energy sector, including carbonate rock mining (shale)
deferral not allowed

ERM ENERGY SUPPLY SECTOR



FOSSIL2 - AES

I) GENERAL

Type:	recursive generalized equilibrium (US energy markets)
Perfect foresight:	no (except some use simple extrapolation)
Time horizon/periods:	2030 x 1
Data time frame/bm:	parameterized
Documentation used:	7/90: "Overview of Fossil 2" 11/91: completed model questionnaire

II) FOCUS

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

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; disposable income to GNP elasticity is .8; each subsector minimizes energy service cost by choosing combination of fuels and end-use/conservation technologies to meet that demand ("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 nonprice-driven energy efficiency improvements; transportation sector inputs from other models: baseline service demands, efficiencies, and vehicle stocks, etc.
Energy/macro. link:	feedback to GNP affects baseline end-use demand paths: elasticity of the ratio of weighted average current fuel price to weighted average 1950 fuel price to GNP is -.12. GNP then affects housing stocks (0.05), comm floor space (.8), industrial production index (1.4), and transportation stocks (.5 for LDV's and .8 others)

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, with multipliers typically between .8 and 1.25.; also long-term (lagged) price response in transportation sector adjusts efficiency levels if prices deviate from reference price inputs, with elasticity of .2
Other EEI:	industrial sector energy intensity changes over time to reflect sector/product mix shift and process changes; explicitly-modelled efficient end-use technologies chosen either when cost-effective or through mandate
Energy-using capital:	stock vintaged because of changing efficiencies and fuel-use characteristics over time, with turnover exogenous and determined by assumed average useful lifetimes; 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; curves shift over time to reflect assumed new technologies' availability and prices in different R&D scenarios

<u>IV) SUPPLY</u>

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 in case of utilities conform to regulatory measures (utilities)
	market allocation
	    market shares determined by logit market share algorithm, transportation costs are included in final costs

Imports/exports:	maximum import capacity by source; Alaska oil/gas production/pipeline capacity minimum and maximum; natural gas (Pan-American), oil (Pan-American and OPEC), and LNG imports are assumed marginal supply
International oil price:	exogenous reference price/demand path, with price adjusted via "supply elasticity" of .25 if demand changes relative to reference case
Primary fossil energy:	conventional onshore oil and gas stripper wells Gulf of Mexico offshore oil and gas enhanced Oil Recovery (EOR) thermal EOR Alaska Oil onshore NGL's Gulf of Mexico NGL's Tar Sands onshore and Gulf of Mexico associated gas unconventional natural gas high-cost unconventional natural gas

myopic suppliers, with detailed modeling of investment and capacity utilization; also discovery/depletion treated explicitly with assumed "normal" find rate until 5% of resource remains, then multiplier goes from 1 down to 0 linearly with decrease in resource stock from 5% down to 0%; then capital cost changes as (drilling cost/ft) / (find/ft), so MC increases

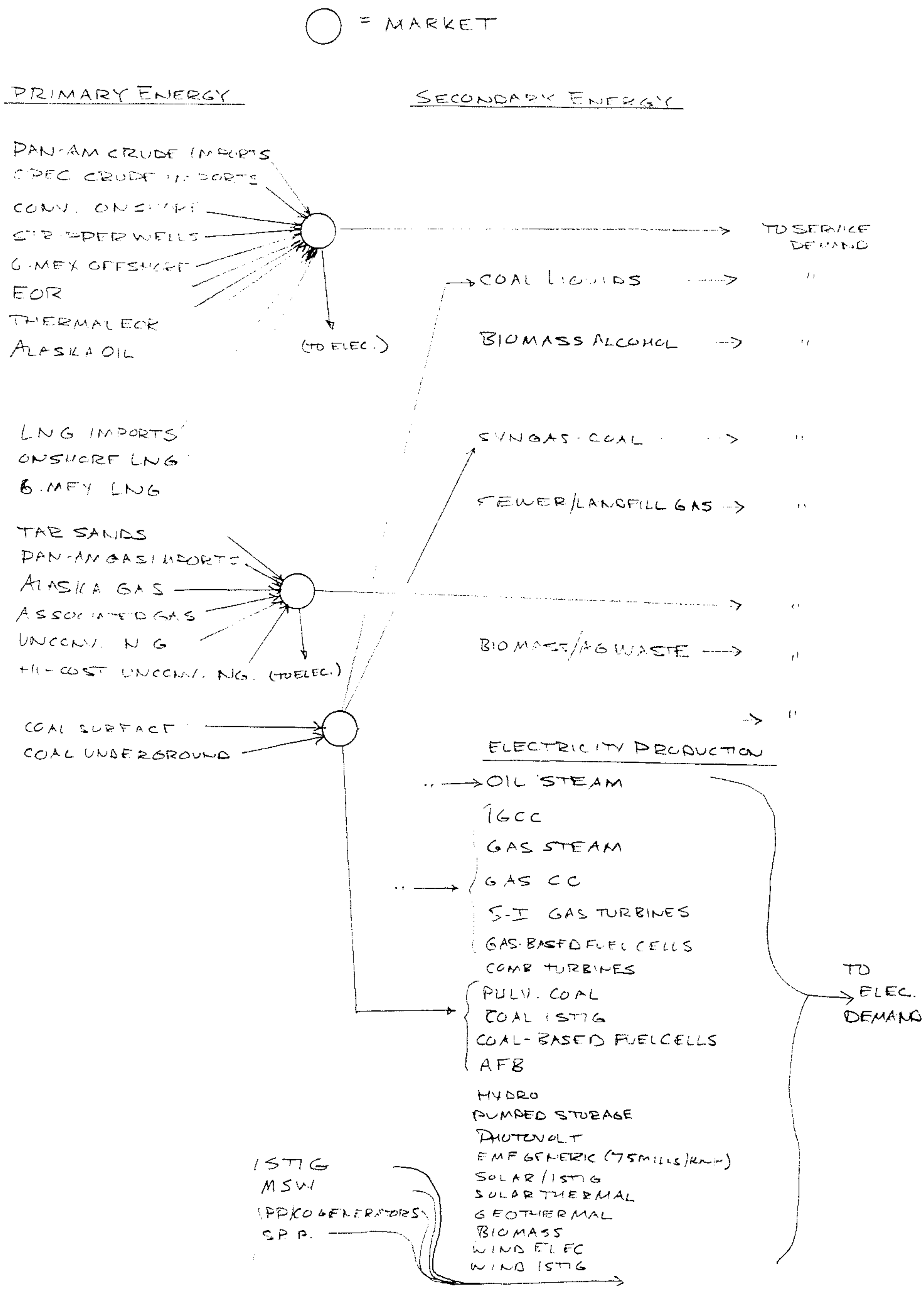
	coal surface mining
	coal underground mining detailed modeling of capacity adddition and other financial characteristics; demand forecasts are extrapolations of past demand; costs include return on equity (variable), production, and delivery charges; production costs escalate as reserves are depleted
Primary nonfossil energy:	none explicitly modeled
Secondary liquids:	coal liquids detailed modeling of investment and capacity utilization; operating parameters change over time to reflect technical change
	biomass alcohol exogenous, meets end-use demand directly
Secondary gasses:	syngas from coal detailed modeling of investment and capacity utilization; operating parameters change over time to reflect technical change
	sewer and landfil gas exogenous, meet demand directly
Secondary solids:	direct use coal detailed modeling of investment and capacity utilization; operating parameters change over time to reflect technical change
	biomass, agricultural waste exogenous, meet demand directly
Conventional electricity:	dispersed solar, wind, and photovoltaics exogenous, meet demand directly
	pumped storage
	hydroelectric exogenous production levels
	other technologies, 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; contruction lag is included; price determined from regulated cost process which determines average cost of electricity production
	pulverized coal
	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
	photovoltaics
	solar thermal
	solar/ISTIG
	geothermal
	biomass
	wind electric
	wind/ISTIG
	costs are fuel costs, OM, capital cost, and "avoided cost" payments to NUGs
	EMF generic non-carbon electric
	75 mills/kwh
NUG electricity:	municipal solid waste
	exogenous, meets demand directly
	IPP/cogenerators
	endogenous, meets industrial demand directly
	small power producers (biomass, geothermal, hydroelectric, solar thermal, wind electric)
	costs are fuel costs, OM, capital cost, and "avoided cost" payments to NUGs
Advanced electricity:	intercooled steam injected gas turbines (ISTIG)
	costs are fuel costs, OM, capital cost, and "avoided cost" payments to NUGs
Supply technology change:	operating parameters change over time to reflect technical change

V) ENVIRONMENTAL

Emissions:	CO_2 via coefficient by fuel and end-use
	CH_4 via coefficicnt for coal mining/NG distribution
	NO_x, SO_2 via coefficient by fuel and technology where appropriate
Carbon offset:	carbon offset supply function, may be purchased in lieu of carbon tax; no information of sequestration dynamics or on costs which are included in supply curve

FOSSIL2 ENERGY SUPPLY NETWORK



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.

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
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:	linear cost function (Leontieff production 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 unconventional 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* depend 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"

nuclear

- exogenous constant price supply, treated as "fuel cost"

photovoltaics

- "infinite" supply at constant price, treated as "fuel cost"

Secondary liquids: coal liquefaction

- costs endogenous, OM costs increase after 25 years
- no technical progress assumed
- 90% availability, endogenous capacity level and utilization

refined crude

- costs endogenous, OM costs increase after 25 years
- no technical progress assumed
- 90% availability, endogenous capacity level and utilization

ethanol from biomass

- (50% efficiency process!)

methanol from natural gas

- 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
- 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

- 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
costs endogenous, OM costs increase after 30 years
no technical progress assumed
80% availability, endogenous capacity level and utilization
coal
costs endogenous, OM costs increase after 40 years
technical progress assumed
71% availability, endogenous capacity level and utilization
nuclear
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
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
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
costs endogenous, OM costs increase after 30 years
technical progress assumed
80% availability, endogenous capacity level and utilization
solar
available 2000, costs more before
costs endogenous, OM costs increase after 30 years
technical progress assumed
30% availability, endogenous capacity level and utilization
wind
costs endogenous, OM costs increase after 20 years
technical progress assumed
30% availability, endogenous capacity level and utilization
photovoltaics
available 2000, costs more before
costs endogenous, OM costs increase after 30 years
technical progress assumed
30% availability, endogenous capacity level and utilization
geothermal
costs endogenous, OM costs increase after 30 years
technical progress assumed
80% availability, endogenous capacity level and utilization

Supply tech. change:

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
	not deferrable, no foresight on level of C-rights	

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

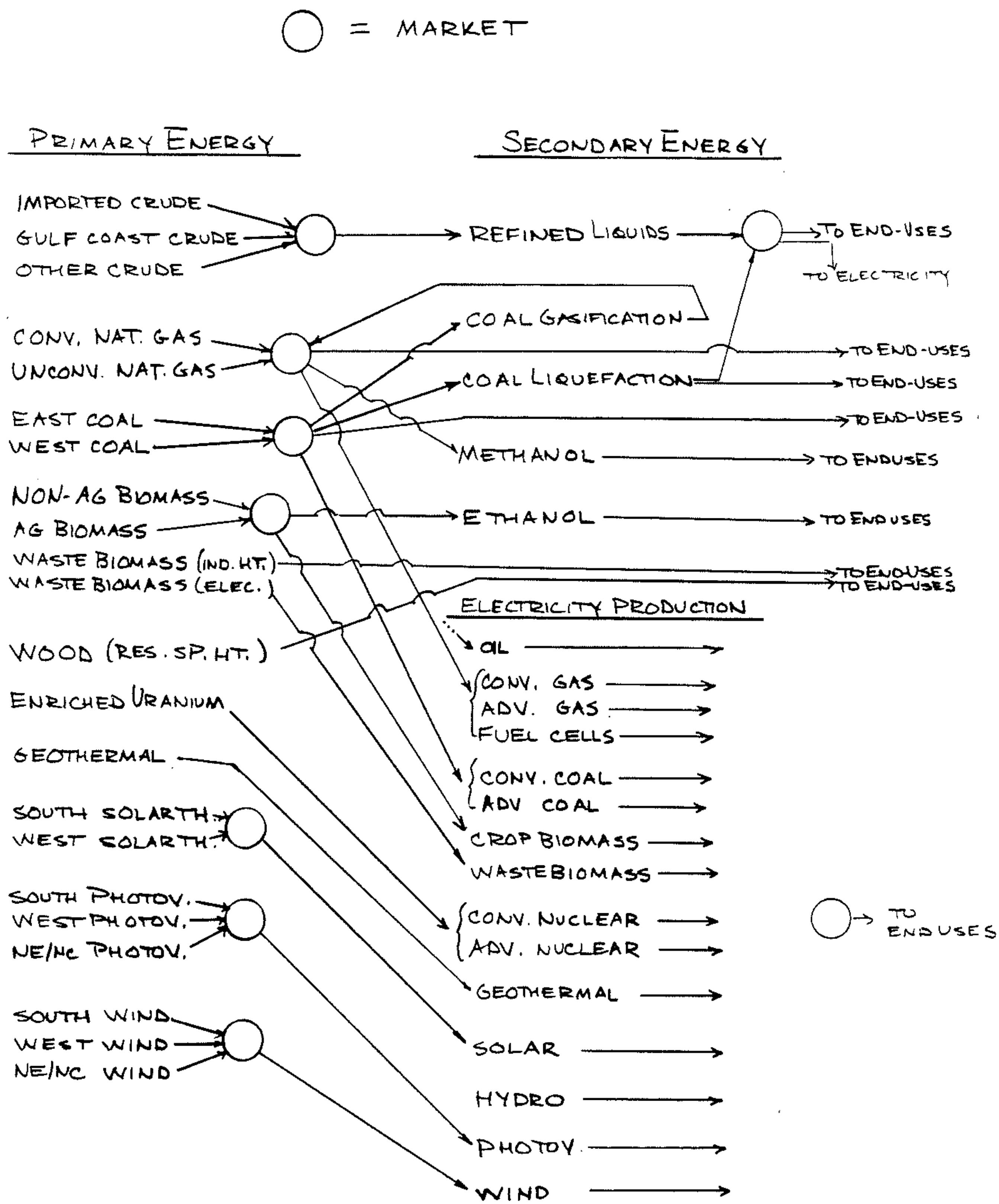
potential temp change:

$$\Delta P(t) = \alpha \, \Delta RF(t)$$

actual temp change, by gas:
lagged -- see GEMINI documentation

Concentration feedbacks: CO_2 on agricultural productivity is possible

GEMINI ENERGY SUPPLY NETWORK



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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

GLOBAL 2100 - Manne/Richels

I) GENERAL

Type:	parallel intertemporal nonlinear optimizations
Perfect foresight:	yes
Time horizon/periods:	2100 x 10
Data time frame/bm:	1990 benchmark, parameterized
Documentation used:	8/91: "Buying Greenhouse Insurance - the Economic Costs of CO2 Emission Limits"

II) FOCUS

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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

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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
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 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 for a given vintage of productive inputs (does not change after installed): $$\text{actual supply} = \text{service demand} \prod_{\tau=0}^{t-1} (1-eei_{\tau})^{10}$$ 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.:	-

<u>IV) SUPPLY</u>

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; oil exports from USSR and CHINA have small upper bounds to 2030 of 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 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

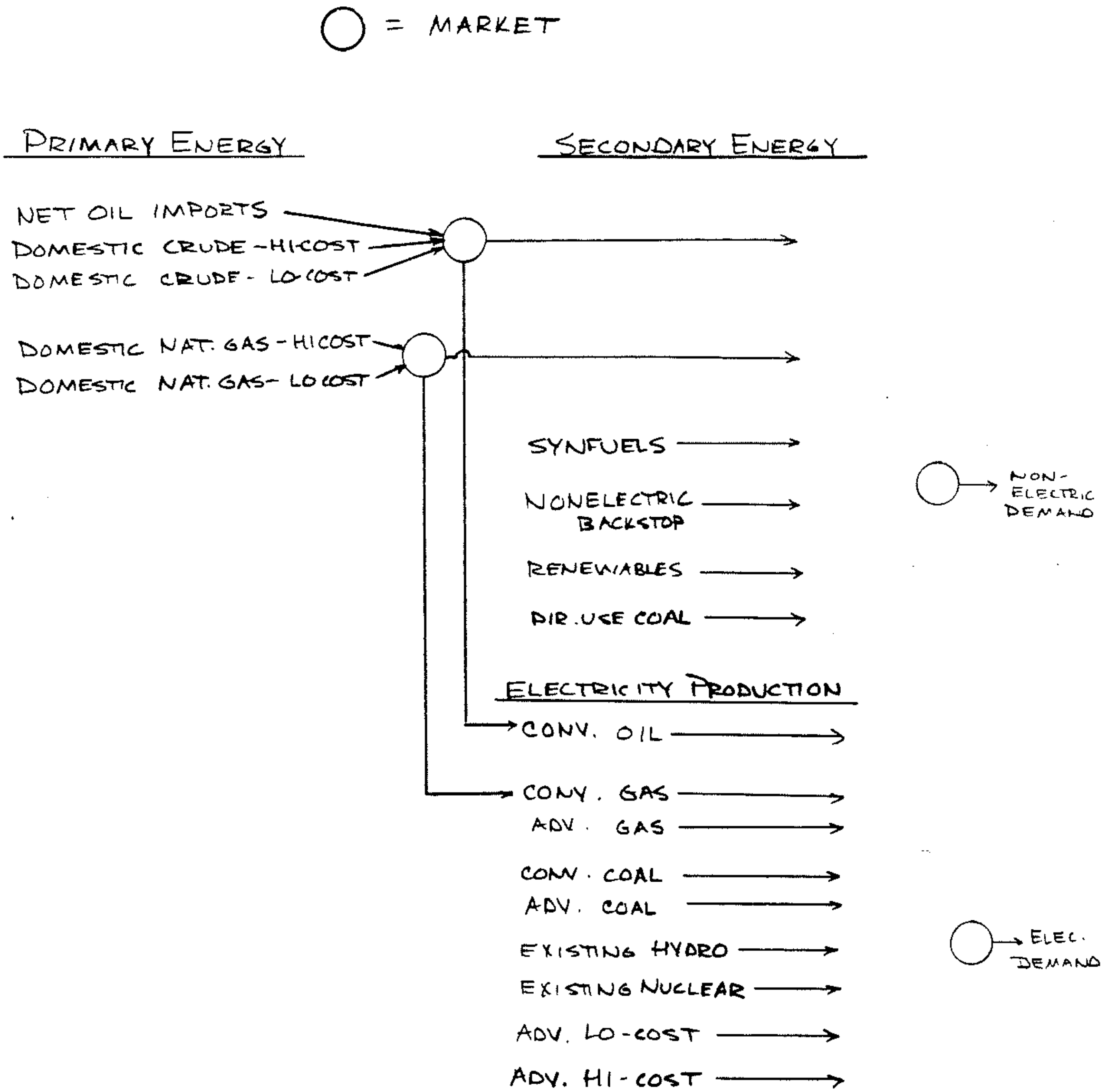
Advanced electric:
- coal
  - available 2000 with cost and heat rate parameters
  - usage decline rate bounded at 95%
- natural gas
  - available 2000 with cost and heat rate parameters
  - capacity .2 TKWH in 2000 to 1000 after for all regions
  - usage decline rate bounded at 95%, can be exceeded at quadratically-increasing MC
- advanced low-cost (Carbon free)
- advanced high-cost (Carbon free)
  - 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 -- each region's energy sector limited advancement or deferal of exercise of rights allowed

GLOBAL 2100 ENERGY SUPPLY NETWORK



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 Macro-Energy - ICF

I) GENERAL

Type:	recursive generalized equilibrium of global energy markets
Perfect foresight:	no (recursive)
Time horizon/periods:	1985 - 2100, x 5 to 2025 and x 25 to 2100
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.

Energy/macro. link: -

Price elasticities: see above

Other EEI: 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 are calibrated off of other detailed end-use models

Explicit conserv. tech.: -

IV) SUPPLY

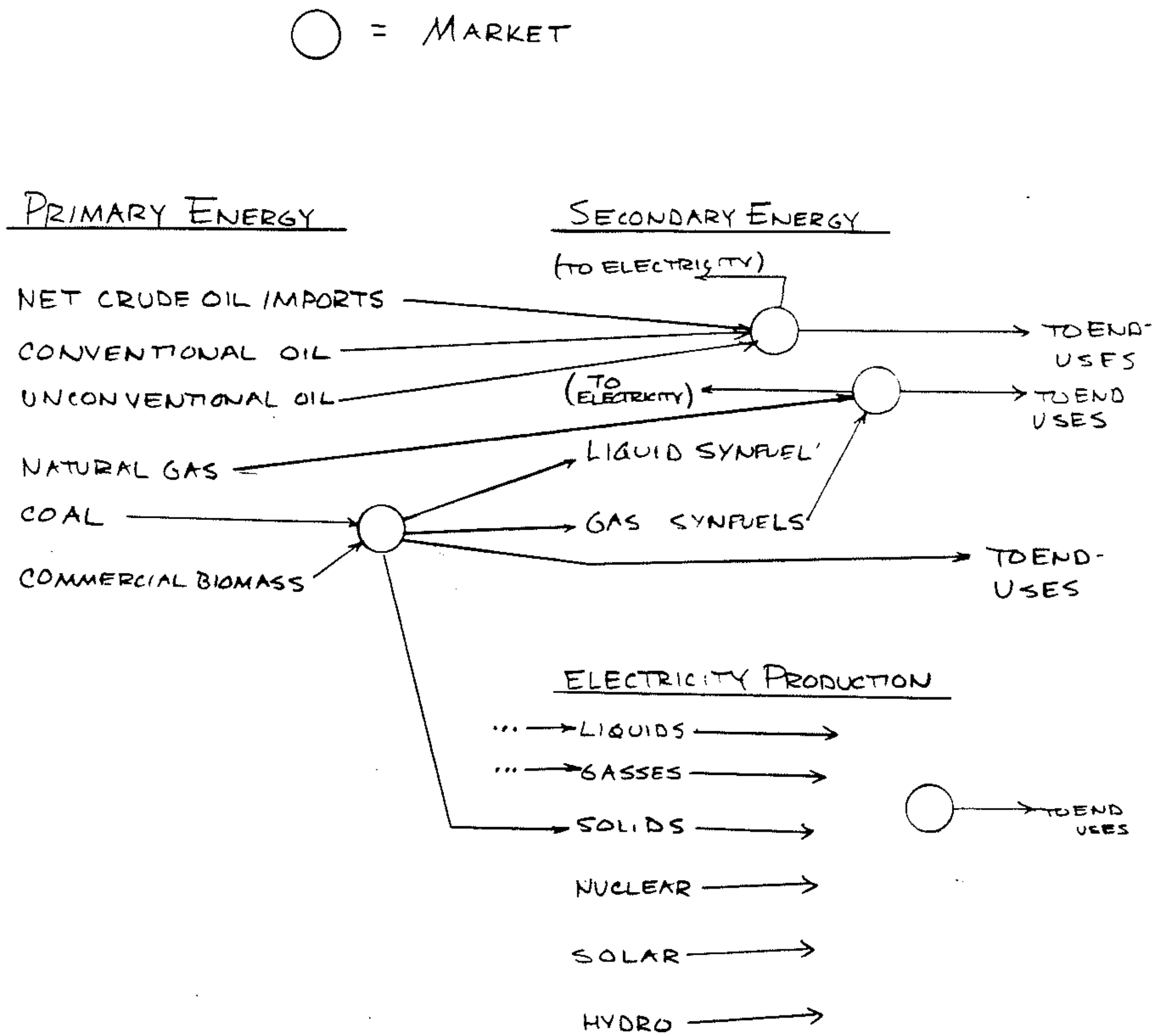
Choice of supply mix:	global energy market equilibrium: regional process-network representation of energy supply: primary resources, transmission, refining, distribution, conversion, and global market allocation with regional price differences to reflect transport, taxes, etc. primary resources see below 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 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 and other secondary energy forms: share = $((\text{cost of production for given process}) / (\text{cost of coal or biomas feedstock}))^{\beta}$ 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: approx \$45/BBL equiv up to \$100/BBL equiv at 275 EXAJ
Secondary liquids:	synliquids from coal synliquids from biomass costs are non-fuel costs plus fuel costs divided by efficiency

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 nuclear generation costs; political factors can be included by adjusting fuel share weights solar exogenous cost parameter, plus costs for backup and storage costs decline over time to reflect technological progress hydro production is logistic function of time times fraction of technically feasible resources that will ultimately be produced; used to meet demand directly
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 over fixed useful life; new capacity meets excess demand over existing capacity; new capacity has new operating parameters and costs which are exogenously specified

V) ENVIRONMENTAL

Emissions:	CO_2, N_2O, CH_4, CO, NxO via fuel/technology coefficients -- each region and sector no deferal or advancement allowed

GLOBAL MACRO ENERGY SUPPLY NETWORK



?

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 nuclear 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

no different.

GOULDER - Goulder

I) GENERAL

Type:	intertemporal general equilibrium of U.S. economy
Perfect foresight:	yes
Time horizon/periods:	2030 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

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

where G is Cobb-Douglas in 17 specific consumption goods; the aggregate time endowment in efficiency units is exogenous and grows at $g = 2\%$, which accounts for population growth and labor augmenting technical change; 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 imperfect 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

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: only labor-augmenting technical change; sum of it and population growth rate is 2%

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; adjustment cost function per unit investment is convex in I/K and has the form

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

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,

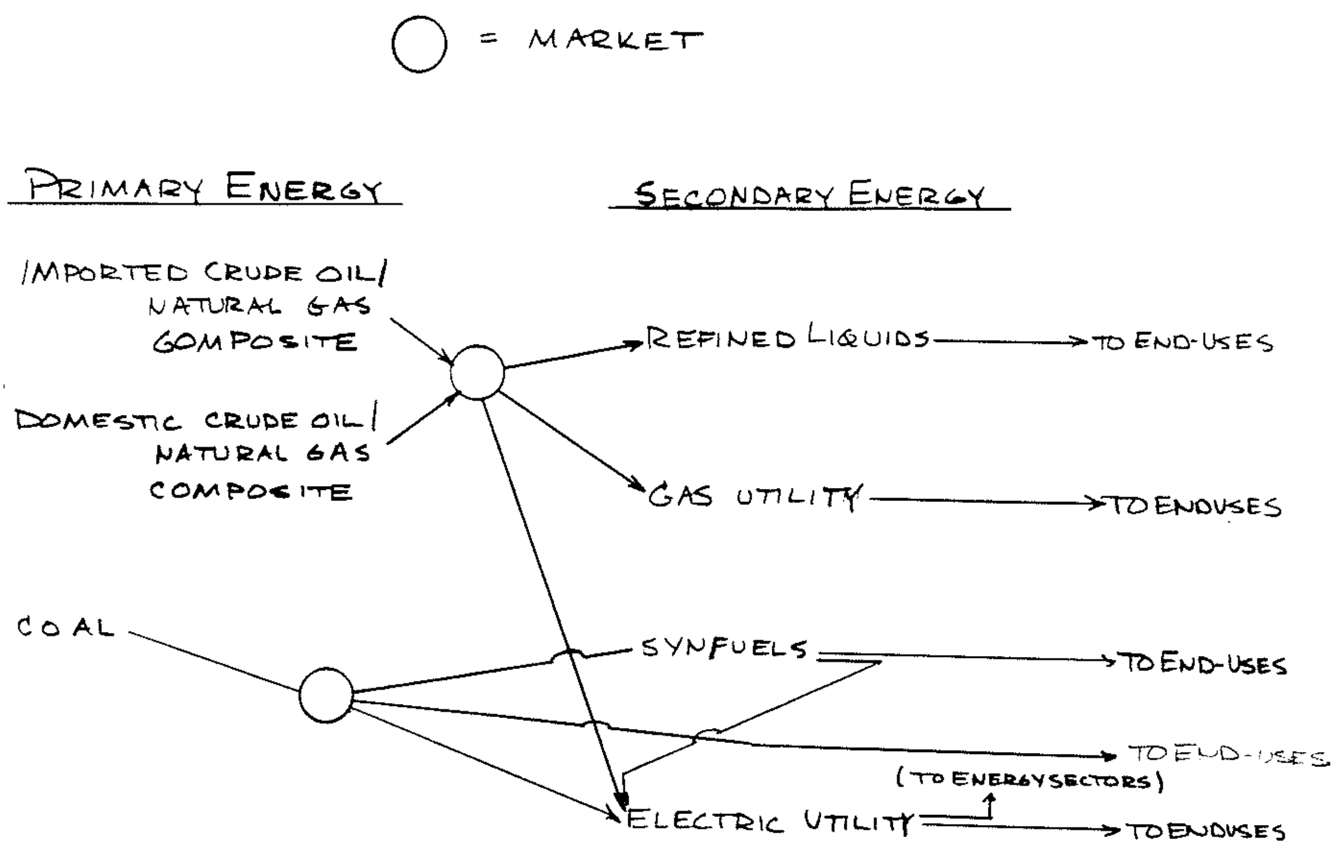
$$\gamma(Z) = \gamma_0 - (Z/Z^*)^2$$

	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:	CO_2 via coefficients for coal, crude oil/gas aggregate, with weights for aggregate coming from benchmark year and assumed constant -- US total emissions
	no deferral of emissions allowed

GOULDER ENERGY SUPPLY NETWORK



GREEN - OECD

I) GENERAL

Type:	recursive global general equilibrium
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: "GREEN: 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: USA, EC, Japan, O-OECD, USSR, China, Energy-exporting LDC's, India, 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-clay specification;

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,which is the fixed factor in agriculture sector; GDP rates and rates of technical progress calibrate model dynamics
Energy/macro link:	general equilibrium
Price elasticities:	parameters in CES production functions; Leontief inelastic
Other EEI:	energy-bundle augmenting technical progress at .5%/year which, along with assumed GDP growth rates, imply rates of technical progress for capital/fixed factor bundle, as well as labor; no autonomous sector shift between energy-intensive and non-energy intensive industries, but product shift within sectors is included in EEI parameter
Capital stock:	putty-clay specification, 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 given the supply elasticity, disinvestment occurs when demand for capital is less than depreciated old capital; net investment can come from "old" or "new" capital 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

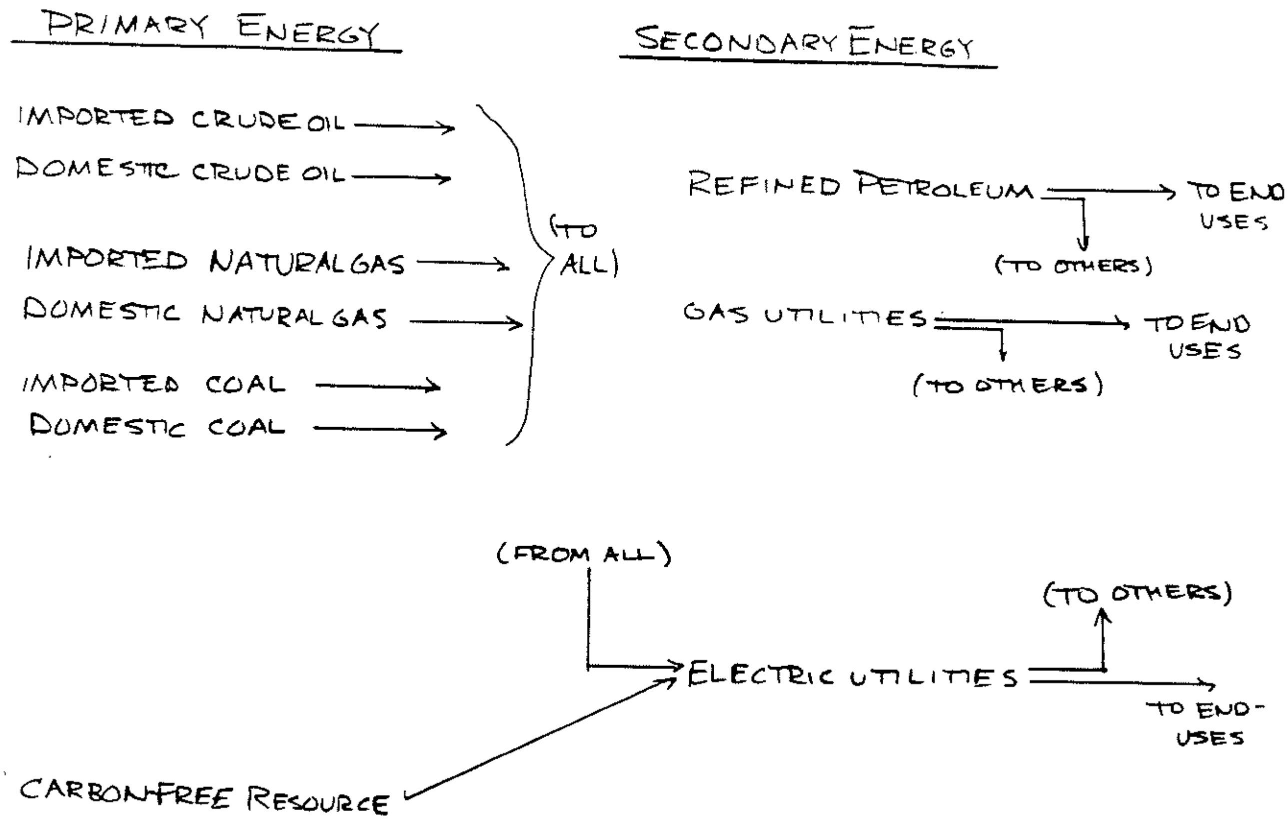
	production fixed ratio of proven reserves
	reserve additions are ratio of remaining undiscovered resources, which is price-sensitive through constant elasticity parameter
	coal
	production Leontief as above, where fixed factor is coal
	constant elsticity of supply, finite but large
Primary nonfossil energy:	carbon-free resource
	constant elasticity of supply = .2
	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

V) ENVIRONMENTAL

Emissions:	Carbon via coefficients -- each global region
	no deferral allowed

GREEN ENERGY SUPPLY SECTOR

○ = MARKET



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

• Z suppl. limits

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

no depend.

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: Trace Gas Accounting System"

II) FOCUS

Model is intended to provide short-term 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 policy scenarios, 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
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, intended to capture technical change, sector shift, and economic maturation
Energy-using capital:	-
Explicit conserv. tech.:	-

IV) SUPPLY

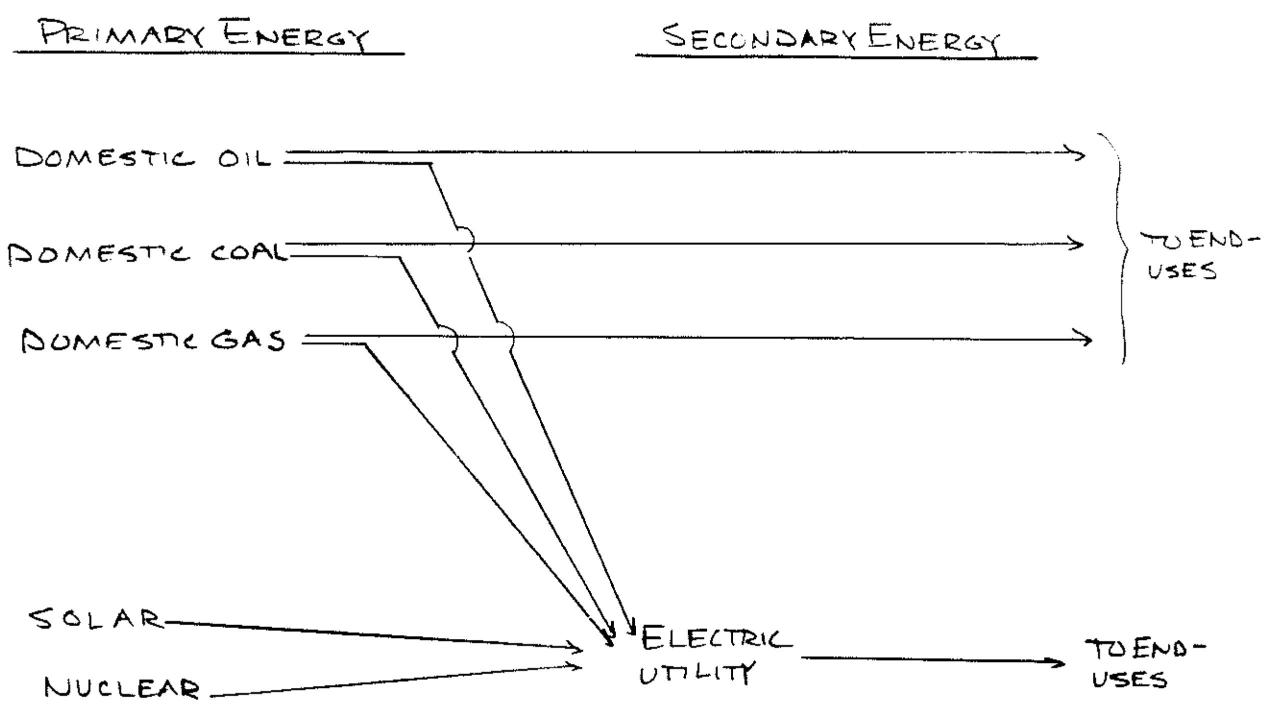
Choice of supply mix:	electricity demand and direct-use fossil fuels demand endogenous; derived primary fossil and nonfossil demand from electricity production based on exogenous country-specific fuel mix and

	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 (fixed) and direct demand own-use and distribution losses implicit in model
Primary nonfossil energy:	nuclear solar supply derived from electric sector parameters (fixed)
Secondary - all:	none explicit
Conventional electric:	public utilities sector fuel use determined by exogenous fixed parameters reflecting fuel mix and conversion efficiency charactereistics
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

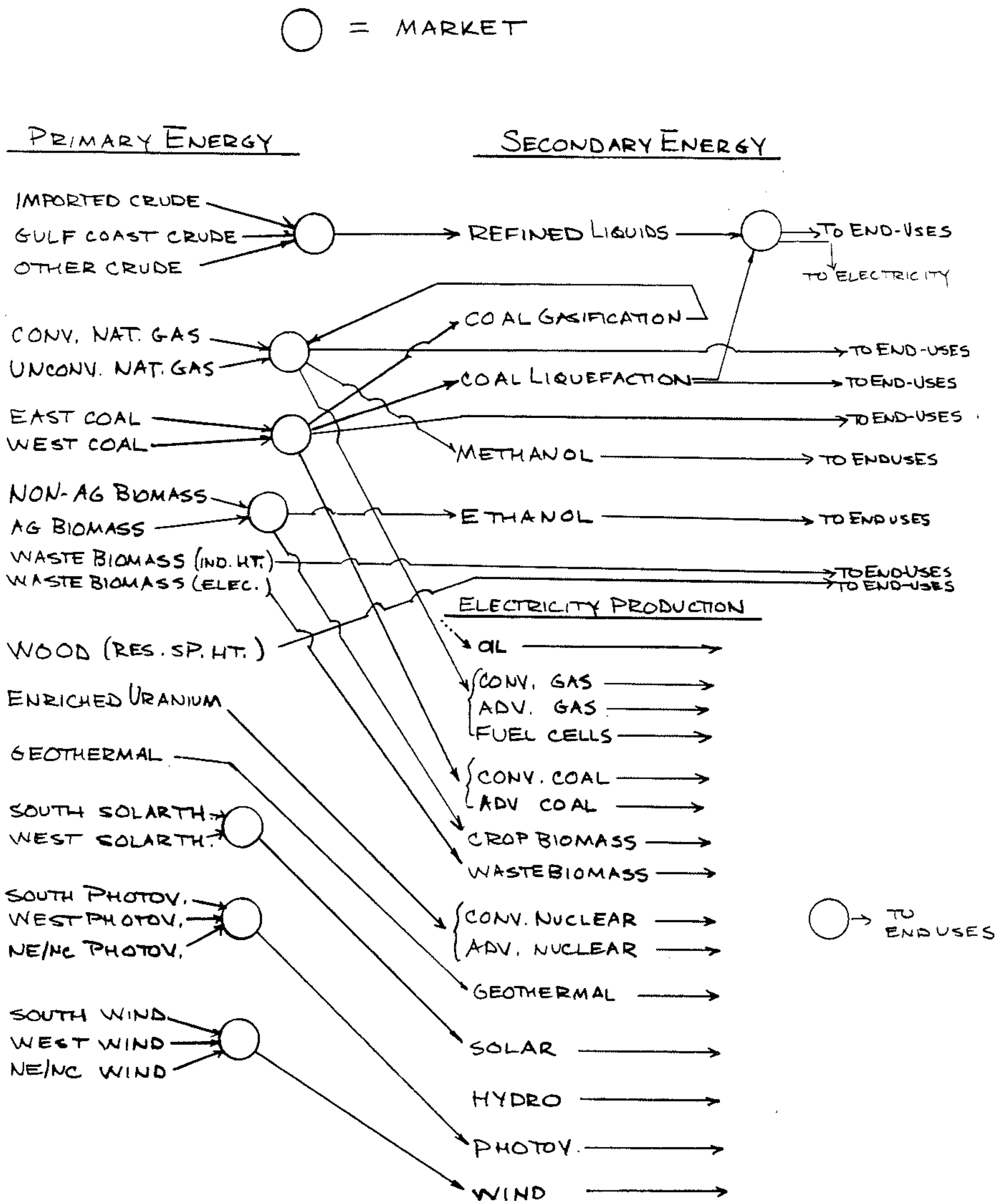
V) ENVIRONMENTAL

Emissions:	CO_2 via country- and fuel-specific coefficients, which also reflect utility process data -- each sector and country no policies can be modelled unless model is linked to macro driver

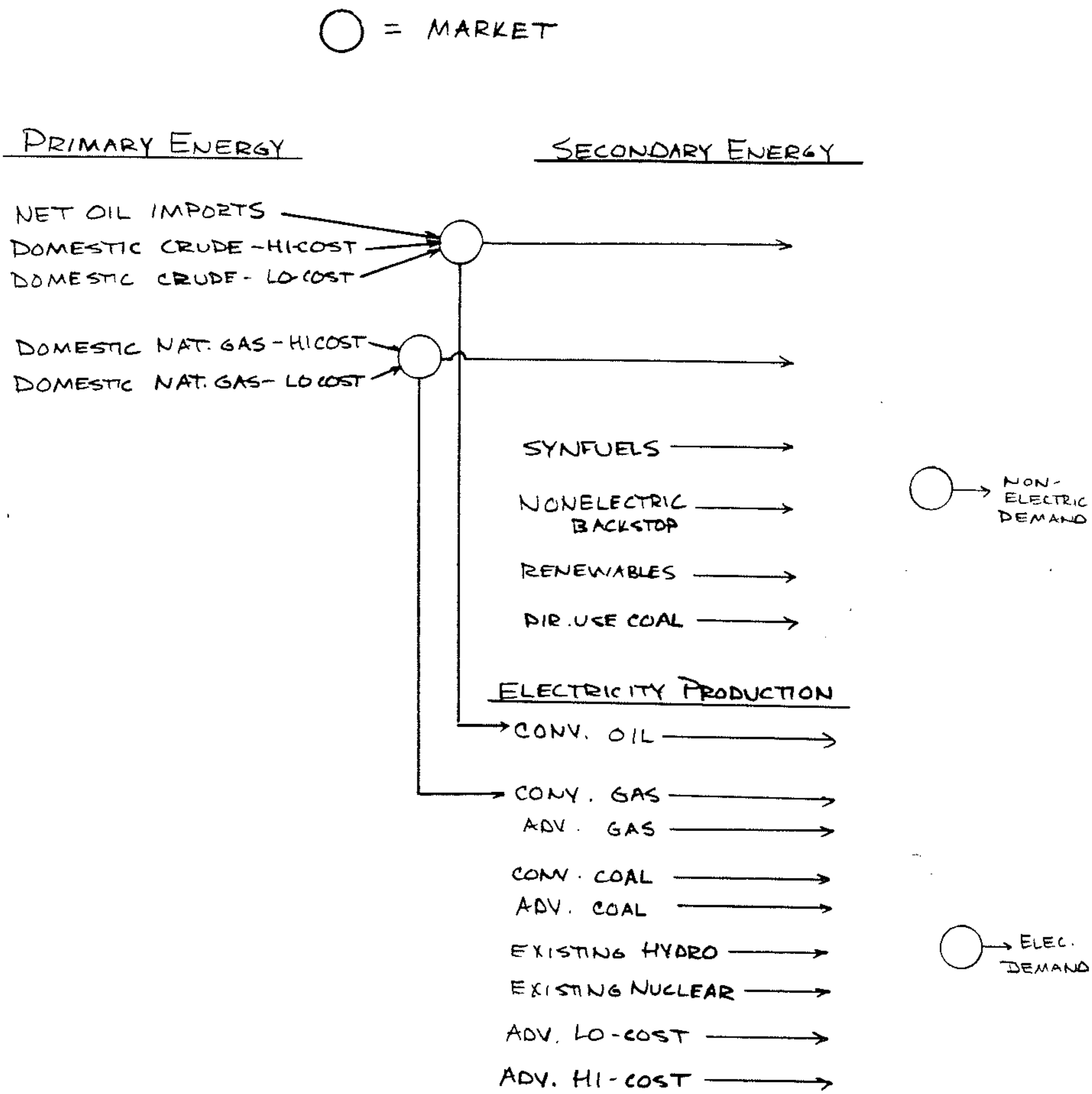
T-GAS ENERGY SUPPLY NETWORK



GEMINI ENERGY SUPPLY NETWORK

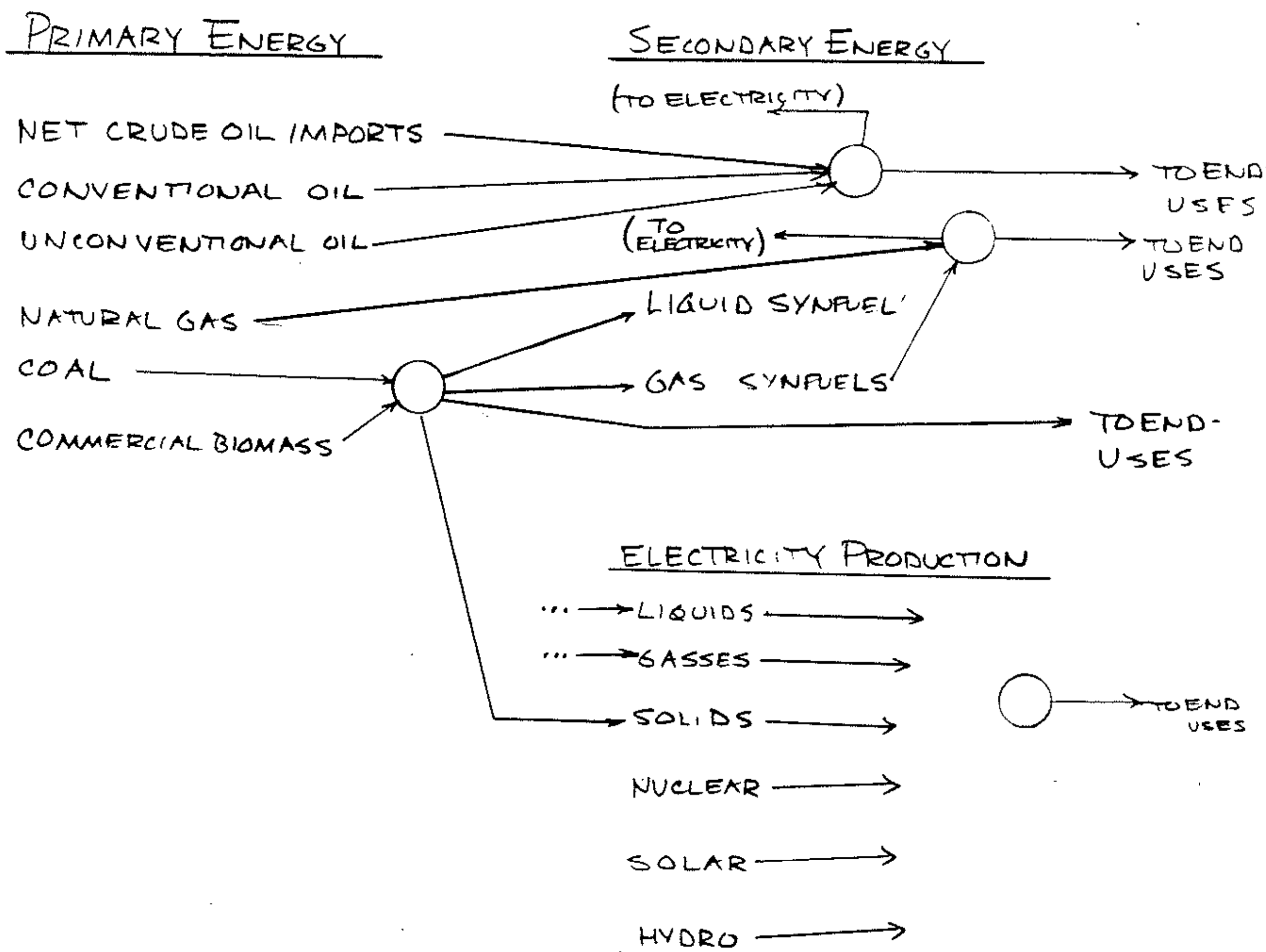


GLOBAL 2100 ENERGY SUPPLY NETWORK



GLOBAL MACRO ENERGY SUPPLY NETWORK

○ = MARKET



GREEN ENERGY SUPPLY SECTOR

○ = MARKET