APPENDIX A

OVERVIEW OF EMISSIONS AND COST MODELING TOOLS FOR ESTIMATING THE PROSPECTIVE BENEFITS AND COSTS OF THE 1990 CLEAN AIR ACT AMENDMENTS

In its analysis of the costs and benefits of the Clean Air Act Amendments of 1990 (CAAA), EPA will employ several modeling tools to estimate CAAA compliance costs and project emissions under different regulatory scenarios. This appendix describes the modeling systems EPA proposes to use for these aspects of the second prospective analysis, as well as several other models that EPA considered in developing this analytic blueprint. Several of the organizations that developed the models described here have produced model documentation, which is cited in the reference list located at the end of this appendix.

The first section of this appendix describes ControlNet, EPA's proposed model for estimating costs and projecting emissions for non-EGU point sources in the second prospective. In its analysis of electric utility emissions and costs, EPA plans to use the Integrated Planning Model (IPM), which is presented in the second section of this appendix. EPA also considered Resources for the Future's Haiku model for this component of the second prospective. An overview of Haiku follows the presentation of IPM. After describing the main characteristics of Haiku, the focus of this appendix then shifts to computable general equilibrium (CGE) modeling. Although EPA examined several economic models to assess the social costs of the CAAA, the Agency eventually narrowed its options to two modeling systems: the Jorgenson/Ho/Wilcoxen (J/H/W) model and the All-Modular Industry Growth Assessment model (AMIGA).

MODELING EMISSIONS AND DIRECT COSTS

Since the emissions reductions and compliance costs attributable to the CAAA are so closely related, some of the tools that EPA proposes to use in the second prospective solve for the two simultaneously. This type of tool is particularly useful for analyzing rules that allow sources to choose from an array of control strategies, each of which has different implications for emissions and costs. Summaries of these models are presented below. In addition, the reference list at the end of this appendix contains a citation for the ControlNet User's Guide.

ControlNet

To support the development and implementation of the National Ambient Air Quality Standards (NAAQS) for criteria pollutants established by the U.S. Environmental Protection Agency (EPA), Pechan developed ControlNET. ControlNET is a relational database system in which control technologies are linked to sources within point, area, and mobile sources emissions inventories. The database of control measures contains comprehensive information on each measure, including control efficiency and costing data. Currently, ControlNET contains 453 source category and pollutant-specific control measures, applied within a 759,733 record data file. Controls are supplied for all criteria pollutants and NH_3. The control measure data file in ControlNET includes each technology's control efficiency, calculated emission reductions by source, and estimates of the costs (annual and capital) for application of each control.

ControlNET includes data gathered for more than 450 different control measures for NO_x, VOC, SO_2, PM_{10}, $PM_{2.5}$, and NH_3 for utility, non-utility point, area, mobile, and non-road sources. Each control measure has an associated control efficiency, annual cost, capital cost, and operation and maintenance costs. Every control measure is applied to relevant sources in the 1999 National Emission Inventory (NEI) to create a large database of possible controls with their associated emission reductions and costs. Pechan's recently developed interface for ControlNET allows users to view and filter the database of all possible controls (by state, county, regional area, SIC, SCC, sector, pollutant, and cost per ton value) and specify specific controls to create control scenarios.

Because ControlNET is designed for evaluating the cost and effectiveness of adding additional controls to point, area and mobile sources, the model's control cost equations were developed so that information typically reported in emissions databases are the primary drivers of the equations included in the model. Key variables included in these databases include stack gas flow rate, design capacity, and emissions. Stack gas flow rate is the primary variable used for estimating the costs of PM controls such as electrostatic precipitators and baghouses, whose sizing and cost are a function of flow rate. Flow rates typically reported in point source databases are of central importance in estimating stack gas plume rise. Estimates of control costs for many other point source controls, such as SCR, NSCR, and low NO_x burners, are based largely on design capacity. For sources such as electric utility boilers, design capacity is usually reported in megawatts, while for non-EGUs, design capacity is reported in SCC units per year or per hour, where SCC units are normally fuel consumption or the production rate. Finally, all cost equations are designed to use emissions as an important variable in case other primary variables (e.g., flow rate or design capacity) are missing, or for area source categories for which no other information related to the size of individual sources is available.

IPM

This appendix provides a brief overview of IPM. Additional information is available in IPM's supporting documentation as cited in the reference list at the end of this appendix.

IPM is a dynamic, linear programming model of the electric power sector that represents a number of key components of energy markets--fuel markets, emission markets, and electricity markets--as well as the linkages between them. The model determines the least-cost method of meeting energy and peak demand requirements over a specified period of time, considering a number of (non)regulatory constraints (e.g. emissions limits, transmission capabilities, fuel market constraints, etc.).

IPM models electricity markets in different regions of the country by modeling electricity demand, generation, and intra-regional transmission and distribution. All existing power generators are captured in the analysis, including those that use renewable resources and independent and cogeneration facilities that sell back to the grid. In addition, IPM accounts for demand-side resource options and the hourly load impacts they have.

IPM endogenously forecasts fuel prices for coal, natural gas, and biomass by balancing fuel demand and supply for electric generation. The model also includes information on fuel quality parameters. Other items IPM estimates endogenously include emissions changes, regional wholesale energy and capacity prices, incremental electric power system costs, changes in fuel use, and capacity and dispatch projections.

To simplify the model, IPM analyzes model plants over a series of model years. Model plants represent aggregations of existing units; retrofit, repowering, and retirement options available to existing units; and new units the model can build over the time horizon of a model run. Model years group a cluster of years together, which significantly lowers model run time.

As a linear programming model, IPM minimizes an objective function representing the summation of all costs incurred by the electricity sector over the entire planning horizon of the model, expressed as the net present value of all component costs. Since IPM minimizes the total cost function for the entire utility sector, the choices that a model plant makes in the model may not represent the least-cost solution for that particular plant. Choices that minimize costs for the entire sector might not always coincide with choices that minimize costs for individual units.

To minimize the value of the objective function, IPM systematically changes the value of several decision variables that directly affect component costs. The decision variables in IPM are as follows:

1. *Generation Dispatch Decision Variables* represent generation from each model plant. IPM uses these variables to calculate plant fuel costs and plant VOM costs.

2. *Capacity Decision Variables* represent the capacity of each existing model plant and possible new plants in each model run year. These variables are necessary for calculation of total fixed operating and maintenance (FOM) costs for each model plant as well as the capital costs associated with capacity addition.

3. *Transmission Decision Variables* represent electricity transmission along each transmission link between model regions in each run year. IPM multiplies these variables by variable transmission cost rates to obtain the total cost of transmission across each link.

4. *Emission Allowance Decision Variables* represent the total number of emission allowances for a given model year that are bought and sold in that or subsequent run years. IPM uses the emission allowance decision variables to capture the inter-temporal trading and banking of allowances.

5. *Fuel Decision Variables* represent the quantity of fuel delivered from each fuel supply region to model plants in each demand region for each fuel type and each model run year. These variables are compared to constraints (see below) that define the types of fuel that each model plant is eligible to use and the supply regions eligible to provide fuel to each specific model plant.

Manipulation of these decision variables is subject to a number of constraints:

6. *Reserve Margin Constraints*–Each generating unit must maintain a minimum margin of reserve capacity.

7. *Demand Constraints*–Model plants must meet demand. The model divides regional annual demand into seasonal load segments as specified by a load duration curve, represented as a step function. Each segment of the function defines the minimum amount of generation required to meet the region's demand in the specified season.

8. *Capacity Constraints*–Generation at each model plant may not exceed maximum plant generating capacity.

9. *Turn Down/Area Protection Constraints*–Some generating units can shut down at night, but others must operate at all times.

10. *Emissions Constraints*–Model plants must comply with emission constraints. IPM can consider any of a number of emissions constraints for SO2, NOx, mercury, and CO2, including tonnage caps and maximum emission rates.

11. *Transmission Constraints*–Transmission is constrained by the maximum capacity of each transmission link or the maximum capacity of two or more links (joint limits) to different regions.

12. *Fuel Supply Constraints*–Each generating unit can consume only those fuels compatible with its particular generating technology. In addition, a plant can only purchase fuels from supply regions eligible to provide fuel to that plant.

Haiku

We present a brief description of Haiku in this appendix. The interested reader can find additional information in the Haiku reference manual, which is cited in the reference list at the end of this appendix.

Developed by Resources for the Future, Haiku is a simulation model of regional electricity markets and interregional electricity trade in the United States. Using an iterative convergence algorithm, Haiku simulates utilities' responses to public policy choices and estimates multiple equilibria in multiple linked markets. In the past Haiku has been used to model responses to potential NO_x, SO_2, and CO_2 emissions regulations.

Haiku simulates several aspects of utility behavior. Using separate electricity demand functions for residential, commercial, and industrial customers, Haiku estimates electricity prices, the composition of electricity supply, inter-regional electricity trading among National Electricity Reliability Council (NERC) regions, and emissions of NO_x, SO_2, CO_2, and mercury. Estimates of NO_x and SO_2 emissions are based in part on the endogenous selection of NO_x and SO_2 control technologies. Haiku estimates generator dispatch based on the minimization of the short-run variable costs of generation. Estimation of all these items occurs for 4-6 model run years over a 20-year time horizon.

In estimating market equilibrium, Haiku first finds an equilibrium for each region of the country before solving for the level of inter-regional electricity trade necessary for prices to equilibrate. At the regional level, Haiku estimates market equilibrium for each of four time periods (super peak, peak, shoulder, and baseload), three seasons (summer, winter, and spring/fall), and each of 13 NERC subregions. Regional supply functions are constructed using information on capacity net of outages, operating and maintenance costs (including pollution control costs), and fuel costs for 46 model plants (31 existing, 15 possible in the future), each representing a group of generators aggregated by region, fuel type, technology and vintage classifications. Haiku adjusts model plant supply functions to reflect endogenously selected NO_x and SO_2 emissions control technologies.

Haiku also includes modules for coal and natural gas markets that calculate prices based on changes in factor demand. All other fuel prices are specified exogenously. Haiku holds the cost of capital and the cost of labor constant.

COMPUTABLE GENERAL EQUILIBRIUM MODELS

As part of its update of the 1999 *Benefits and Costs of the Clean Air Act: 1990 to 2010* (*Prospective Analysis)*, EPA proposes the use of a computable general equilibrium (CGE) modeling approach to estimate the impacts of the 1990 Clean Air Act Amendments (CAAA) on the U.S. economy. EPA's *Benefits and Costs of the Clean Air Act: 1970 to 1990* included a CGE analysis of the social costs associated with the implementation of the Clean Air Act's provisions, using the Jorgenson/Wilcoxen dynamic CGE model of the U.S. economy. However, the Agency's 1999 *Prospective Analysis* did not include a general equilibrium modeling approach due in part to the level of effort required to calibrate and run a CGE model, as well as limits on the resolution of available cost data.

CGE modeling efforts estimate the comprehensive macroeconomic effects of broad policies (such as the Clean Air Act) that affect multiple industries and products within the economy.[1] These models provide a relatively complete estimate of the social costs of regulation because they capture both the positive and negative impacts of price changes throughout the economy. At a minimum, CGE models estimate changes in production by sector for the geographic scope of the model. In addition, most identify employment effects by sector, relative price changes among both inputs and products, and the impacts of policies on trade (i.e., changes in levels of import and export). Finally, several recent efforts estimate net impacts by incorporating productivity-linked benefits (e.g., avoided health effects) into modeling scenarios.

Given these recent advances in CGE design, we have reviewed recent CGE modeling efforts that address environmental policy. We have identified two potential CGE modeling options:[2]

< **Jorgenson/Ho/Wilcoxen Model of the U.S. Economy:** An update of the dynamic national CGE model used to assess the social costs of Clean Air Act in EPA's Retrospective Analysis. The model was recently updated to address benefits and to perform prospective assessments of impacts.

< **All-Modular Industry Growth Assessment Modeling System (AMIGA):**

---

1 For a brief overview of the use of different types of general equilibrium models (i.e., input/output models, linear programming models, and CGE models) as well as partial equilibrium and multi-market models, in the assessment of costs related to environmental regulation, see EPA's *Guidelines for Performing Economic Analyses*, September 2000, EPA 240-R-00-003.

2 In addition, a number of available "world models" (e.g., Wilcoxen's G-Cubed Model and MIT's EPPA recursive-dynamic CGE model, and CRA's Multi-sector, Multi-regional Trade (MS-MRT) model) address general equilibrium effects of international environmental policy issues, such as efforts aimed at reducing greenhouse gas emissions. While many world models have regional (i.e., national or multi-national) capabilities, the level of aggregation in these models is generally too high to address specific sectors within a single national economy. If EPA wishes to address potential international trade or environmental effects associated with the Clean Air Act, a limited application of one of the available world models may be useful.

A dynamic CGE model recently used for the Jeffords-Lieberman request for an analysis of a multi-pollutant emission reduction strategy. The model possesses a rich representation of technology and disaggregates the economy to a finer degree than most CGE models.

Our review concludes that both the Jorgenson/Ho/Wilcoxen (J/H/W) model and AMIGA could be used to assess the prospective impacts of the 1990 CAAA. Below we provide a brief overview of each of the models; Exhibit A-1 provides a summary of key model features.

Exhibit A-1

Comparison of J/H/W and AMIGA General Equilibrium Models

Traits	**Jorgenson/Ho/Wilcoxen**	**AMIGA**
Calibration/ Estimation	Econometrically estimated from 25 years of data.	Calibrated to 1992 BEA data.
Number of Sectors	35 sectors included in model	200 sectors included in model
Reporting	Economy wide and by industry	Economy wide and by industry
Employment Impacts	Reported in model	Reported in model
Treatment of Technology	Exogenous and endogenous components of technological progress.	Extremely rich representation of technology. Technology assumptions based on EIA projections of technology cost and efficiency. Updated periodically.
Treatment of taxation	Captures effects resulting from the interaction of taxes and environmental policy.	Captures effects resulting from the interaction of taxes and environmental policy.
Intertemporal Optimization	The model calculates a dynamic equilibrium where consumers and capital owners optimize with consideration for the future.	The model calculates a dynamic equilibrium where consumers and capital owners optimize with consideration for the future.
Treatment of Productivity Increases from Health Improvements	Can introduce exogenously. Improves the quality component of labor.	Can introduce exogenously by entering estimated change in worker productivity.
Peer Reviewed/ Published works	Theoretical basis of the model peer reviewed in several journal articles. The model itself is not available for review.	Peer reviewed paper forthcoming in *Energy Economics*. Unpublished reviews from Cornell, MIT, and EMF. The model code is available for review.

Exhibit A-1 **Comparison of J/H/W and AMIGA General Equilibrium Models**		
Traits	**Jorgenson/Ho/Wilcoxen**	**AMIGA**
Past Uses	CAA Retrospective, NCEE applications	Jeffords-Lieberman request on a multi-pollutant emissions strategy, Possible use for Lieberman-McCain greenhouse gas proposal
Cost	Unclear	Less than $100,000 for this application.
Availability	Current Production Changes: Summer 2003. Consumption changes: Summer or Fall 2004	Summer 2003

Jorgenson/Ho/Wilcoxen Model

The Jorgenson/Ho/Wilcoxen (J/H/W) model is a dynamic computable general equilibrium (CGE) model that was used to estimate the social costs associated with regulations under the 1970 Clean Air Act.[3] The model estimates several macroeconomic effects resulting from the compliance with environmental regulations, including changes in gross national product (GNP), aggregate consumption, and energy flows between sectors. The model estimates long-run changes in the supply of production factors (i.e., capital, labor, imports, and intermediate inputs to production) and rates of technical change, degrees of substitutability among inputs and commodities in production and final demand (i.e., levels of consumption, investment, government activity, and foreign trade). It includes the following basic features:[4]

- **Dynamic model:** The J/H/W model is a dynamic model. In other words, it contains functions that update time-dependent variables (e.g., labor supply or technology development) endogenously, based on projections of the trends for these variables in the economy and the activity that is predicted in the model. An advantage of dynamic models (in addition to a potentially more realistic reflection of changes in activity over time) is that they can be used

[3] The current version of this model reflects efforts by Mun F. Ho and is referred to as the Jorgenson/Ho/Wilcoxen Intertemporal General Equilibrium Model.

[4] For a more detailed description of the Jorgenson/Wilcoxen model and its application to the Clean Air Act, see Appendix B of EPA's *Benefits and Costs of the Clean Air Act: 1970 to 1990.*

to develop and compare analyses with different time horizons.[5]

- **Detailed production and consumption functions:** The J/W/H model contains a unified accounting framework consistent with national product accounts for 35 distinct industry sectors, as well as household and government functions. This allows for a relatively detailed treatment of impacts in industries specifically affected by the CAA and amendments, including the incorporation of industry-specific compliance costs.

- **Parameters estimated econometrically from historical data:** The J/H/W model incorporates information on economic activity (including production factor pricing and technological change) dating back to 1977. These data are used to predict household and firm behavior in a manner consistent with the historical record, as opposed to relying on theoretical values and behavioral predictions.

In addition, the J/H/W model incorporates a detailed representation of saving and investment, reflecting changes in behavior as prices change as a result of policy (e.g., energy prices). Consistent with long-run assumptions, the model reflects free mobility of labor and capital between industries that is appropriate for the 30-year time horizon considered in the second prospective.

---

[5] In contrast, *static* models provide a single projection of a market's adjustment to a new equilibrium after a shock (e.g., a policy) has been introduced; the time horizon is determined by the point at which the market achieves its new balance.

AMIGA

We present a brief summary of AMIGA in this appendix.[6] More detailed information is available in AMIGA's supporting documentation as cited in the reference list located at the end of this appendix.

AMIGA is a dynamic general equilibrium modeling system of the U.S. economy that covers the period from 1992 through 2030. It was originally developed by the Policy and Economic Analysis Group at the Argonne National Laboratory to evaluate the effects of policy combinations dealing with climate change. AMIGA includes information on more than 200 sectors of the economy, which allows it to present extremely disaggregated information on the effects of policy changes. Some of AMIGA's most important characteristics include the following:

- The model computes a full-employment general equilibrium solution for demands, prices, costs, and outputs of interrelated products, including induced activities such as transportation and wholesale/retail trade.

- AMIGA calculates national income, Gross Domestic Product (GDP), employment, a comprehensive list of consumption goods and services, the trade balance, and net foreign assets and examines inflationary pressures.

- The model projects economic growth paths and long-term, dynamic effects of alternative investments including accumulation of residential, vehicle, and producer capital stocks.

- AMIGA reads in files with detailed lists of technologies (currently with a focus on the electric power generating industry) containing performance characteristics, availability status, costs, anticipated learning effects, and emission rates where appropriate.

- AMIGA benchmarks to the 1992 Bureau of Economic Analysis (BEA) interindustry data for more than 200 sectors of the economy.

The AMIGA modeling system is programmed in the C language. Like other large, integrated modeling systems, AMIGA includes modules for a number of key sectors of the economy. The output of each module may be used as input for other modules. AMIGA includes the following modules:

---

[6] This section is based largely on the abstract of *A Framework for Economic Impact Analysis and Industry Growth Assessment: Description of the AMIGA System*, Donald A. Hanson, Argonne National Laboratory, Argonne, IL, April 1999. Several excerpts included in this section are drawn directly from this document.

- **Household demand**: AMIGA includes a module for household demand which uses consumer preferences, relative prices of delivered goods, and permanent income to determine consumer spending.

- **Government purchases and programs**: Most government expenditures are taken to be exogenous. Energy purchases, however, are based on the energy efficiency of the stock of equipment used by government agencies.

- **Residential buildings and appliances**: This module represents existing housing and appliance stocks, available new technologies, and near commercialized technologies soon to be available. It allows the average efficiency of household equipment and residential structures to change with time. It also allows the penetration of more efficient technologies to lower the cost of supplying energy-intensive building services.

- **Commercial buildings and appliances**: This component of the model includes floor space and capital equipment services to the commercial business and government sectors of the economy including personal and business services, administrative offices, wholesale/retail trade, warehousing, financial services, schools and hospitals.

- **Motor vehicles**: This module provides personal transportation services to households, businesses, and federal, state and local governments. It allows transportation demand and fuel efficiencies to change over time.

- **Utilities**: This module represents the operation of the existing stock of generating equipment and power plants to determine their capacity factors, dispatching units against the load curve in order of variable costs. It also can incorporate the costs of SO_2 emission allowances and any future carbon charges.

- **Industrial production activities**: Industrial production activities are organized into separate modules to more easily handle the representation of different production technologies and their characteristics. Each module contains representations of labor, capital, and energy substitutions using a hierarchy of production functions. AMIGA currently uses five distinct lists/modules. Within these modules is information on more than 200 individual industry sectors.

- **Industrial Capital**: AMIGA contains disaggregated data on the capital stocks of a number of industries, allowing the model to capture effects such as the depreciation and retirement of capital, as well as substitution between different types of capital equipment.

Model Structure

AMIGA goes through the following series of steps to arrive at equilibrium:

1. Computation of all prices.

2. Calculation of flow quantities, such as sector output, demands and labor effort, taking prices, market shares, and input intensities as given.

3. Verification that all variables have converged with sufficient precision. If they have not converged enough, the model readjusts wages and/or the opportunity cost of capital so that excess demand for labor and capital is closer to zero.

4. The model returns to step 2, given the revised values for input intensities, market shares, and flow quantities.

The model repeats this routine until it reaches equilibrium. Since AMIGA calculates equilibria within and between modules simultaneously, the model's operating shell first calls pricing programs from the individual modules, then the input intensity programs, followed by the quantity programs.

Social Costs

AMIGA can capture the social costs associated with environmental regulation in several ways. Since the model allows prices to change throughout the economy in both intermediate and final output markets, equilibrium quantities under different regulatory scenarios can change from their pre-regulatory equilibrium, which allows the model to capture deadweight losses associated with regulation. In addition, AMIGA incorporates taxes into its modeling framework, so it therefore measures any tax interaction effects that result from regulation.

REFERENCES

ControlNet

- U.S. Environmental Protection Agency. *ControlNet User's Guide*. May 2003.

IPM

- ICF Consulting. *IPM Global Modeling*. **http://www.icfconsulting.com/Markets/Energy/doc_files/IPMglobal.pdf**.
- ICF Consulting. *Introduction to the Integrated Planning Model*. **http://www.icfconsulting.com/Markets/Energy/doc_files/IPM_Overview3.pdf**.
- U.S. Environmental Protection Agency. *Documentation of EPA Modeling Applications (V.2.1) Using the Integrated Planning Model*. March 2002. **http://www.epa.gov/airmarkt/epa-ipm/chapter1.pdf.**

Haiku

- Paul, Anthony and Dallas Burtraw. *The RFF Haiku Electricity Market Model*. June 2002. **http://www.rff.org/reports/PDF_files/haiku.pdf.**

AMIGA

- Hanson, Donald A. *A Framework for Economic Impact Analysis and Industry Growth Assessment: Description of the AMIGA System.* Argonne National Laboratory, Argonne, IL. April 1999.

APPENDIX B

MODEL PERFORMANCE DOCUMENTATION FOR REMSAD, CAMX, AND OTHER COMPETING AIR QUALITY MODELS

This appendix provides references to a collection of technical documentation used in support of the air quality model selections made in Chapter 5. This documentation includes model evaluations, user's guides, model performance statistics, and comparative analyses and peer reviews of a number of competing air quality modeling systems. EPA's decision to use REMSAD for PM modeling and CAMx for ozone modeling relied upon careful consideration of the results presented in these documents. Also provided are references to documentation supporting the incorporation of the BEIS-3 emissions inventory model to treat biogenic emissions. The references listed here are grouped by air quality model, and the order of references proceeds from general information to model evaluation and finally to comparative analyses:

Regulatory Modeling System for Aerosols and Deposition (REMSAD)

- ICF Consulting. 2002. *User's Guide to the Regional Modeling System for Aerosols and Deposition (REMSAD) Version 7*. July. http://remsad.saintl.com/documents/remsad_users_guide_07-22-02.pdf

- *Overview of the REMSAD Modeling System*. 2001. **http://remsad.saintl.com/overview.htm**. See also: "What's New?" and "Frequently Asked Questions" sections.

- US EPA. 2003. *Draft Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines.* **http://www.epa.gov/nonroad/r03008.pdf**

- Lake Michigan Air Directors Consortium (LADCO). 2002. *Air Quality Modeling of PM2.5 Species.* **http://www.cmascenter.org/workshop/session4/baker_abstract.pdf**

- Jay Haney. 2002. *Computer Requirements for REMSAD. Systems Application International (SAI)*. LADCO/TNRCC Linux Computing Workshop. http://www.ladco.org/reports/presentations/march25_computing/rpo_computing_032602a.pdf

- Douglas, Sharon, et al. ICF Consulting. (2002). *Application of REMSAD Modeling System to the Midwest*. Memorandum to Mike Koerber, LADCO. January 18.

- Mansell, Gerard et al. Environ. (2001). *REMSAD Modeling Protocol*. Western Regional Air Partnership Modeling Forum. **http://www.emc.mcnc.org/projects/wrapjs/docs/REMSADprotocol.pdf**

- Western Regional Air Partnership: Modeling Forum Discussion Threads. 2002. *Model Evaluation and New REMSAD vs. CMAQ Comparisons*. https://pah.cert.ucr.edu/pipermail/wrap-modeling-forum/2002-March/000034.html, https://pah.cert.ucr.edu/pipermail/wrap-modeling-forum/2002-April/000067.html

- *Comparison of PM2.5 Modeling Capabilities of REMSAD, MODELS-3/CMAQ, URM, and CAMx*. 1999. **http://www.vistas-sesarm.org/tech/modcompare.pdf**

- US EPA. 2002. *Operational Evaluation and Comparison of CMAQ and REMSAD - An Annual Simulation*. http://www.cmascenter.org/workshop/session4/timin_cmas-slides.ppt

Models-3/Community Multiscale Air Quality (CMAQ) Modeling System

- US EPA. *User Documentation for the Models-3 Framework and the Community Multiscale Air Quality Model (CMAQ)*. **http://www.epa.gov/asmdnerl/models3/doc/science/science.html**

- *An Assessment of Models-3 Performance During the 1999 SOS Nashville Study*. **http://www.cmascenter.org/workshop/session3/bailey_abstract.pdf**

- *2002 Models-3 Users' Workshop References List*. **http://www.cmascenter.org/workshop/2002wspresent.html**

Comprehensive Air Quality Model with Extensions (CAMx)

- *User's Guide to the Comprehensive Air Quality Model with Extensions (CAMx) Version 3.10*. 2002. **http://www.camx.com/pdf/CAMx3.UsersGuide.020410.pdf**

- *Overview of CAMx*. **http://www.camx.com/overview.html**

- US EPA. *Overview of CAMx, including reference list of additional peer review studies*. Support Center for Regulatory Air Models (SCRAM). **http://www.epa.gov/scram001/7thconf/information/camx.pdf**

- Sonoma Technology Inc. 1997. *Peer Review of ENVIRON's Ozone Source Apportionment Technology and the CAMx Air Quality Model*.

Biogenic Emissions Inventory System (BEIS)

- US EPA. *Background Information on BEIS*. **http://www.epa.gov/asmdnerl/biogen.html**

- US EPA. 2002. *The Impacts of Biogenic Emissions Estimates from BEIS-3 on Ozone Modeling in the Southeastern US.* http://www.epa.gov/ttn/chief/conference/ei11/modeling/arunachalampres.pdf

- *Integration of the Biogenic Emissions Inventory System (BEIS3) into the Community Multiscale Air Quality Modeling System*. **http://ams.confex.com/ams/pdfview.cgi?username=37962**

- US EPA. 2002. *Advances in Emissions Modeling of Airborne Substances*. **ftp://ftp.epa.gov/amd/asmd/pierce/eiip_emoverview.ppt**