U.S. Environmental Protection Agency
Office of Research and Development
Under GSA Contract No. CFF220

Final Report on Support, Update and Improvement of USEPA MGA-MARKAL Model Database

EXECUTIVE SUMMARY

International Resources Group

Submitted to:

Cynthia Gage
US EPA Office of Research and Development

USEPA Mailroom
Mail Code: E305-02
Research Triangle Park, NC 27711

Submitted by:

International Resources Group (IRG)
1211 Connecticut Avenue, NW · Suite 700
Washington, DC 20036 · United States
Tel: +1 202/289-0100 ·
Fax: +1 202/289-7601
www.irgltd.com

January 2006

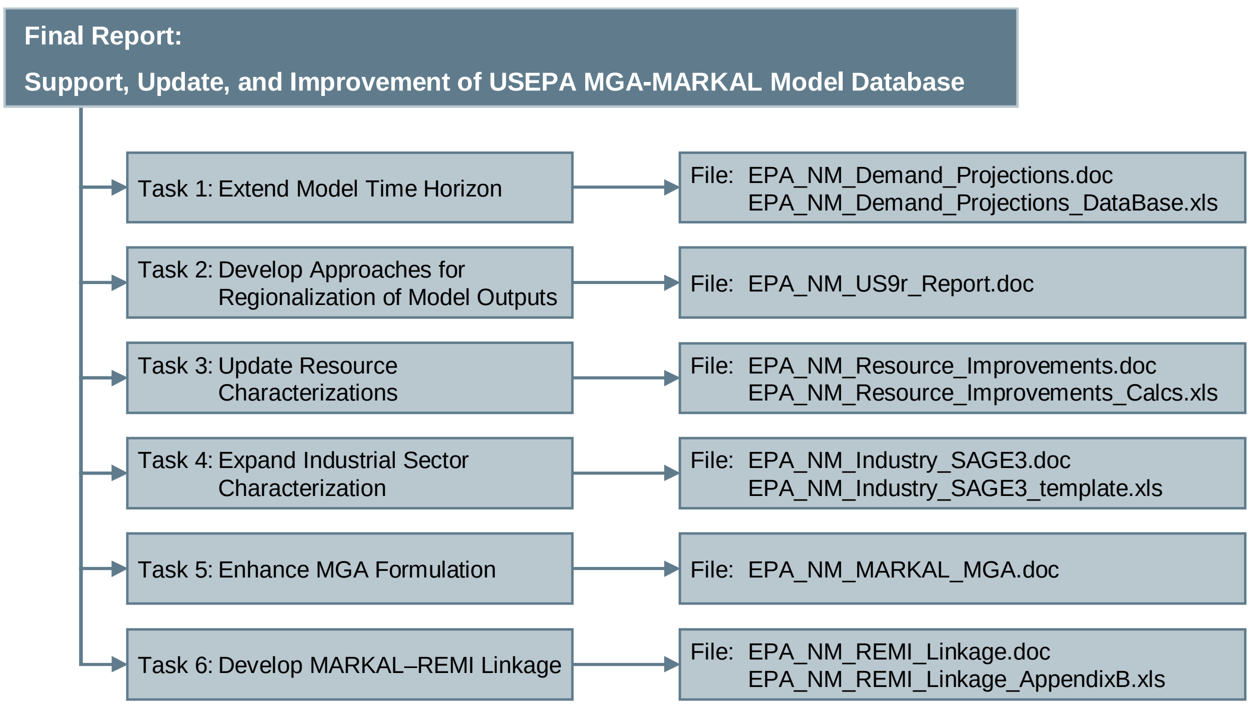
CONTENTS

LIST OF EXHIBITS

1 STRUCTURE OF THE REPORT

The deliverables identified under this support contract are completed by this Final Report and all the interim reports that accompany this report. These interim deliverable reports were all previously submitted to EPA_ORD, and their final updated versions are now included with this Final Report. The structure of this Final Report and all the task reports and their accompanying spreadsheet workbooks where applicable is shown in Exhibit 1.

Exhibit 1: Structure of this Final Report



Owing to the distributed nature of the documentments making up this Final Report the Table of Contents from each of the Word DOC files noted in Exhibit 1 are reproduced at the end of each associated section in this summary of the report.

2 SCOPE AND OBJECTIVES

The US EPA Office of Research and Development (ORD) is engaged in the Climate Change Air Quality Assessment (AQA), wherein the EPA's National Risk Management Research Laboratory's (NRMRL) Technology Assessment and CO-Control (TACT) Team is using the MARKAL (MARKet ALlocation) model to assess the role of technological change in the US energy system, and the related impacts said changes will have on future air quality. Under the stewardship of ORD the EPA National MARKAL (EPA-NM) model has matured and is now at a point where it is nearly ready to be employed as part of the AQA.

However a number of data and model formulation and linkage areas needed to be addressed and refined in order for the EPA-NM to be able to fully contribute to the AQA as desired. This support contract was designed to address these needs according to the following six tasks as shown in Exhibit 1. Each of the tasks was largely independent of the others, and specific reports were prepared for each task. Those Task Reports are bundled with this summary Final Report as the final deliverable to EPA.

3 SUMMARY OF TASK RESULTS

This section provides a brief summary of the main results from each task. The Task Reports contain the complete detailed results of these tasks, and the contents of each Task Report are provided in the introduction section of this summary.

3.1 Task 1: Extend Model Time Horizon

The original focus of this task was to extend the horizon of the model from 2035 to 2055. The most important aspect of this work involves the extension of the demand projections out to 2055, and this element of the work was given priority after some of the resources for this task were redirected to Task 6, MARKAL-REMI linkage.

Two approaches were evaluated to determine which one was preferred by EPA for extending the demand sectors: residential, commercial, industrial, and transportation. One option was identified and developed as part of the MARKAL-REMI linkage task[1]. That approach proposed to develop the reference case demand projections using the REMI-to-MARKAL (R2M) linkage which appears capable of generating growth rates for MARKAL demand categories that can be tied to reference year demands. The output from an analogous REMI PI model could then be used to develop the MARKAL sub-sector-level demand projections. Demand projections for both reference case and alternative scenario cases could be developed using the output from the analogous REMI PI model. However, EPA decided not to pursue this option and indicated a strong preference for a more transparent and deterministic approach to the Reference case demand projections.

The report, *Technical Approach to Extending Demand Projections for the USEPA National MARKAL Model*[2], describes the recommended methodologies developed to both validate the current demands projections against those of the Energy Information Administration (EIA) as reported in the AEO and to extend the EPA-NM projections from 2025 to 2055. Based on this report, the EPA may decide to implement these proposed methodologies for extending each of the sectoral demands. This report incorporates the interim report of December 2004 describing the proposed approach applied for the residential sector.

For each of the demand sectors (residential, commercial, industrial, and transportation) the following methodology steps were taken to develop the proposed baseline demand projections for EPA-NM:

- Matching the EPA-NM sub-sector demand structure with the demand definitions in the AEO/NEMS data base;
- Comparing the current 1995 to 2035 model demands to the AOE-2005 projections;

---

[1] See file EPA_NM_REMI_Linkage.doc for the report on the MARKAL-REMI linkage task.

[2] See File EPA_NM_Demand_Projections.doc for the report.

- Description of a methodology for calculating the demand projections based on survey data where possible, and
- Adjustments to the input data required to match the current AEO demand projections for the sector.

TABLE OF CONTENTS FOR EPA_NM_DEMAND_PROJECTIONS.DOC

3.2 Task 2: Develop Approaches for Regionalization of Model Outputs

EPA-ORD has strong interest in getting regional results out of the national model. The EPA's Air Quality Assessment (AQA) will be applied at a regional scale using regionalized general circulation and CMAQ models. Under this task, the IRG team identified ways that the national outputs of technology penetrations and associated emissions could be downscaled to a regional basis so that they could be compatible with the needs of the AQA. Initial consideration was given to approaches to simply regionalizing the model results. The IRG team then outlined in a "white paper" several approaches for scaling the national model outputs to a regional scale, and this note is provided in Appendix A.

These approaches were discussed in a meeting with EPA that examined their effectiveness and reached the following conclusions. The first approach, which is development of a full regional model as presented in a report provided to EPA in October 2002[3] remains the recommended and preferred approach. However, resources and time constraints prohibit embarking on this undertaking at this time. The other approach would be to follow the NE-MARKAL methodology, which relies heavily on the AEO/NEMS regions, mining the RECS/CEBCS/MECS/eGRID+767/… data sources and transforming them into the state models. For a national regional model the AEO/NEMS regions would be used.

[3] Regional US MARKAL Model: Issues and Options

Based on the discussion, it was decided that the IRG team would investigate the possibility of establishing a NEMS-like 9-region national MARKAL model. This activity became the focus the remainder of this task, and the report, *US9r - NEMS-2-MARKAL/TIMES: Data, Transformations, and Issues*[4], was prepared that documents the details of how a 9-region US MARKAL model could be developed.

TABLE OF CONTENTS FOR EPA_NM_US9R_REPORT.DOC

3.3 Task 3: Update Resource Characterizations

Under this task, the IRG team reviewed the resource characterizations for fossil fuels and biomass and investigated the various data issues identified by EPA-ORD in the Statement of Work. The report,

[4] See files: EPA_NM_US9r_Report.doc and EPA_NM_Resource_Improvements_Calcs.xls

Technical Approach to Resolve Data Issues for the USEPA-MARKAL Model Database - Resource Supply[5], provides the team's recommendations for improving the resource characterizations and for addressing the various data issue.

That report reviews the fossil resource characterizations in the current model and proposes making several improvements to the coal, oil and natural gas resource characterizations. The coal sector of the existing EPA-NM model has been represented at a fair level of detail, with the characterization of over a dozen different surface and underground mining basins. However, the natural gas and oil sectors are strictly represented by aggregate supply curves.

Regarding the fossil resources (coal, oil and natural gas), the analysis and recommendations provided in that report were impacted by recent work for EPA's OAP Coalbed Methane Outreach Program by some IRG team members. The focus of that work was the development of a scenario for methane mitigation and accounting. (The final version is scenario METHA in the EPA-NM ANSWER database.) During that work, aspects of the fossil fuel resource characterizations were reviewed and modified, and that work provided the starting point for this analysis. While the report primarily focuses on the existing EPA National MARKAL model (EPA-NM) there is some discussion of the implications on a possible nine region US model (EPA-US9r).

In the biomass resource area the recommended modifications were more extensive, as the model currently had only three biomass resources, covering only woody biomass. It was recommended that agricultural residues and energy crops be added to the database, and that new supply curves be adopted that are based on the most recent biomass resource data from EIA/DOE[6], which is a 1999 analysis of four biomass types and the amounts that are potentially available at given market prices.

TABLE OF CONTENTS FOR EPA_NM_RESOURCE_IMPROVEMENTS.DOC

[5] See file: EPA_NM_Resource_Improvements.doc

[6] Antares Group Inc., "Biomass Residue Supply Curves for the U.S.", Landover, MD, September 1998.

3.4 Task 4: Expand Industrial Sector Characterization

The IRG team reviewed with EPA-ORD the current representation of the industrial sector, especially in regard to the industrial technology characterizations to ensure that they are representative enough to differentiate the various fuel demands so that interactions with other sectors can be realized. Currently the industrial sector from the SAGE model has be adapted and integrated into the EPA-NM model.

As just noted, the EPA-NM industrial module is modeled via the industrial template for the USA region of the SAGE model. A brief report, *EPA- US National model Industrial Module from SAGE Model*[7], builds upon the EIA-DOE documentation of the SAGE model[8]. This document describes the changes required to adapt the template to the EPA-NM model. As part of Task 1, the template document for the EPA-NM industrial module was modified and updated, and that document forms part of this report[9].

TABLE OF CONTENTS FOR EPA_NM_INDUSTRY_SAGE3

3.5 Task 5: Enhance MGA formulation

MARKAL is a dynamic, inter-temporal partial equilibrium model of an energy system. The model identifies the least-cost evolution of the system over time, given assumptions about future energy demands, energy and environmental policies, technology characteristics, and fuel resources. Outputs include technology penetrations, fuel use and prices, emissions, investment patterns, and fuel tax revenues.

The dependence of MARKAL on input assumptions can be problematic as many input assumptions are subject to considerable uncertainty. Further, since MARKAL represents a simplified, linearized representation of complex system, aspects of the real-world energy system phenomena and interactions cannot be expected to be captured perfectly. As a result of these limitations, the least-cost pathway chosen by the model are often not considered the optimal pathway in the real world. Instead, pathways that appear suboptimal to MARKAL may in fact be better when uncertainties in input assumptions and system representation are resolved.

[7] See file: EPA_NM_Industry_SAGE3.doc

[8] For a complete description of the industrial module, see the section 2 and section 5 in the following document: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m072(2003)2.pdf.

[9] See file EPA_NM_Industry_SAGE3-Template.xls

Another consideration is that the least-cost solution output by MARKAL provides only a single technological pathway toward meeting energy service demands. A MARKAL user may be interested in whether there are alternative viable pathways. If such solutions exist, the similarity and differences among these solutions provide information regarding the flexibility available in cost-effectively achieving performance constraints. Since MARKAL (and other energy system models) do not typically produce a set of alternative solutions, many interesting and viable energy pathways may be overlooked. Some of these pathways may be better than others with respect to unmodeled issues, including practicality of implementation and equity.

To address the issues raised here, in collaboration with EPA-ORD the IRG team implemented techniques collectively known as Modeling to Generate Alternatives (MGA)[10,11] to methodically identify a set of alternative, near-optimal pathways. The initial formulation though needed to be refined, and under this task constraints were added to the MGA formulation of the MARKAL model that limit the cost deviance from the least-cost for any particular technology group or demand category to being less than or equal to a user-defined fraction. The goal of this modification is to more nearly reflect the range of possible consumer and corporate behavior. Under the previous implementation, technological choices are only governed by the overall cost constraint, and as such, individual sectors may adopt technologies that are highly inefficient with respect to cost.

In addition, EPA-ORD is increasingly interested in multi-region MARKAL models, including the NE-MARKAL developed by NESCAUM in concert with IRG, and the forthcoming US9r. EPA-ORD thus requested that the MGA formulation be expanded to the multi-region formulation which was accomplished as part of this task.

This work was documented in as report, Modeling to Generate Alternative (MGA) with the MARKAL Model[12].

Table of Contents for EPA_NM_MARKAL_MGA.doc

[10] Brill, E.D., S. Chang, and L.D. Hopkins. Modeling to generate alternatives: The HSJ approach and an illustration using a problem in land use planning. *Management Science*, vol. 28, no. 3, pp. 221-225. March 1982.

[11] Brill, E.D., Jr, J.M. Flach, L.D. Hopkins and S. Ranjithan. MGA: A decision support system for complex, incompletely defined problems. *IEEE Transactions Systems, Man, and Cybernetics*. Vol. 20, No. 4, July/August 1990.

[12] See file: EPA_NM_MARKAL_MGA.doc

3.6 Task 6: Develop MARKAL - REMI linkage

The IRG team examine the potential to develop linkages between MARKAL and the REMI Policy Insight economic model. The team proposed approaches for harmonizing MARKAL and economic modeling assumptions used by REMI Policy Insight and the EPA-NM (e.g. AEO assumptions, etc.). In cooperation with the EPA Project Officer, the team selected and tested the most appropriate approach for developing post-processors to extract pertinent information from MARKAL outputs for use as REMI Policy Insight inputs, and to develop pre-processors to incorporate REMI Policy Insight outputs to modify MARKAL demand inputs.

MARKAL is a bottom-up model of the integrated energy sectors of a geographical entity (state, province, country, region), or of a set of interconnected geographical entities. It is a dynamic model that computes a partial equilibrium on energy markets over a user-chosen horizon divided into time periods. The model is driven by a set of energy service demands, specified for each sector and sub-sector of the economy, at each period in the planning horizon. A run of MARKAL in turn produces results of the energy producing and consuming sectors at the level of individual technologies, and of groups of technologies constituting a sector or a sub-sector. The scope of the model is confined to the energy sectors (both suppliers and users of energy) and does not directly simulate other economic phenomena such as production, capital formation, consumption, wages, or employment.

Two aspects of MARKAL models motivate the need to run these models in conjunction with other tools and models that are economy-centered.

- First, the construction of the energy service demands to be used as inputs requires a coherent set of assumptions on the growth of the various sectors where energy service demands are located.
- Second, although MARKAL is especially well suited to the representation of a large variety of energy and environmental policies and measures, it does not directly assess the impacts of the policies and measures on the economy as a whole.

The work under this task is documented in the report, *Linking the MARKAL and REMI Policy Insight Models*[13]. The report and accompanying workbook show how these two needs can be met, and examine approaches whereby the REMI PI output for a reference scenario might be used to help create the MARKAL inputs, in particular with regard to projecting energy demand services, and how REMI PI might accept MARKAL outputs to further assess the economic impacts of energy and environmental policies that have been simulated by the EPA-NM or other MARKAL models.

TABLE OF CONTENTS FOR EPA_NM_REMI_LINKAGE.DOC

[13] See files: EPA_NM_REMI_Linkage.doc and EPA_NM_REMI_Linkage_AppendixB.xls

4 APPENDIX A: NOTE ON APPROACHES FOR REGIONALIZATION OF THE EPA NATIONAL MARKAL MODEL

This note describes an approach to "regionalize" an existing MARKAL model. EPA-ORD has strong interest in getting regional results out of the national model. The first option that was considered was full regionalization as presented in a "white paper" provided to EPA in October 2002 (Regional US MARKAL Model: Issues and Options). This remains the recommended and preferred approach, but resources and time constraints prohibit embarking on this undertaking at this time (though the NE and OH efforts are beginning to come at the problem from the other (micro/state) direction).

A 2nd approach was to consider direct regionalizing of the results. EPA-ORD put forward some ideas on a possible way of approaching this that were given consideration, but ultimately this approach was met with a great deal of skepticism and abandoned.

However, the approach proposed is an intermediate route that would be an improvement over a scheme that simply apportions of the results. What is proposed is to instead apportion the description of the RES according to the regions (AEO/NEMS, see below), and from there derive regional splits. These splits would then be applied to the current RESID and end-use demands of the EPA-NM.

Exhibit A1. Allocate the RESIDs and Demands to Regions[14]

Technology	Region1	Region2	Region3	...	TOTAL
T11	.2	.34	.3		1
T12					
Demand T1	.15	.3	.25		useful energy demand

For the electric sector, either the allocating of the RESIDs approach can be employed, or plant characterization extracted from eGRID/EIA767, as is done for NE-MARKAL and soon OH-MARKAL. For refineries etc, the same RESID splitting approach, and the SRCENCP simply replicated in the various regions. This would result in an apportioned EPA-NM that should be ready to go, as by design self-calibrated to the original national model. This approach can only be considered once a fully calibrated national model exists.

---

[14] A utility will be put in place to apply said table to the EPA-NM and establish the MARKAL load templates.

To complete the reference scenario picture the new technologies in the EPA-NM will be transfer to a technology library, and treated by means of a technology inheritance mechanism, existing EPA-NM Adratios will need to be redefined, trade options introduced, SRCENCP (and refineries) adjusted, and demand FR(Z)(Y) refined. But this approach was deemed not credible enough and dropped.

There is one other approach that worth considering. NE+OH-MARKAL rely heavily on the AEO/NEMS regions, mining the RECS/CEBCS/MECS/eGRID+EIA767/… data sources and transforming them into the state models. If the AEO/NEMS regions can be used for the EPA-ORD work we could investigate the possibility of establishing a NEMS-like 9-region national MARKAL model (with work needed to add in trade, plus other things not thought about yet (e.g, split state boundaries). With NE-MARKAL expanding to 12 states and OH-MARKAL about to get underway examining what would be involved in automating the approach and implementing it to establish the EPA-US9r. As MARKAL and NEMS are very different animals, and used for different purposes, there are clearly merits to both. Furthermore, applying both frameworks from common data sources (easily updated) has additional positive implications in terms of data maintenance and annual re-calibration. Of course EPA assumptions can be introduced and future technologies descriptions augmented.

Finally, if the MARKAL/REMI linkage comes together, and REMI can/will be used for projecting future energy demands, then either of these last two approaches may be linked with a 9-region REMI.

International Resources Group
1211 Connecticut Avenue, NW Suite 700
Washington, DC 20036 United States

Tel: 202/289-0100
Fax: 202/289-7601
www.irgltd.com